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Kakali Mukhopadhyay *Editor*

Applications of the Input–Output Framework

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Applications of the Input–Output Framework

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This volume is dedicated to Professor Debesh Chakraborty who has inspired many researchers and scholars to investigate various economic and social issues both within and outside India. He was himself a tireless pursuer of input–output research, and his guidance opened up many a new dimension of socioeconomic investigation using various methodologies, chief among which was, of course, input–output economics. This edited volume is a humble offering to "him" whose mentorship we shall always remember with profound gratefulness. Springer has published several of his works including the work co-authored by Mukhopadhyay on water pollution, on which "he" spent his last days ignoring his severe ailment. On behalf of the Input–Output Research Association of India, we offer this homage to the life member of IORA and founding member of IIOA who has literally and figuratively dedicated his life to input–output research. He will be missed but the memory of his greatness as an economist and a wonderful human being will live with us forever.

Preface

Applications of the input–output analysis, originally formulated by Leontief, have reached new heights through the collective imagination and execution of the I–O community. The evolution of a new generation of input–output models to address the growing concerns of society stands testimony to the versatile exercise of this form of analysis. In recent years, the use of this model has been extended through enhanced methodologies to better investigate the socioeconomic phenomenon. Moreover, research in this field has allowed nuanced datasets to develop where data had previously not even existed.

Input–output analysis facilitates the integration of alternate models of economics to simulate and analyze complex trends in economies. Its diverse use in the analysis of trade, agricultural markets, regional variations, productivity in manufacturing units, services sectors, energy, and environmental concerns—to name a few—explains its ever-growing importance in the methodology of academic research in the social sciences. The model allows accurate identification of intersectoral dependencies and linkages that play a gargantuan role in the field of policy making. The overarching theme of this tool of analysis is its malleability and potential for modeling a diverse range of economic issues and evaluating the policy directions that governments across the world head toward.

Since 2014, the Government of India has undertaken numerous new schemes, under various ministries, and launched significant fiscal and monetary drives to support them. The complete implications of most of these moves remain largely unknown, and the trends indicate that it will take several years to understand them. At this crossroad, it is really a daunting task to grasp even a thin directional indication toward which the economy of the largest democracy of the world is now heading. In fact, our economy has taken a route through which not many countries have passed in their pursuit of growth.

In this effort, the 19th National Conference of the Input–Output Research Association of India (IORA) jointly organized by the Gokhale Institute of Politics and Economics and University of Mumbai was held from January 11 to 12, 2017, at the Gokhale Institute of Politics and Economics, Pune. The publication based on the conference very well captured few unique ideas furnished by some reputed scholars, who made some sincere efforts to extend the basic analytical tool under "Input–Output Framework" and perceive the possible impacts of some very important policy decisions adopted by the Government of India very recently and have been able to come up with few interesting policy suggestions to guide our future course of action. The purpose of the book is to highlight the versatility of the Leontief model that is now being extended to cover a diverse field of policy issues ranging from agricultural productivity to science and technology and from carbon hot spots to energy and environmental consequences.

It embodies the vast scope of input–output analysis to capture the larger economic dynamics, as well as presents the broad spectrum of research engagements by researchers in this expanding field. At the same time, it also aims to address the technique and methodology attributable to the computational framework of input–output method.

Overall, the approach of this book is quite unique in the sense that it did not confine its treatment within the boundary of rigorous mathematics only, rather it tried to offer a set of new "Developmental Ideas" and combine its analysis with some prolific assessment of recent government policies adopted so far. This book provides a fresh perspective on the ever-growing relevance of input–output analysis in problem solving, even today.

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This book is an outcome of the 19th IORA conference in 2017 co-organized by the Gokhale Institute of Politics and Economics (GIPE) along with the Department of Economics, University of Mumbai (Autonomous), India. This volume is a valuable collection of important and thought-provoking articles on input–output framework presented at the 19th IORA conference. I wish to thank all the contributors.

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Her research focuses on energy and environment, trade and environment, air pollution and health, economics of health, regional economic integration, R&D, and food safety. She has received a number of international fellowships and awards by the World Bank, the Asian Development Bank, the Indo-Dutch Program, and the Ford Foundation, and very recently, she has received the Presidential Award from the Chinese Government. She has also received the Best Professor Award in Energy and Environmental Economics in 2017 and 2018, under the National Education Award in India. She holds a key expert position at the United Nations 2030 Agenda for

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She has numerous publications in peer-reviewed journals of international repute. She has authored five books in various fields of energy, environmental pollution, and trade. She has completed several studies on behalf of the United Nations Environment Programme, UN-ESCAP, UNCTAD, Asian Development Bank, Shastri-Indo Canadian Institute, Public Health Agency of Canada, Genome Canada and Genome Quebec, Agriculture and Agri-Food Canada, BioFuelNet Canada, West Bengal Renewable Energy Development Agency, Indian Council of Social Science Research, and South Asian Network for Development and Environmental Economics—SANDEE.

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Introduction

Kakali Mukhopadhyay

Research in input–output has advanced ahead of the traditional framework of input–output to include other mathematical and statistical techniques. This has allowed studies in this area to go beyond the general equilibrium framework. The work of Quesnay (1694–1774), Walras (1834–1910) and the brilliant interpretations and reformulations by Leontief (1953) led to the development of the fundamental principles upon which the input–output model was based. Quesnay's 'Tableau Economique' provides an iterative solution to the structural interdependence in the economy: Leontief was able to move this formulation to a more general one and, in the process, expand the capabilities of the model.

As developed over the years, the input–output model captures the full system effects, sector-by-sector analysis, supply chain linkages and also allows various scenarios to be modelled. These make it more advantageous than other economic models. An interesting feature of input–output analysis has been its widespread adoption throughout the world, transcending the distinctions between developed and developing, and between centrally planned, socialist and market economies. The adaptability of the input–output structure to various extensions including analysis of government constitutes the novelty of the framework.

The 19th National Conference of the Input–Output Research Association of India (IORA), jointly organised by Gokhale Institute of Politics and Economics and University of Mumbai, was marked by two keynote speeches by eminent economists fetched substantial value addition to the programme. One of our distinguished keynote speakers Thomassin was invited to talk on 'Advances in Input–Output Modeling' considering the input–output contribution to the world economy so far. His speech was primarily devoted to the evolutionary path of input–output analysis

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from its inception to current advances by different statistical organisations of the world. It also captured some major breakthrough in this field so far from the three continents—North America, Europe and Asia.

Another eminent key speaker Sengupta addressed the august participants on the topic 'Development of a New Generation of Input–Output Model to Address the Issues of Human Wellbeing and Sustainable Development: an i2Sim Approach'.

In addition to these two keynote speeches, a wide range of areas addressed by the research scholars and practitioners in the conference included methodological developments in input–output modelling, regional modelling, agriculture, manufacturing and service sector-related modelling. Other fields discussed in the conference were trade, energy and environment. Furthermore, we considered the applications of the Leontief model to other problems plaguing the economy—especially India.

A selection of the papers is presented here. One of the authors conducts investigation into the model's applicability in the field of agriculture—a persistent problem area for governments in the developing world due to the stagnation that has crept into the sector and worsened by its subsequent neglect.

Agricultural productivity is a central problem of most developing countries that face persistent stagnation in this sector. The use of I/O modelling extensions allows a novel approach to the peculiar problems associated with agricultural productivity and surplus labour employment.

Ghosh's paper uses the I/O framework to resolve the apparent contradiction between the Leontief system, which leads to a reduction in total output when there is an increase in the efficiency of intermediate inputs, and the neoclassical system technological progress, which leads to higher output. The same is applied in the context of Indian agriculture where water and roadways are among the most vital but scarce resources in Indian agriculture. With the objective to increase water efficiency in the irrigation supply chain over a time period of 10 years (2014–2023), the NITI Annual Report 2014–15 endorses Pradhan Mantri Krishi Sinchai Yojana (PMKSY) as one of the major activities to be undertaken in promoting Indian agriculture. In a similar fashion, the Pradhan Mantri Gram Sadak Yojana (PMGSY) has also been launched to build road networks across the country. The present exercise calculates elasticity of final demands with respect to intermediate inputs, which is expected to provide some insights for successful targeting and implementation of the PMKSY and PMGSY programmes.

Input–output tables have also been used by various scholars to analyse the impacts of productivity changes in manufacturing sectors. The increasing capacity building and speed of technological innovation have allowed large-scale data-intensive empirical evidence that allows for the accounting of productivity changes in any economy.

An innovative study by Kuroda, Ikeuchi, Hara and Huang aims to develop a recursive dynamic model of science, technology and innovation policy for analysing socio-economic impact through decomposition of sectors and to analyse the Internet of things (IoT) implementation for information allocation and processing to accelerate its productivity for manufacturing. The data used in the model were sourced from Japan's input–output table with the expansion of the tangible and intangible capital investments by considering long/short run variables, labour market modelling, value-added and wage determinant, government balance sheet, foreign and the final demand variable. By reviewing the economic impact through examination of several alternative policy options of government investment in science, technology and innovation, changes of economic structure could be foreseen with implications, such as work hour change, accumulation of tangible and intangible knowledge stock. The study demonstrated policy options by introducing different levels of the processing efficiency index (P index) in the activity divisions of marketing, planning, R&D, etc. Simulation results for manufacturing sector show the efficiency improvement would increase the production, public and private R&D investment and consolidate the knowledge stock for the expansion of knowledge infrastructure that rose total factor productivity.

Given the exponential expansion of service sector in this century and its prime importance to most governments across the developing world, the input–output table provides an effective structural framework to focus on service sector-related problems. Karar and Karar Mukhopadhyay seek to measure the contribution of the unorganised services sector using an input–output structural decomposition analysis framework. The study aims to investigate the unlikely growth of the services sector in the Indian economy and the nature of structural change the country experienced between 1983 and 2012. The results suggest that in place of technological advancement, India developed drastic changes in demand, mainly domestic demand. The monumental rise in domestic consumption and investment demand, and not export demand, has sustained the drive towards services field. Such studies find that the revival of technology upgradation and removal of domestic regulations on internal trade and financial intermediaries pose the main challenges to the growth of the Indian services sector. The growth of exports must also be facilitated. Such an analysis provides an empirical framework for sound policy recommendations concerning one of the main sectors of employment in India.

The versatility of the input–output tables comes from the fact that it is malleable to scholars as a tool of analysis. Unlike sectors like manufacturing and agriculture, tourism is not presented explicitly in the national accounts and in the supply and use tables, although its elements are embedded in other sectors of national accounts, like hotels, transport services, food and beverages. The study by Munjal is a novel attempt to recognise tourism as a separate sector in the framework of the supply and use tables and subsequently in the input–output tables using the relevant ratios obtained from the Tourism Satellite Account (TSA) of the economy. It is a unique tool to document the direct GDP and employment contributions of tourism to national economies. The inter-linkages of tourism sector with other sectors of the economy is assessed and quantified. Also, for the first time for the Indian economy, the impact of hypothetical 'disappearance' of this sector is realised through the input–output models using the hypothetical extraction method (HEM).

Input–output models also appear to have far-reaching consequences for energy economics modelling. Another extension of the Leontief framework is to account for inter-industry energy flow by converting the general input–output matrix to a 'hybrid' energy input–output matrix. Energy input–output analysis typically determines the total amount of energy required to deliver a unit of product to meet the final demand, both directly as the energy consumed by an industry's production process and indirectly as the energy embodied in that industry's inputs. In Chaudhuri's paper, energy input–output framework is used for the analysis of household energy requirement for India for the year 2007–08. The result shows large differences in total energy consumption pattern in rural and urban sectors and substantial differences among income classes too. The study attempted the impact of various policy options by introducing different levels of the processing efficiency index in the activity divisions of marketing, planning, R&D, procurement, operation and sales, conservative, the deviations of economic variables in the production process. Results suggest that for the manufacturing sector, the efficiency improvement would increase the production, public and private R&D investment and consolidate the knowledge stock for the expansion of knowledge infrastructure that would in turn raise TFP and the human resource. This study aims to additionally address the critical problem of technology gap that is unavoidable in the face of industrial expansion.

Joshi and Sharma construct a social accounting matrix for the Indian economy to provide keen insights into the developmental impacts of renewable energy. The study focuses on two established categories of solar deployment, namely domestic content requirement (DCR) and open, and involved the construction of independent solar I–O blocks as a new sector in the national input–output table. The analysis finds that the greater wage generation occurs for urban households in medium and high skill category which is associated with solar deployment strategy. DCR deployment appears to have higher backward integration and higher cross-sectoral linkages. Domestically manufactured solar panels are expected to have a wider distribution effect in terms of wages even to the lower deciles of per capita expenditure. Therefore, DCR appears to be a better strategy for inclusive economic growth along with green growth. The paper provides an exercise in investigating the possibility of energy technology development while considering inclusive distribution of welfare from such developments and in that allows for a mechanism to analyse policies.

Since the late 1960s, the input–output model has been extended by several researchers to explore problems related to pollution caused especially by domestic economic activities. In 1970, Leontief himself attempted this form of extension. The study by Tariyal has used the demand-driven model by Leontief (1936) which is extended to environmental input–output framework using sectoral emission output coefficients with the help of satellites emission data from World Input–Output Database (WIOD). It enables comparative analysis of carbon hot spots responsible for CO_2 emissions in India and China. The analysis allows us to identify the sectors that deserve more attention for mitigation policies for India and China. The analysis of the results reveals that Indian and Chinese 'Construction' sector has had the largest domestic CO_2 footprint among all sectors in 1995 and 2009. However, 'hot spot' analysis has revealed that the requirements from the both Indian and Chinese 'Electricity, Gas and Water supply' (EGWS) sector contribute significantly to the footprint of the 'Construction' sectors. This finding should indicate to policymakers that significant gains can be made in terms of reduced CO_2 emissions either by reducing the 'Construction' requirements for output from EGWS or by making EGWS less emission intensive.

Verma and Pal attempt to analyse the incidence of environmental taxes in the rural and urban consumers' groups using an environmentally extended social accounting matrix (ESAM) framework. Relative price changes of the commodities and their shares in households' consumption basket have been used to compute their tax burden. The results thus obtained show that eco-taxes become overall progressive in the rural sector and the degree of overall progressivity increases in the urban sector due to these transfers, thereby making these taxes more equitable. The study will help policymakers in understanding the implications of environmental taxes and to design the pathways of reduction of carbon emissions to meet the Paris Accord.

India's fast-expanding intra-industry trade (IIT) is a key factor behind the considerable rise in merchandise export. Given the perpetual conflict between trade growth and environmental concerns, it is an important task to find out whether such rapid growth in IIT has any detrimental effect on the environment. Towards that goal, Dasgupta and Mukhopadhyay measure the shares of pollution content of India's 'inter-industry trade' and 'IIT' and its impact on the environment. The study applies the Grubel–Lloyd index to estimate the shares of IIT (including vertical and horizontal) in India's total trade with the USA and the EU (27). The paper observes that the shares of the vertical IIT are dominant over those of the horizontal IIT and found that India's export in IIT with the USA and the EU (27) are pollution intensive. The results of pollution in terms of trade also reinforce evidence on the pollution haven effect.

The use of input–output models has also been increasingly used to understand issues related to global value chains (GVCs) and product fragmentation. It has contributed to the demystifying and structural analysis of issues related to international trade—a very important development strategy in most developing countries. Sikdar explores the indirect effects of tariffs and non-tariff measures on the manufacturing sector of the Indian economy. India has seen increasingly strong participation in GVCs for chemicals, electrical equipment and other manufactures and service GVCs, particularly business services owing to the use of Indian intermediates in exports of other countries. The paper provides the detailed bilateral restrictiveness index for the inputs of manufacturing industries to India over time and hence investigates the path of NTMs to the downstream industries and the final absorption in the context of the Indian economy.

Unlike many other branches of regional economics and regional science, the development of regional and interregional models occurred almost contemporaneously with the growth of interest in national-level input–output modelling. While I–O models were originally carried out at the national levels, it was eventually extended to investigate and reflect unique features of regional or sub-national problems. The problem in this regard varies in two respects primarily—(a) the structure of production in a particular region may be different from the national input–output data, and (b) the effect of exogenous trade in particular sectors may be much higher than the national case. India is marked by large and highly diverse variations across its geographical extent due to climate and soil characteristics. The input–output model, in this context, plays a centrally important role in addressing these problems peculiar to specific regions. The following papers extend the model to analyse problems varying from Finland to China and the capital formation across states in India. The last model discussed uses the model to investigate the variations in employment creation in both skilled and unskilled sectors.

Flegg and Tohmo review the available empirical evidence on the performance of Kronenberg's Cross-Hauling Adjusted Regionalization Method (CHARM) for two contrasting regions: Uusimaa, the largest Finnish province, and the central Chinese province of Hubei. In the case of Hubei, CHARM is used to construct a detailed regional input–output table with 42 sectors including 17 different types of manufacturing. CHARM does not generate realistic estimates of Hubei's sectoral exports, imports, trade volumes and supply multipliers. This outcome is attributed to the difficulty of getting satisfactory estimates of regional technology, heterogeneity and final demand for this data set. This problem is, in turn, linked to the relatively small size of Hubei, which generates around 4% of China's GDP. By contrast, Uusimaa produced 34.6% of Finland's national output in 2002. These findings highlight the crucial importance, especially in relatively small regions, of adjusting for any known divergence between regional and national technology, heterogeneity and final demand. Various strategies are explored for implementing such adjustments.

Bhanumati and Mukhopadhyay prepare the supply and use the input–output table for four regions across the nation to provide a comprehensive picture of the economy by presenting estimates for capital formation of each institutional sector and external and inter-state trade. The study focuses on Odisha, Gujarat, Punjab, Haryana, Maharashtra, Karnataka, Tamil Nadu and West Bengal. The eastern region covers Odisha and West Bengal. It is a well-endowed region especially with coal, minerals and water, but has remained poor and underdeveloped as compared to the western region (Gujarat and Maharashtra). Perhaps, the explanation lies elsewhere in human resource development and removal of institutional constraints. Similarly, while the northern region (Punjab and Haryana) started out as agrarian states, they have diversified into chemical industries, much to the advantage of their economy. The southern states (Karnataka and Tamil Nadu) have monopolised the textile industry, but the key question, here, is whether they need to look at alternate industries, as the textile industry has since been outgrown by other industries. The estimates also validated the general perceptions regarding Maharashtra's significant share in the national investment scenario and that the chosen eight states contribute more than 50% of India's total. It also found that contrary to general belief, Odisha, Karnataka and Gujarat have been consistently investing a greater proportion of their incomes on growth-related aspects than Maharashtra. The paper also attempts at identifying ways to make use of available information to improve the regional supply–use framework to include regional differences. Such distinctions play crucial roles in the exercise of policy assessments.

The study by Sinha, Prabhakar and Jaiswal capture the role of key infrastructure sectors such as roads and buildings and canal irrigation construction in the economies of two Indian states (Gujarat and West Bengal) to examine their potential in generating employment and also to analyse the quality of such employment using the new data set from the two states for the year 2009–10. The employment multipliers in Gujarat are highest for rural roads construction and irrigation canal construction in West Bengal. The induced effects for both formal and informal employment are highest for buildings construction, which shows that the effect of including households to take into account induced multiplicative effects is high for buildings in the Gujarat economy. The induced effects for formal employment are highest in buildings and national highways/urban roads construction and for informal employment are highest in national highways/urban roads construction in West Bengal. This shows that buildings construction and national highways/urban roads construction generate employment in West Bengal. They found that a 10% increase in investment in irrigation canals construction sector leads to 86,446 extra workers being hired in Gujarat and 48,768 extra workers being hired in West Bengal. Also, this shock leads to Rs. 12.98 billion growth in Gujarat's economy and Rs. 3.02 billion growth in West Bengal's economy. Similar investment in buildings construction sector results in 1,766,938 extra workers being hired in Gujarat and 3,628,008 extra workers being hired in West Bengal. It may also be noted that the informal jobs created in the economy are much higher than the formal jobs created in both the states. The investment impact of the study sectors seems to have nearly similar impacts on the two states in terms of growth but generally has a much higher impact in employment for West Bengal. This reflects the labour-intensive nature of the West Bengal economy compared to Gujarat.

Circling back to the beginning, as a part of his keynote speech, Sengupta developed a new approach to modelling the Indian economy, with the objective of optimising the use of a production system with inter-sectoral interdependence for attaining a level of human satisfaction at the societal level without any requirement of monetary evaluation of satisfaction at the abstract level. Furthermore, this new alternative approach would allow observing and appreciating the difference between an agnostic approach versus a guided approach to generate the GDP or an appropriate well-being index of an economy, with their obvious differential policy implications.

A reading of these papers will indicate their contributions towards solutions of the theoretical and operational problems of this field and broadening of its scope.

The Evolution of Input–Output Analysis

Paul J. Thomassin

Abstract The static input–output model has been used by academics and policy analysts for decades to investigate real world problems and provide advice to policy makers. From its initial development, the input–output model has continuously evolved to incorporate more complex situations in a systematic manner. This includes integrating other biological, physical and social models into the input–output framework, developing dynamic models, and incorporating uncertainty to better analyze these complex real world problems. This paper outlines the history of input–output analysis and some of the specific country experiences. It explores the conceptual extensions of the basic input–output model that have significantly broadened its scope and discusses the numerous areas of application of input–output models and the insights of these applications. Finally, the paper makes suggestions on the future use of input–output analysis.

1 Introduction

Over the past few decades, substantial progress has been made in extending the input–output framework beyond the simple static model. The scope of the model has been expanded to capture the complexity of real-world problems in a systematic and integrated manner. This paper investigates the evolutionary path of input–output analysis from its inception, as developed by Wassily Leontief, to current advances by BEA-Washington, Statistics Canada, and Eurostat. Now, 17 years after Leontief's death and 27 years after the creation of the International Input–Output Association dedicated to input–output studies, it is time to ask the question: what has happened to input–output analysis? Virtually all developed nations and many

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developing countries maintain sets of input–output accounts to complement their national income accounts. This paper studies the evolution of input–output analysis by reviewing some of the countries' experiences with a focus on the works on three continents: North America, Europe, and Asia.

Input–output analysis is borrowed from classical theory of general interdependence and aimed to explain the workings of an economy through directly observable structural relationships. The original two-sectoral input–output system was designed to appropriately describe production, consumption, and distribution in a simple economy through a single process, coined "the circular flow". In 1936, this model was further developed with the support of the first input–output tables and a mathematical model which preserved the concept of the circular flow. At the very outset, it aimed to provide a detailed quantitative description of the various disaggregated components of any economic system. The interdependence of sectors in the economy is represented by a set of linear equations, the coefficients of which are empirically determined.

The first input–output tables constructed by Leontief were those of United States (US) for the years 1919 and 1929 which later culminated in the first input–output conference in 1950. During this period, Leontief's closed economy system was transformed into the open input–output model and made it a key tool to answer pertinent socio-economic questions relating to employment and the economy in the period following World War II. This simple tool has, in recent times, developed into a powerful one, continuing to answer questions of heightened relevance. With researchers pushing the theoretical and practical boundaries of this form of analysis, the input–output model has become an influential technique in various fields of research and is not only limited to employment and industrial productivity.

The paper is comprised of eight sections. Section 2 captures the history of input–output analysis. Section 3 discusses the country initiatives; Sect. 4 is devoted to common issues in the input–output framework: productivity, technical change and efficiency. The discussion of the numerous applications and extensions of input–output models and the insights is given in Sect. 5. Section 6 discusses the global models and their linkages at the national and regional levels using various international organization databases. The recent advances in input–output analysis are presented in Sect. 7. The paper makes suggestion on the future of input–output analysis.

2 History of Input–Output Analysis

Input–output analysis is generally associated with the work of Leontief, *The Structure of the American Economy* 1919–1929 and *Studies in the structure of the American Economy*, for which he was awarded the Nobel Prize in Economics in 1973. His work was conceived for the first time in 1927 at the Institute for World

Economics in Kiel, Germany. It has been argued that the basis of input–output analysis can be found in the classical political writing of early economists, such as Quesnay, Walras, Marx, and von Bortkiewicz, and their emphasis on the circular flow of the economy (Kurz and Lager 2000; Kurz and Salvadori 2000).

Leontief's contribution can be distinguished from that of his predecessors (Quesnay, Karl Marx, Leon Walras, and Ladislaus von Bortkiewicz) because of his emphasis on empirical work. This was distinctly different from the mathematical and theoretical developments of these earlier economists. While these earlier authors tried to address specific questions in a limited context, Leontief's input–output analysis could address a wide variety of problems and provided a means by which theory could be used to provide insight into real policy situations (Baumol 2000).

Leontief joined Harvard in 1932 after a brief time at the National Bureau of Economic Research in order to build his first transaction table of the US economy (Kohli 2001a, b). He was able to design and estimate his first transaction tables because of the increased availability of expenditure and revenue data. The advantage of the Leontief accounting system was that it created a bridge between the theory and measurement and its ability to address policy problems (Kohli 2001a, b).

His initial model worked within a closed system that, later, treated final demand and value-added components exogenous which allowed for the analysis of the open economy. The US government published input–output tables for 1947, 1958, and 1963 and since 1967 for every year ending in "2" or "7".

During World War II, Leontief industrialized the defence sector in the input–output tables, analysing the impact of war on demand for national and local industries, thereby calculating the capacity constraint within the economy. After years of practicing this sectoral modelling, he expanded the framework to incorporate the environment, presenting pollution calculations on a sector by sector basis. The environmental equations within the system played the dual role of pollution entering into the production function, both as input and output.

Since Leontief's original work in the 1930s, the use of this model has been extended to applications in the field of development economics and regional variations. Until the 1940s, most of the input–output applications were based on the original model by Leontief and were used to analyse macroeconomic flows within and between countries. The main motivation behind the development of this model was to increase the understanding of how different elements of the economic system are interrelated.

Richard Stone modified the framework of input–output analysis during his years spent as the Director of the Department of Applied Economics and the Programme for Growth at the University of Cambridge. This framework became extremely popular both nationally and internationally by developing a standard system of national accounts. Input–output analysis became a framework of interest when he was working on the new Social National Accounts. This ended up being extremely important to the development of national accounting as a policy tool, not only in

Britain, but in the rest of the world as well. Stone's purpose was to present the philosophy underlying his model, stressing its practical scope and then proceeding with the illustration of the model itself, which represents the bulk of the work of the Cambridge Growth Project. This further clarified Stone's view on the need for balanced intervention by a central authority to control the economy, in order to progress towards socially agreed objectives. As observed by Pasinetti (1992), it is essential to understand which relations in the economic system are independent of the institutional set-up and which are not.

The social accounting matrix became an economic tool that has a wide-ranging impact on the field of economics. Its application was not restricted to its original form and has now been used in collaboration with other models to investigate a wide range of issues especially social and environmental problems (Rose et al. 1989). Of late, greater advancement has been made in the areas of social accounting for the forecasting of technological change by both economists and engineers.

The main contribution of the input–output model is that it presents a formal numerical representation of the economy. It also allowed for the creation of databases for several countries and regions and has been integrated into computable general equilibrium models. In fact, despite the limitations of the model itself, actual input–output tables along with various assumptions have been used for various purposes. Input–output models will be in great demand from a diverse range of fields for both academic and policy research across many countries.

Constructions of input–output tables:

Since 1991, *supply and use tables* have constituted the main statistics on the production structure of the Dutch economy and form the basis from which input–output tables are derived. The time series of supply and use tables start in 1987 which facilitated the benchmark revisions of the Dutch national accounts and could be derived from existing input–output tables (Kazemier et al. 2012). The main relation consists of industry-by-industry input–output tables of the entire economy derived by summing up each single commodity in the input–output table. This process is time-consuming and expensive and is done for all benchmark revision years.

Due to the time-consuming and expensive nature of survey-based input–output tables, a number of non-survey techniques have been developed to estimate input–output tables. One form of non-survey estimation uses a composite cross-entropy approach that allows an amalgamation of two kinds of apriori information from past periods and regionalization (Vazquez et al. 2015). This method can use a number of initial heterogeneous matrices to estimate the new input–output tables; however, it can only be used with matrices that have semi-positive interior cells and margins. The empirical application of the method on the input–output tables for the Euro Area 2007 supports this adjustment process. Using two sets of data, when neither process is applicable to all industry, therefore suggests and encourages the use of the data weight prior estimators. This method allows the consideration of apriori weights different from equal weight of two initial input–output tables where one consistently performs better than the other. Moreover, modifications to the objective functions are possible when individual cells and blocks can be weighted in each apriori, rather than the industries.

The commodity and industry technology assumptions form the basis for the construction of commodity input–output tables. An extension allows input–output econometric tests to facilitate the construction of appropriate hybrid technology-based commodity input–output tables (Rueda-Cantuche et al. 2018). The study provides weighted likelihood ratios of the commodity and industry technology assumptions. While the tests should ideally lead to statistically significant conclusions on the selection of the most appropriate technology assumption, but the tests are affected by the heterogeneity in commodity classification. Given this heterogeneity, the tests sometimes present inconclusive results due to the fact that the proposed tests are not single tests of one assumption against the other but independent tests which provide likelihood ratios for each technology assumption separately.

Raa and Rueda-Cantuche (2007) constructed a technical coefficient matrix in a supply–use framework with competing commodity and industry technology models. They established a method that would encompass a single formula featuring input–output coefficients for the amounts of commodities used by an industry to produce another commodity. The framework allows the testing of which of the models better fits the data, i.e. competing industry or industry technology. It can, therefore, be used to apply both models to different inputs and provides a mixed technology model.

While a large number of studies have been dedicated to updating input–output tables, the general assumption is that the overall structure of the economy remains unchanged during an interpolation period. However, the experience of rapid development and fast speed changes suggests that such an assumption may be incorrect. Wang et al. (2015) combine a matrix transformation technique and forecasting to provide a new perspective on methods for updating input–output tables assuming that there are statistically significant trends in economic structural change. The authors combine the matrix transformation technique (MTT) and time series models to extrapolate input–output tables with total value added during targeted years. The paper finds that the comprehensive performance of the MTT is a better method to proceed with.

3 Country Initiatives

Since its conception in the USA, other countries have found substantial use for their input–output tables. Economists and social scientists have found relevance in its ideas and sought to develop their own tools to create cohesive methodologies to produce input–output tables.

Leontief first developed the US tables that were published in the Structure of the American Economy, 1919–1929. It was a closed system that was responsible for a bill of goods or set of final demands that were exogenous to the table solution. In 1939, attempts were made to analyse the effects of demobilization on employment and reconciliation with the national income accounts with the help of Duane and Hoffenberg (1952). The system was the most accurate portrayal of the economy at the time and generated interest among policymakers and academics alike. At the end of the World War II, the Planning and Research Division of the Air Force set up an inter-agency project known as the Scientific Computation of Optimum Programs. Due to the increased funding, Leontief and the Bureau of Labour were able to develop a detailed table of 450 industrial and 50 autonomous sectors.

Until 1968, no distinction was made between industries and commodities. In 1972, there was a major change in the presentation of input tables with the segregation into make and use tables according to the proposal of the 1968 System of National Accounts. It explicitly recognized the difference between industries and commodities. The main problem associated with the US tables was the time lag in generating.

The 1992 table was the last published on the Standard Industrial Classification basis which included 498 intermediate sectors, and divided the government expenditures into consumption and investment, with the former including an estimate of the depreciation of government capital stock. Following this, the North American Industry Classification System (NAICS) presented a shift in the classification of economic data which created a new information sector that including publishing, motion pictures and sound recording, broadcasting and telecommunications, information services, and data processing along with new auxiliaries that included establishments that served administrative management, storage, or distribution functions within a large company. This and other innovations broke the consistency and comparability between the 2002 tables and other input–output tables. International standards of the presentation of input–output tables have also evolved that are valued at basic prices instead of producers prices, which is in correspondence with the System of National Accounts supply and use table presentation used internationally.

The development of the input–output concept in Russia had early beginnings. According to Belykh (1989), V. K. Dmitriev made an early contribution in 1904 by developing a system of equations in order to estimate full labour costs. His ideas were largely forgotten until 1959 when V. S. Nemchinov brought them back when input–output analysis was struggling to gain recognition in the USSR. One of the controversial individuals within the development of the input–output concept was A. V. Chayanov. He made significant contributions to mathematical economics by addressing the problem of the optimal size of an agricultural enterprise and in the modelling of a peasant household. The controversy revolves around whether he utilized Dimitriev's work to develop a modified account balance system for agriculture. Belykh (1989) argues that his approach was simply an accounting balance approach and did not include an input–output balancing mechanism.

During the 1920s, planning was a main preoccupation in the Soviet Union (Remington 1982). Part of the theoretical developments that occurred was the interdependencies of all components of the economy. These interdependences were often described as links in a chain. A. A. Bogdanov made several important contributions. One was in the development of general systems theory, while a second was in the planning process (Belykh 1989). Bogdanov recognized that industrial sectors were dynamic and each industrial sector had both forward and backward linkages (Remington 1982). The process required an iterative approach in order that all of the inputs would be available given the resource availability. The other system element that was brought into consideration was "proportionality", which represented the same concept as equilibrium. This was important because it recognized that all sectors are part of a broader whole economy.

Two additional issues were investigated during this time. The first was to identify the appropriate unit of measurement for both inputs and outputs. Several suggestions were made; however, given the fall of the currency, the unit used in the planning process was physical units (Remington 1982). The second issue to be addressed was how to bring the system into balance. It was L. Kritsman who proposed the idea of iterative balancing as a means of bringing things into equilibrium. Though work was done in this area for planning the economy, there was no mathematical formulation of the balancing method (Remington 1982; Belykh 1989).

The Soviet Union had developed a 38 sector inter-industry model of the Russian economy using 1959 transactions. One of the major differences between the use of input–output tables in centrally planned and market-based economies was the type of analysis which were undertaken. In market-based economies at the time, input–output models were used to estimate the industry requirements needed to fulfil changes in final demand, while in centrally planned economies the analysis focused on the material requirements of total output, i.e. intermediate demand by industries and determined final demand (Miernyk 1968).

During the period of the USSR, inter-industry balance accounts were used for planning and forecasting purposes. With the fall of the USSR, the Russian Statistical Agency continued to develop input–output tables for Russia. The Russian input–output benchmark accounts were based in 1995, and appropriate methods were used to develop accounts in current prices from 1996 to 2003 (Baranov et al. 2016). One of the problems with these accounts is that tables were based on the product and industries that were in existence during the Soviet period. Once Russia went into transition, these product and industry accounts did not represent the changing industrial structure in the economy. As a result, the extrapolation of data to 2003 did not accurately reflect the changing industrial structure of the economy. This problem is being rectified with a new benchmarking exercise based on a new classification system (Baranov et al. 2016). The experience with the Russian input–output tables emphasizes the importance of taking into consideration changes in industrial structure as economies go through a transition process.

The first experimental input–output table of Canada was for the 1949 economy and was released in 1956. This table used a square industry-by-industry accounting framework. Starting in the 1960s, Statistics Canada adopted a rectangular, commodity-by-industry framework for its input–output tables. The development of the input–output tables was originally designed at the national level; however, periodically provincial or regional tables were developed by disaggregating the national tables into regions. During this period, constant price and nominal price models were developed on an annual basis with an appropriate time lag (Statistics Canada 2016a).

A major revision to the data collection system started in the 1990s. This revision occurred because of the increased emphasis on provincial and territorial accounts. As a result, many of the survey instruments were redesigned and sample sizes were increased to generate provincial supply and use tables (Statistics Canada 2016b). The current supply and use tables contain 470 product classes and 233 industrial sectors in 14 regions (ten provinces, three territories, and one region "outside Canada" that includes embassies, etc.). In total, there are approximately 1.5 million cells in the supply and use tables.

The final demand table includes five major categories: household consumption and non-profits serving households, business investment, government expenditures, export and imports (Statistics Canada). The final demand table includes 470 product classes, 280 final demand categories, and 14 regions.

The data collection system generates annual national and inter-provincial supply, use, and final demand tables with a 3-year time lag. The input–output models generated from these tables are more accurate for policy analysis. Recently, changes in the definition of confidential data have allowed the tables to be published without any data suppression.

The basic structure of the input–output model developed from the supply, use, and final demand tables is as follows (Ghanem 2010):

$$g = [I - D(I - \beta - \alpha)RB]^{-1} D(I - \beta - \alpha)(\mathrm{Re} + x)$$

where

- g is provincial gross output matrix, which is a matrix of the vectors of gross output by industry for each province,
- I identity matrix,
- D is a block diagonal matrix of each provincial market share matrix (14 regions),
- R is the provincial commodity share matrix, composed of 14-by-14 sub-matrices,
- B is a block diagonal provincial industry technology for each region (14 regions),
- e matrix of domestic final demand for all provinces,
- x is a vector of inter-provincial exports by commodity for each province,
- β is a block diagonal matrix of inventory leakages,
- α is a block diagonal matrix of scrap leakages.

The redesign of the data system to collect information at the provincial or regional level provides an additional dimension to the analysis that can be undertaken with the inter-provincial input–output model. The new data collection system allows the industry technology and market share by industry to vary by province and region. This is important in a country like Canada because of the spatial variation in industries and the industry technology employed across the country.

The redesign of the data collection system allows for more robust analysis to be undertaken to address policy concerns. The inter-provincial tables allow industrial technology and market shares to vary spatially which provides an added dimension to the analysis. Further enhancement to the data collection system would suggest that input–output models will continue to be used for policy analysis.

Publication of the first input–output tables for Japan occurred in 1955 for the year 1951. These tables were provisional tables developed by Japan's Economic Planning Agency (EPA), The Ministry of International Trade and Industry (MITI) with the support of related ministries and agencies. The 1951 tables consisted of nine sections by the EPA and MITI and 182 sections by the agriculture and forestry sectors. However, due to the two sections, unavoidable divergence occurred in estimates as a result of different classifications and categorization. For the 1955 input–output table, a uniform code was created and distributed among six ministries and agencies to make a cohesive system of national accounting with 1955 as the benchmark year. Since the publication of the 1955 input–output tables, input–output tables are compiled every 5 years (Ministry of Internal Affairs and Communication Japan, ND).

From 1962 to 1963, a new framework was developed to compile the input–output tables which were more consistent with the system of national accounting. This allowed for comparability of long-term time series and international comparability on the basis of the Standard Industrial Classification for Japan and the International Standard Industrial Classification of all Economic Activities. Since then, the system has continued with extensions till 1975 when the number of ministries involved in data collection increased to 11 government ministries. Various sectors were divided to enhance estimation. In 1995, the input–output tables accounted for indirect taxes through the inclusive of the consumption tax. It was also set up to comply with the recommendations of the 1993 System of National Accounts. In addition, the changes reflected the economic and social structure of Japan with new sector classifications. In recent times, Lagrange's method of indeterminate multipliers has been used for the aggregation of preliminary reports (Ministry of Internal Affairs and Communication Japan, ND).

4 Productivity, Technical Change and Efficiency

The creation of input–output tables and the following analysis form two separate domains; economic accounting and forecasting, respectively. The implication of robust economic accounting lies in the ability to investigate different kinds of economic phenomenon. Questions of productivity, technological change, and efficiency play an important role in determining a country's economic growth over time.

The question of total factor productivity (TFP) has remained an important issue in the economic literature. Over the years, economists have attempted to answer the question of TFP and its static and dynamic counterparts. The static and dynamic input–output framework can address these questions. While traditional TFP is defined in terms of growth accounting of a specific sector, the static unit TFP of a commodity evaluates productivity growth on an economy-wide basis, including the more efficient use of factor inputs in all linked industries. The input–output model can be used to estimate the impact of productivity change, for example the effective rate of TFP proposed by Hulten (1978). The effective TFP is also identical to the TFP of Peterson's vertically integrated sector where each sector produces one type of final output making use only of factor inputs. Petersen (1979) and Wolff (1985) have used this approach to measure TFP for the UK and USA, respectively, using Leontief's static input–output framework. Aylin-Ahmavaara (1999) has proposed a fully effective rate of TFP using the dynamic input–output framework to evaluate capital as a produced input, whose formulation was based on a balanced growth solution.

Economists are interested in both how an individual economy changes over time and how economies compare at a given point in time. Jorgenson et al. (2007) investigated the industry origins of productivity in the US economy over the period 1960–2005. They used aggregated estimates of value added, capital and labour input, and total factor productivity across industries to estimate productivity by industry over time. They found that the production possibility frontier was a good proxy for the underlying growth rate in TFP by industry over time and that the aggregate TFP growth is a good approximation of the Domar-weighted sum of TFP growth. Second, they found a divergence between the aggregate value-added estimated from the production possibility frontier and those estimates derived from the aggregate production function. The difference in estimates comes from the assumption of equal value-added prices used in the aggregate production function. Third, the authors found that aggregate data can mask the heterogeneity of individual industry productivity. They concluded that in order to understand productivity growth, individual industry data must be included in the analysis (Jorgenson et al. 2007).

Technological change is often considered the basis behind productivity growth; however, recently several authors (Raa 2005; Raa and Shestalova 2011; Raa 2017; Shestsava2017) have incorporated estimates of efficiency change as part of productivity analysis. Efficiency can be brought about by improvements in the organization of firms and sectors and a better allocation of resources between industries. Raa and Shestalova (2011) identify the four main ways of measuring TFP: (1) Solow's aggregate production function model, (2) index numbers, (3) data envelop analysis, and (4) the Domar aggregation approach. The latter approach is the one most often associated with input–output analysis. The differences in the estimates from these four approaches are the result of behavioural assumptions and the prices used in the analysis. In the Solow aggregate function, it is assumed that there is no slack in production and that there is proportionality between prices and marginal products, while in the index number estimates, it is assumed that there is no production slack and prices reflect marginal value. The index number estimates of TFP reflect technological change. On the other hand, data envelop analysis uses shadow prices and reflects the marginal values of the production function, which is based on observed behaviour. Data envelop analysis provides an estimate of inefficiencies within the economy. Raa and Shestalova (2011) developed a new approach using the Domar aggregation that takes into account the technological change components of the Solow and index numbers and the efficiency measurement of data envelop analysis. The technological change component can be measured using the structural input–output approach, while efficiency can be measured by the improved allocation of productive factors across industrial sectors. This advance allows for both technological change and efficiency to be measured in productivity analysis.

This discussion brings us to the issues surrounding capital, labour, energy, material, services (KLEMS), and productivity. Broersma and van Moergastel (2007) used the supply and use tables of the Dutch economy from 1987 to 2001 to investigate intermediate input use by commodity and industry. The estimation of intermediate inputs is needed in analysing productivity growth. Their extrapolation method provided reasonable estimates of the published inputs in current prices. The method can also be used to estimate the volume of intermediate inputs. They concluded that this method is a useful tool to generate capital, labour, energy, material, and service (KLEMS) data that can be used for productivity analysis (Broersma and van Moergastel 2007).

The most common comparison of productivity is for an individual country over two points in time. As new technologies and globalizations have become a larger issue, there is growing interest in international comparisons of country output, input, and productivity growth. Inklaar and Timmer (2007) undertook a study that compared seven industrialized countries in terms of their use of inputs to produce output at a detailed industry level. The seven countries included in the analysis were France, Germany, the Netherlands, UK, USA, Australia, and Canada. They used a "level comparison" to measure gross output rather than value added for each of the countries and industries. Eurostat and EU KLEMS data were used to provide the necessary data on labour (two types—university degree and non-university degree), capital (two types—information and communication technology (ICT) and non-ICT), energy, materials, and services, while individual country data were available for the USA, Australia, and Canada for these items. The authors netted out intra-industry trade from the data sets. The results indicated that there was very little difference in the structure of production, with the exception that the USA used more skilled labour and more ICT capital (Inklaar and Timmer 2007).

Imports are becoming a more important component of the industrial structure of industries and countries. Accessing imported goods and services can be a means of increasing the productivity and competitiveness of industries within a country (OECD 2012). In order to address this issue, Gu and Yan (2017) estimated effective multifactor productivity (MFP) growth for a number of countries including Canada. Effective MFP measures productivity growth for products instead of by industries and takes into account productivity gains in both domestic and international upstream industries; i.e. productivity growth is not only in terms of increased productivity of the product but also the indirect increase in productivity of the intermediate input going into the product. The data used in the analysis were the World Input–Output Database and the EU KLEMS database. Using this information, capital, labour, expenditure shares of final demand and the Leontief inverse for several countries were estimated. Gu and Yan (2017) concluded that MFP for Canada was partly due to the productivity gains in intermediated inputs that were imported from other countries, in particular the USA, and that Canada gained more from increased productivity of imports than other countries.

Measuring productivity based on firms and industries within a country's boundary may not be a good means of measuring global value chains (GVCs) because GVCs fragment production across firms, industries, and countries. As a result, GVCs are similar to vertical integration across countries and industries. KLEMS data tend to be country- and industry-specific. Timmer (2017) identifies a new methodological approach that is based on the input–output approach by Leontief that uses the cost equations generated in the model. Traditionally, KLEMS data are used to estimate productivity as the gross output of an industry as a function of intermediate inputs and domestic factor inputs, while this new approach estimates productivity using the final output of the product as a function of domestic and international factor inputs (Timmer 2017). Using this approach, the production function is estimated using only factor inputs, both domestic and international. The benefit of this approach is that it addresses the question of intangible capital, specialization in labour skill and capital-intensive activities, and the fragmentation of production that occurs across the GVC. The case study of the GVC for the production of German automobiles illustrated the methodology and the data requirements. The data used in the analysis were the World Input–Output Database. This approach identifies tasks and the factor inputs going into these tasks and how these tasks combine to generate output. This allows for a greater understanding of labour and capital substitution both domestically and internationally (Timmer 2017).

5 Extensions of the Input–Output Model

Richard Stone followed a methodological approach similar to Leontief in that quantitative foundations were used to make theory relate, effectively, to empirical data. This included the integration of input–output tables within the Social National Accounts, his research on the social accounting matrices (SAM), and the adjustment and updating of the technical coefficients (RAS method). His ideas flowed from a concern about society as a whole and by the desire to make it better. Stone incorporated a variety of tools and methods and concentrated on reconcile theory to empirical evidence. Moreover, Richard Stone's contributions to input–output analysis went hand-in-hand with his more general contributions to economics (Stone and Pesaran 1991).

Social National Accounting proved to be an important innovation to the whole framework of national accounting by using an industrial breakdown of the business enterprise sector in such a way as to enable the construction of input–output tables similar to those developed by Leontief. Stone aimed to complement the two concepts so as to make the input–output analysis more flexible and capable of extension to many other aspects of economic activity, apart from production. In addition, Stone presented transaction models, that is, models of economic interdependence which involve a matrix of transactions and a matrix of responses. He explained these using static and dynamic models, such as an elementary static model on Keynesian lines, the input–output model of Leontief, and Goodwin's model of labour and capital (Stone and Pesaran 1991).

According to Stone, social accounts are a consolidation without much regard to the details of the commodity composition of production, but at the same time they are too focused on the technological relationships which exist in the production sphere. This led to the historical reconstruction of the first input–output tables for the USA, the UK, the Netherlands, Denmark, Norway, and Italy. From this exercise, it was concluded that a complete system of social accounts must be able to handle transactors in all their aspects as producers, consumers, and accumulators. In the international standard systems of national accounts, this classification is achieved by a limited solution by which classification is reduced to "private" and "public" (Stone and Pesaran 1991).

At the end of the 1950s, Stone's efforts resulted in a book, Social Accounting and Economic Models, which explained the principles of national accounting, and showed how the various transactions can be laid out as matrices, known as social accounting matrices (SAMs). The book also discusses the various models of behaviour, an input–output system for production, a linear expenditure system for the demand of non-durable goods, and dynamic demand functions for durable goods. In 1962, Richard Stone and Alan Brown published *A Computable Model of Economic Growth,* the first of a series of 12 volumes issued by the Department of Applied Economics and known as the "Green Books". In particular, Pyatt and Round (1985) contributed to the development of SAMs at the World Bank, which eventually produced a worldwide standard version which, with further extensions and modifications, has been widely used to the present. Once the SAM was developed, it turned out to be a very flexible and extendable analytical tool. Further advancements were made when Stone and his colleagues developed a special method of updating the technical coefficients, known as the RAS method. The acronym indicates that the updating of the coefficients is made by pre-multiplying and post-multiplying the matrix of technical coefficients "A" by two suitable matrices "R" and "S". The problem of variation of technical coefficients had been illustrated by Leontief in his early work, but it was Stone who provided a computational technique to be adopted at the international level. Stone showed that once sufficient information is available, it is possible to integrate the information provided in the table by including more complex forms of relationship between inputs and outputs. Having shown that transaction models can serve as a major methodological tool to extend input–output analysis, he explored the short-term forecasting power of transaction models. They explained how economic models might help us to reconcile the advantages of central planning with those of individual initiative. The core issue is the availability of information and the feasibility of decision-making dependent on the information (Stone and Pesaran 1991).

The first application of input–output analysis was to the educational system. The second was the use of Markov chain methods for formalizing hypothesized relationships. The focus was on improvement of the growth model. When input–output analysis is applied to demography, a further difference occurs, as output coefficients, rather than input coefficients, are fixed. In this case, the model is better defined as an "allocation model". The market system has proved itself to be a practical means of regulating the production and consumption of goods. However, the market system has failed to provide a solution for externalities, especially pollution. According to Stone and Pesaran (1991), a solution can be achieved only through further improvements in science, rather than from a denial of science.

A prominent feature of the Leontief model is that its versatility facilitates the use of the model to analyse problems in the field of social science, especially the functioning of markets. Lopes and Neder (2016) discuss the dichotomous role played by qualitative and quantitative analyses in shaping the ideologies underlying the study of political economy. The two extreme ideologies in political economy are capitalism and Marxism. Both of these extremes are theoretical forms of economic organization. Capitalism is defined by the accumulation of surplus in terms of profits, interest rates, etc. The model maximizes the utility of individuals by identifying the objective function of profit maximization. Political economists have argued that this does not take into account the essence of use value, incorporating only the material expansion and pushing the limits towards higher growth. Marxism is a different social organization that is based on a planning perspective. Despite the differences in ideologies of Marxism and capitalism, input–output analysis can be used to address the dynamic behaviour of variables in the political economy covering the qualitative and quantitative aspects of the economic models. Such analysis is made by using the devices proposed by Sraffa, Leontief, and Lange to identify an objective function for the whole system (Lopes and Neder 2016). The paper brings out a classical phenomenon associated with input–output models, namely their applicability to other systems and the versatility with which it can implement changes to facilitate the investigation of economic problems.

Raa and Shestalova (2015a, b) identify the complementarity between the quantity and value systems in input–output analysis as the basis of the complementarity approach to computable general equilibrium. Stochastic analysis is largely facilitated by the numerical weighting of the latter and the linear programming approach. The duality of prices and quantities appears to allow for the connection between them in a symmetric manner. Furthermore, stochastic analysis allows for the analysis of uncertainty in the economy's structure. Complementarity is used to explain the inability to achieve targets set out in the Kyoto Protocol, and confidence intervals are derived for consumption reductions (Raa and Shestalova 2015a). Environmental regulatory constraints are associated with primary input constraints and the numerical demonstration points towards the applicability of the model to stochastic analysis of input–output scenarios.

Production inventory refers to the level of materials and supplies on hand for use in manufacturing and is considered different from work-in-process inventory (value of materials being used in production at any given time) and finished goods inventory (value of goods to customers). Input–output analysis along with the Laplace transformation has been used extensively in the academic literature surrounding production inventory. The use of the Laplace transformation allows the imposition of timing properties in the Leontief input–output matrices with the help of the Leontief inverse. Such a model helps in the analysis of assembly systems especially ones with capacity requirements and safety stock problems. It can also be used in a broader sense for industries with a divergent material flow (Raa and Shestalova 2015a, b).

Grubbstorm and Tang (2000) acknowledge the potential for simulating production opportunities through both the input–output analysis and material requirement planning (MRP) models despite their origins in different contexts. Both models focus on the internal demand of products and the paper explores the parallels in theme and outcomes. It allows for the economic valuation of input items. It can be further used in the study of capacity and structural requirements of production assemblies and non-assemblies. The generalized input–output matrix allows the model to capture the time quotient, the required amounts of components, and the transformation solves the problems of treating differential equations of the changes in stocks and flows and time lags along with acting as a moment-generating function and for use as an economic evaluation principle. The method has further implications in the study of performance of dynamic input–output models on the macroeconomic scale.

The initial formulation of the Leontief environmental model extended the original input–output table by adding pollution generation and identifying key pollution elimination sectors and is essentially used in the analysis of common-pool resources (CPRs). The paper by Allan et al. (2007) generates an empirical Leontief environmental input–output system and endogenizes waste generation and waste disposal activities. Its application can be extended into the analysis of other CPRs such as highways and irrigation systems. It specifically demarcates the waste disposal sector from the sewage and sanitation sector in order to differentiate waste disposal by source to cater to the Scottish input–output accounts. It is important to note that the application of the Leontief environmental model can be used with CPR of waste generation and disposal. It also furthers the existing input–output database through the incorporation of elements of green accounting.

Physical input–output models are an interesting and convenient tool for evaluating environmental and economic policies. L'Abbate (2012) challenges the viability of already existing circular flow of goods under a monetary framework and proposes the input–output method in physical terms to evaluate the detailed inputs that bypass the production threshold transformation. This includes the raw materials extracted from natural resources in physical output terms along with the generation of waste which comes along with different disposal methods and is not included in the monetary flows in the system. Although Malthusian ideologies have been challenged by neoclassical economists, the growth trajectory is no longer a single subset of what benefits the economy which also takes into consideration the future sustainability through the dynamic role of the environment in the system. The proposed methodology of constructing physical input–output tables helps in understanding the interaction of micro-macro material flows, identification of physical units of natural resources that go into economy and income generation (Timmer et al. 2015). This model aids in the detection of corrective policy measures to sustain the growth within the environment domain.

6 Global Databases

Independent databases of production, consumption, and distribution supported individual country input–output tables. This allows countries and regions within countries to undertake macroeconomic analysis with input–output models. More of the analysis that is being undertaken would benefit from the integration of country models. As a result, several attempts have been made to standardize databases that could form the basis of input–output models.

The World Input–Output Database (WIOD) includes databases, accounting frameworks, and models in order to help policymakers to strike the right balance between growth, environmental degradation, and inequality taking into account multiple countries. The core of the database consists of two sets of data, supply and use tables and data on international trade in goods and services. These data sets are then taken together with extensive satellite accounts and integrated into sets of inter-country input–output tables. Flowing from the WIOD comes the World Input–Output Table (WIOT) which is a combination of national input–output tables. The advantage of this data set is that it recognizes the use of products based on their origin, i.e. by a domestic industry or a foreign industry (Timmer et al. 2015).

The main characteristics that distinguish it from other databases (GTAP, OECD, and IDE-JETRO) include:

1. Use of national supply and use tables (SUTs),
2. Flow from output and final consumption series to a time consistent series,
3. Explicit link to international trade statistics,
4. Explicit attention for trade in services, and
5. Extension with socio-economic and environmental satellite accounts.

Another example of the use of multiple databases is the Industry Forecasting at the University of Maryland (INFORUM). INFORUM aims to improve business planning, government policy analysis, and the general understanding of the economic environment by using dynamic inter-industry macroeconomic models and econometric models. These models combine the input–output structure of the economy with econometric equations in a dynamic framework and enable policymakers to answer questions about the impact across industries, apart from just forecasting (INFORUM 1967).

Aside for forecasting, EXIOPOL is dedicated to estimating external costs of a broad set of economic activities for Europe. The database includes a detailed environmentally extended input–output framework, with links to other socio-economic models. Apart from applying these results to the present, it also aims to evaluate the impact of past research in this field. Its greatest relevance is in its orientation towards evidence-based policy questions (Tukker and Heijungs 2007).

Moreover, due to globalization, there has been increased interest in the application of supply and use tables in combination with input–output tables, i.e. enhancement of the statistical basis. This aids in the analysis of environmental effects in the context of sustainable development, with tables on physical flows, extended monetary tables, or social accounting matrices. The main intention of EUROSTAT is to ease the compilation process, improve quality, and create a sense of coordination among the various methods used (Eurostat 1995, 2001, 2005, 2006).

The development of global multi-regional input–output (MRIO) models allows the linking of political strategies to address global environmental challenges. The models provide a strong base for the investigation of regional homogeneity and heterogeneity and, through collaboration with the input–output community, could allow the successful construction of national input–output accounts and global MRIO models. There are also other possibilities in the realm of time series models and global value chains (Weinzettel et al. 2011).

Currently, more effort has been directed to developing global multi-region input–output (GMRIO) models; however, they fail to capture the heterogeneity of regions within a single country. The importance of multi-scales lies in its ability to comprehensively analyse the interdependence of the global economy while preserving regional differences. Bachmann et al. (2015) developed methods for integrating multi-region input–output data sets from multiple spatial scales into a multi-scale multi-region input–output model and demonstrated its feasibility. This model was a Canada-centric model that included 47 countries and 13 of Canada's sub-national regions. It provides a tool for the analysis of global concerns in a more spatially detailed focus. The main advantages of multi-scale models are that the analysis is not restricted by the representation of the sub-regions and does not consider the impact of exogenous states of individual sub-regions. The disadvantage, however, is that the error quotient of the MSMRIO is higher than for a multi-region input–output model. Moreover, the multi-scale approach is recommended for global studies focusing on countries with a great degree of regional variation (Bachmann et al. 2015).

Dietzenbacher et al. (2013) provide their views on the future of input–output analysis and the progress in areas of data collections, methods, theory testing, focus, and scope. The authors foresee greater scope in exploiting sources of information and linking input–output tables with other aspects of economic systems with improved quality. Improved data will improve the accuracy of GMRIOs, MSMRIOs, and IOTs. There is also the possibility of more accurate estimation as a result of increased data availability and therefore increases the potential of more sensitivity analyses. The authors also predict a new system of environmental accounts by the year 2038 and foresee the possibility of abandoning national responsibility for account compilation through the mandates of dynamic GIS and MDHS classification procedures to call upon a new generation of information systems ranging worldwide.

7 Recent Advances in Input–Output

The widespread application of the input–output framework has lead to its rapid evolution through mixed models of various kinds. These include models that take into account carbon footprinting, disaster forecasts, and the monetization of losses due to natural disasters, dynamics, and mitigating uncertainty.

Carbon footprinting refers to the attempt to capture the total amount of greenhouse gas emissions that are directly and indirectly resulting from an activity or accumulated through the life cycle of a product. Wiedmann (2010) showed that input–output analysis has the potential to contribute significantly to the practice of carbon footprinting. The merging of these two practices is interesting for several reasons. Input–output analysis uses a systems' approach to understand the interactions between different sectors of an economy. It has now become standard practice to form extensive input–output tables for economies according to the system of national accounts. Meanwhile, carbon footprinting is a much newer concept that has emerged from a generalized description of total greenhouse gas emissions due to manmade activities. Carbon footprinting is often used synonymously with the impact of climate change due to individual, communities, nations, companies, and products.

Given the various definitions in the literature, there is a large ongoing debate regarding the most appropriate method for carbon footprinting. Methodologically, the "full life-cycle perspective" has been addressed using either a bottom-up or top-down approaches. The bottom-up approach is based on process analysis (PA), i.e. an Attributional Life Cycle Analysis, while the top-down approach uses an environmental input–output analysis (EIOA) formulation. The former refers to the environmental impact of individual products from "cradle to grave" using specific primary and secondary process data which leads to truncation errors of unknown size. It is also a costly and labour-intensive task. Environmentally extended input–output analysis, on the other hand, provides an alternative economy-wide approach that makes systems cut-offs unnecessary and is appropriate for larger entities such as product groups, sectors, and countries. This latter approach assesses impacts through the assumptions of price, output, and carbon emission homogeneity at sector levels. It is a relatively resource-efficient form of analysis. Developments in energy analysis in the 1970s and life-cycle analysis in the 1990s suggested that the adoption of a hybrid method for carbon footprinting would be able to create an all-encompassing system for analysis. More recently, the debate has shifted towards the merging of the PA and EIOA systems to avoid underestimation of carbon emissions and requires a strict standardization process for its success. This need has been mirrored in the drives by the UK Department for Environment, Food and Rural Affairs as well as the British Standards Institution, The World Resources Institute, the World Business Council for Sustainable Development, and the International Organisation for Standardisation to develop standards for carbon footprinting of products and organizations. Input–output analysis for carbon footprinting provides an accounting of greenhouse gas emissions from a consumption perspective on an individual, local, regional, or national level. It has wide implications for climate policy because it can be used from a consumption perspective to estimate greenhouse gas emissions. Although it is not the only environmental concern that can be addressed through this analysis, the use of input–output analysis for the purpose of greenhouse gas accounting has the ability to support the cause for evidence-based policy-making in countries and can be expanded to include ecological and water footprinting.

The extension of input–output analysis in the areas of short-term forecasting, regional analysis, environmental issues, income distribution, and dynamic analysis has been investigated to a great extent in the literature. In the area of environment, Leontief et al. (1972) suggested its extension to take into account the generation of environmental pollutants by economic activity and the resource costs of pollution abatement. The integration of the environment into input–output analysis has been furthered by Hartog and Houwelling (1974) and Cumberland and Stram (1976).

Another extension applies to a variety of models to assess the economic losses of disasters through input–output and computable general equilibrium models. An increasing number of scholars have developed hybrid approaches that combine both or either in combination with non-economic methods. Natural disasters, which have been rising in frequency with respect to extreme weather and climate events, lead to large-scale destruction of economic value. Okuyama and Santos (2014) divide the impacts of disasters into two types of losses and classify them according to stocks and flows. Stock losses can be defined as damage that arises from the destruction of physical and human capital. Tangible stock losses are generated by asset damage. On the other hand, flow or production losses arise from business interruption and interference in upstream and downstream supply chains. The latter generally is often the main focus in the economic literature.

Steenge and Bočkarjova (2007) investigated the impact of post-catastrophe economics through the input–output framework. They recognized that the size of the catastrophe can have several impacts on the circular flow that exists in the pre-catastrophe economy. These can include impacts on production capacity, labour availability, and final demand. Using geographical information systems and other spatial information can provide insight into the size of the impacts on industrial structure, labour availability, and demand. The lost production capacity can be integrated into the modelling framework using a diagonal matrix. Combining this information; i.e. the lost production capacity in the diagonal matrix, with the pre-catastrophe closed input–output model can identify the imbalances within the circular flow of the economy. This provides a means of identifying the options for the recovery process.

Li et al. (2013) expand on the work by Steenge and Bočkarjova (2007) to include the time element into the recovery process. The time dimension is applied to the recovery process by including labour loss and dynamic equations for labour productivity capacity and capital production capacity. Using this information, a rationing scheme can be devised to allocate intermediate consumption and to estimate the new total production. This process can continue through time until the point when total production capacity, total demand, and labour capacity are equal to the pre-catastrophe total production. Li et al. (2013) incorporate size of the catastrophe, reduction in labour, and production capacity into a dynamic input–output framework that takes into account the imbalance between labour, capital, and final demand during the recovery period. Using simulations of the size of the disaster, as well as behavioural assumptions, allows this approach to be used in the planning process to develop contingency plans.

The most popular models used in disaster impact modelling are social accounting matrix (SAM) models, input–output models, and computable general equilibrium (CGE) models. Most importantly, they are demand-driven models which remain invariant to low- or high-income trends. Due to their linearity and invariance to resilience methods, input–output models tend to overestimate the impacts of disasters. Meanwhile, CGE models are expected to underestimate the same impacts owing to the possible extreme price and quantity changes. In this context, input–output and CGE models are generally used together to create hybrid models or are coupled with other types of models such as biophysical models. Using the Po River as an example, a comparison was made between multi-regional input–output models (ARIO and MRIA) and a regionally disaggregated global CGE model (IEES) (Koks et al. 2016). The study found that the economic losses for the calculated flood scenarios showed varying results with relatively large differences. The differences between the ARIO model on the one hand and MRIA and IEES on the other hand suggest differences in estimation and recovery paths of up to a factor of 7. The differences can be traced back to the linear structure assumed in the ARIO model as compared to the other two models and the ability to have substitution in production, trade, or products in the latter two models. The linear character of the ARIO model reflects outright negative impacts across all regions affected, due to the disaster. Such a result may not be realistic due to the interdependence between areas. This prompts the authors to suggest that flexible models, such as MRIA and IEES, should be applied to assess the impact of multi-regional disasters. Similarly, the speed of recovery is also crucial to the losses in the affected areas. A quick recovery leads to lower losses and can be assessed by all three models under consideration. This study suggests that model outcomes are susceptible to their underlying assumptions. CGE models appear to be better at assessing natural disasters on economic activity including price effects and effects on employment. A detailed assessment of cost-benefit ratios of specific resilience measures can be successfully investigated with both MRIA and IEES models (Koks and Thissen 2014). Moreover, while quantitative models have been useful in a broad array of economic analysis and risk management issues, the underlying structure of the applied model has the potential to distort the results. There are additional problems of data quality, model limitations, and interpretation of results. These problems, however, do not necessarily impede the scope for the growth of such macroeconomic models.

Phimister and Roberts (2017) investigated how uncertainty in the exogenous shock to a CGE model affects the macroeconomic results. The authors compared the results of introducing an onshore wind sector into a regional economy. Two versions of the model were developed and compared. The first version included an onshore wind sector with a known size with certainty. In the second version of the model, the size of the sector was uncertain. The authors used a Gaussian quadrature approach to undertake the systematic sensitivity analysis around the size of the sector. They concluded that the certainty version of the model underestimated the GDP and welfare impacts when compared to the uncertainty version.

Chen et al. (2005) extend the input–output model to include assets that are accumulated and used in production and allow for the specification of asset requirements per sector. It provides an alternative to the capital stock matrix in the standard System of National Accounts. The extension involves taking the depreciation of fixed assets into full account. Such a model allows for the calculation of total holding coefficients that can express the amount of assets that are required to be held in each sector for the satisfaction of final demand. The production systems of modern economies are dependent on appropriate quantities of fixed capital, labour, and financial assets. The scale of economic benefits accruing to the production process is also determined by the quality and quantity of the inputs used which includes assets. This model appears to have been influential by the context of the Chinese economy and is applied to various areas including coal and energy utilization. The paper also suggests the modified model's application including the development of key sectors for Chinese economic development, to predict economic development indicators, to study relations between different regions in China, and to study water conservancy issues in China and its major river basins.

Temurshoev (2015) critically analysed the research on input–output analysis addressing the inherent uncertainty in input–output data. Errors in data can be incorporated into data sets and models for a number of reasons including sampling errors, measurement errors, and errors generated during the IO data compilation process, confidentiality issues, aggregation errors, prices and deflation practices, and reporting errors. Temurshoev (2015) reviewed a number of different approaches to address uncertainty including deterministic error analysis, econometric and other statistical approaches, random error and probabilistic approaches, full distribution approaches, Monte Carlo analysis, Bayesian and entropy approaches, and other techniques. He concludes that input–output researchers must include uncertainty issues in their analysis and that it is no longer advisable for researchers to draw their conclusions from only point estimates. The methods to address the uncertainly issue will depend on a number of factors including the problem being investigated and the data availability. Expanding the analysis to include sensitivity analysis around uncertainty issues adds to the robustness of the analysis and strengths of the conclusions that can be drawn (Temursho 2015).

Roy (2004) models the uncertainty in input–output models by incorporating the inter-regional flow of output-generating spillover effects through capacity generation. Its main focus was on accommodating the joint influence of technology, output capacities, and transportation costs on the pattern of intermediate and final demand flows between regions. He further extended the model by generating probabilistic supply functions as a tool within a potential CGE analysis. Endogenizing certain variables which brought along with it uncertainty provided insights into the interdependencies between output capacities, production technology, and transport costs, and their influence on the pattern of multi-regional or inter-regional flows. This provided an empirical picture to the theoretical foundation, which is an essential piece for the development of an applied model.

Lenzen et al. (2010) incorporated uncertainty in the estimation of the carbon footprint in the UK by using the Monte Carlo technique on a MRIO model.

Uncertainty was incorporated into the model using stochastic random error terms. Randomness in data collected for each variable was assessed followed by calculations of standard deviation, which were then used in the analysis. However, some sources of systematic errors through time and space dimensions remain unanswered due to the difficulty in data collection. Data modelling provided statistically significant results with respect to CO_2 emissions embodied in UK imports (EEI) that were higher than those for exports (EEE) in all years from 1992 to 2004. They also found that CO_2 emissions from EEI were growing faster than EEE, thus widening the gap between territorial (producer) emissions and consumer emissions. The study, despite some limitations, could be used to understand the background inter-linkages of trade industries' ecological impact on the carbon footprint.

Another area that needs further investigation is the analysis of health care and health services. Jewczak and Suchecka (2014) attempted to use input–output analysis to analyse the healthcare system in Poland. They recognized that the development of a System of Health Accounts, which is supported by the OECD, provides a means of organizing health data in a systematic way. However, there are still problems in the organization of the data in terms of flows within the modelling framework. These definitional problems, both in terms of the health service sectors and expenditures related to each service sector, remain a problem in the modelling process.

Other researchers, such as Yamada and Imanaka (2015), have tried to address these data problems by using an input–output model, data from a Statement of Profit and Losses (P/L) for a variety of medical institutions, and a Monte Carlo simulation to take into account a probabilistic sensitivity analysis. Using this medical institution-based approach, the authors were able to estimate the economic impact by treating the individual purchases in the intermediate demand as a final demand change. Using this information, the authors were able to estimate the direct plus indirect impacts of the healthcare system on the economy. However, the question of better-defined data and health service sectors would improve both the modelling and estimation procedures.

A recent approach to address the value of medical prevention was undertaken by Sidney et al. (2017). Many health management companies are introducing well-being improvement programmes as a means of preventing health problems by decreasing the risk factors that are associated with them. Sidney et al. (2017) used a well-being assessment survey to estimate a logistic model of disease prevalence and combined this with an input–output analysis to provide a monetarization of the well-being improvement programme. Further work is needed with both data collection and model development in order to address this new dimension of health improvement.

Non-communicable diseases, such as cardiovascular disease and type II diabetes, are becoming a major concern in both developed and developing countries. Many of these diseases are nutrition-related, in that individuals who are overweight or obese are more likely to acquire these diseases. Mukhopadhyay and Thomassin (2012) used a modified input–output model to estimate the impact of a change in food consumption towards a healthy diet. The healthy diet was defined by the recommended portions of food categories by the Canada Food Guide by age and sex. This was compared to the actual food consumption patterns of Canadians. The difference between actual food consumption and recommended food consumption was used to estimate the change in final demand in food consumption. Additional work on the impact of labour productivity over time as overweight and obesity rates decreased can be undertaken to take into account the time dimension of a change in food consumption behaviour.

8 Conclusion

Wassily Leontief's great contribution to economics was the development of a macroeconomic framework, i.e. input–output analysis, based on actual empirical data that could generate policy-relevant analysis. Leontief firmly opposed arbitrary theoretical foundations and strongly supported its roots in empiricism. The current applications of computable general equilibrium models highlight the limitations of input–output models when used in isolation and therefore have pushed for a significant move towards integration with various other methods and models. The usefulness of input–output analysis continues to grow because of its flexibility and ability to be extended to address policy issues. The greatest support for this method of analysis is indicated by the ever-growing demand in multifarious fields of research.

Input–output analysis has evolved over the years from the initial stages of its theoretical foundations based entirely on production analysis to an applied economic model based on empirical data by Leontief (1936). An attempt has been made to illustrate the evolution of the input–output method and identify future developments to incorporate the various dynamic behavioural aspects of the economy. The paper identifies the different areas of application of input–output analysis in various countries, with some major model development in Canada. Input–output analysis has been consistently used in production analysis, providing the pattern of change in total factor productivity, technical efficiency, and explains the working of variables such as capital, labour, energy, and materials. Richard Stone's contribution to input–output analysis was to provide an extended framework to input–output models that linked the dynamic societal welfare dimensions with the economic sectors of the economy. The development of the social accounting matrix increased the utilization of this modelling approach among government ministries and agencies and provided an expanded platform for further academic research.

Input–output models and analysis have evolved over time to become more of a social model that can be used to evaluate various policy situations including the environment, demand, intermediate inputs, imports, and microlevel attempts to study global value chains. The input–output model can be extended or used conjointly to address a number of issues. For example, Grubbstorm and Tang (2000) illustrated how an input–output model can be used with a material requirement planning (MRP) model and the Laplace transformation to take into account the multi-level, multi-stage production inventory system which takes into account time. Following the various applications, are the recent refinements introduced into the model to incorporate uncertainty, making it feasible to test the carbon footprint, disaster management, and ecological change. Recent works using the input–output framework can provide a critical assessment of the health sector and have broadened the scope for further analysis. This can include investigating the health implications of medical prevention, the health benefits of consuming a healthier diet, detection and treatment of diseases, and health expenditures. The versatility and relevance of input–output analysis in a policy context suggest that this framework has immense potential for its application in a variety of fields and situations.

Finally, new theoretical developments are required to address current deficiencies in the modelling framework. These new theoretical developments will ensure that the modelling framework will continue to address problem situations now and in the future. Support for these new theoretical developments will be made with new and more robust data sources that will assist in application development.

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Part I
Agriculture & Input–Output Modelling

Intermediate Input Technological Progress Translated into Neoclassical Terms—A Study with Reference to the Indian Economy

Partha Pratim Ghosh

Abstract While the demand-driven Leontief system leads to a reduction in total output when there is increased efficiency of intermediate inputs, in the neoclassical system technological progress must lead to higher output. This paper presents an explanation of technical progress that resolves the apparent paradox using India's Input–Output table for 2011–12. The idea of technological improvements has been taken from two current programs of development, namely Pradhan Mantri Krishi Sinchai Yojana (PMKSY) and Pradhan Mantri Gram Sadak Yojana (PMGSY) that would lead to increased efficiency of irrigation and water resource usage and increased efficiency of road connectivity across the country in a multi-sector framework. This paper calculates elasticity of final demands with respect to intermediate inputs, as also price effects arising out of changes in Input–Output coefficients. Results indicate that in order to enhance efficiency of intermediate inputs used in the agricultural sectors, it is necessary to adopt similar efficiency augmenting programs in other sectors of the economy as well. This will lead to a balanced increase in productivity of all sectors and affect agriculture more favorably.

Keywords Input–Output · Agriculture · Efficiency of intermediate inputs
Technological improvement

JEL Classification C67 · D57 · Q16 · O5 · O33

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1 Introduction

Technological progress is believed to be the ultimate source of growth in mainstream economics. Using the production function approach, the sources of growth can be decomposed into increases in factors of production and technological progress, with the latter said to be playing a dominant role in maintaining growth of per capita output. This is the supply-side approach to economic growth. The Leontief Input–Output approach provides an alternative framework for decomposing the growth of an economy into two broad sources, namely final demand and technological change. In this approach, technological change refers to changes in the Input–Output coefficients. Unlike the neoclassical approach, improvement in technology translates into lower output in the Leontief system. This apparent paradoxical result can be explained by interpreting technical change in a way that brings it in line with the concept of technical progress in mainstream economics. However, all said and done, it appears that some basic issues of difference between the mainstream approach and the Input–Output approach persist, in terms of the economic paradigm that these two frameworks explicate.

Compiling and using India's Input–Output table for 2011–12, this paper analyzes the effects of technological progress on various sectors of the economy, especially the impacts on the agricultural sectors. The idea of technological improvements has been taken from two current programs of development, namely increased efficiency of irrigation and water resource usage and increased efficiency of road connectivity across the country in a multi-sector framework.

A recently published document entitled 'Pradhan Mantri Krishi Sinchai Yojana: Enhancing Impact through Demand Driven Innovations' (Research Report IDC-7, ICRISAT Development Centre, PMO Strategy Document Series 2016), mentions that the Pradhan Mantri Krishi Sinchai Yojana (PMKSY) has been launched by the Ministry of Agriculture and Farmers Welfare, Government of India, to improve water-use efficiency as one of its main objectives. This component of PMKSY has been named 'Per Drop More Crop.' The report says that water-use efficiency can be improved from the current level of 35–50% way up to 65–90% through large scaling-up interventions of scientifically proven improved land, water, crop, and pest management options. A government publication entitled 'Operational Guidelines of Per Drop More Crop (Micro Irrigation) Component of PMKSY,' of the Government of India, Ministry of Agriculture and Farmers Welfare released in 2017, gives a detailed description of the objectives, implementation strategies, and various other aspects of the program.

Similarly, a study commissioned by the International Labor Organization (ILO) under the technical assistance project for Pradhan Mantri Gram Sadak Yojana (PMGSY) under the Ministry of Rural Development, Government of India, has been published in 2015 with the title 'Impact Assessment Study of Improved Rural Road Maintenance System under PMGSY.' This report evaluates the impact of the development and maintenance of rural roads for connectivity with remote rural areas of the country. Among other benefits, the report documents the 'Impact of Rural Roads on Agriculture.'

The advantage of Input–Output methodology is its ability to assess the details of inter-sector relations across the economy. Accordingly, it is able to assess the efficacy of various developmental programs in a better way as compared to more aggregative frameworks. It also serves to bring out the points of departure from the neoclassical approach to the study of economic growth.

The paper is organized as follows. Section 2 discusses the framework of the analysis. Details of the data source are provided in Sect. 3. Section 4 presents a brief outline of impacts of selected aspects of PMKSY and PMGSY in the above-mentioned studies conducted by ICRISAT and ILO, respectively. The various scenarios or experiments on increased intermediate input efficiency using India's Input–Output tables with special reference to agriculture are described in Sect. 5. Results of the experiments and discussions on the same are provided in Sect. 6. Finally, the summary and conclusions are given in Sect. 7.

2 Framework of Analysis

The extended Leontief Input–Output framework shows the various uses to which the output of each sector can be put (along the rows of an Input–Output table) as also the production structure of each sector (along each column of the table). The column vector of sector-level outputs is given as $\boldsymbol{x} = (\mathbf{I} - \mathbf{A})^{-1}\boldsymbol{f}$ which is the transpose of the row vector $\boldsymbol{x}' = \boldsymbol{V}'(\mathbf{I} - \mathbf{B})^{-1}$, where $\mathbf{A}$ is the intermediate input coefficient matrix, $\boldsymbol{f}$ is the column vector of sector-level final demand, $\mathbf{B}$ is the matrix of supply coefficients, and $\boldsymbol{V}'$ is the row vector of sector-level value added. These two formulations arise from the balancing equations $\mathbf{x} = \mathbf{Zi} + \mathbf{f} = \mathbf{Ax} + \mathbf{f}$ and $\mathbf{x}' = \mathbf{i}'\mathbf{Z} + \mathbf{V}' = \mathbf{i}'\mathbf{A}\hat{\boldsymbol{x}} + \mathbf{V}' = \mathbf{x}'\hat{\boldsymbol{x}}^{-1}\mathbf{Z} + \mathbf{V}' = \mathbf{x}'\mathbf{B} + \mathbf{V}'$, respectively, where $\mathbf{i}$ represents the unit column vector and $\hat{\boldsymbol{x}}$ is the diagonal matrix of commodity outputs. When intermediate inputs are used more efficiently, it reduces the Input–Output coefficients which are the elements of $\mathbf{A}$. By the power series approximation of the Leontief inverse, the elements of $(\mathbf{I} - \mathbf{A})^{-1}$ would also be reduced. Therefore, the total output required to sustain a given vector of final demand would be lower. In the neoclassical system, output depends on measured inputs and their productivity. Higher productivity must therefore lead to higher output in the neoclassical framework. Apparently, there is a contradiction between the effects of technological improvement in the Input–Output and neoclassical frameworks.

However, it has to be kept in mind that output in the Leontief system does not mean net output as in the neoclassical system. Output in the neoclassical framework is net output or value added. The Leontief output vector x is the total production required to sustain a given vector of final demand and also produce the intermediate inputs required in the process. If the vector of gross outputs x is given, lesser inputs would be required for a given vector of final demand f. There is no contradiction between the two approaches once it is recognized that the total final demand or total value added in the economy is the same as the output obtained from the neoclassical production function. Let us consider the basic balancing equation $\boldsymbol{x} = \mathbf{A}\boldsymbol{x} + \boldsymbol{f}$. Following a technological improvement, if the output vector $\boldsymbol{x}$ is specified, then $\mathbf{A}\boldsymbol{x}$ will be lower and the difference will be sustainable provided that final demand increases correspondingly. This is the same as an expansion of the production possibility frontier that we obtain as a result of technological improvement in the neoclassical framework. For any two time periods 't' and 't + 1' and a given set of prices, we have

$$\begin{aligned}
&\boldsymbol{x}(\mathrm{t}) = \mathbf{A}(\mathrm{t})\boldsymbol{x}(\mathrm{t}) + \boldsymbol{f}(\mathrm{t})\\
&\boldsymbol{x}(\mathrm{t}+1) = \mathbf{A}(\mathrm{t}+1)\boldsymbol{x}(\mathrm{t}+1) + \boldsymbol{f}(\mathrm{t}+1)\\
&\Delta\boldsymbol{x} = \Delta\mathbf{A}.\boldsymbol{x}(\mathrm{t}) + \mathbf{A}(\mathrm{t}+1).\Delta\boldsymbol{x} + \Delta\boldsymbol{f}\\
&\text{Putting } \Delta\boldsymbol{x} = 0, \text{we get } \Delta\boldsymbol{f} = -\Delta\mathbf{A}.\boldsymbol{x}(\mathrm{t}) > 0 \text{ since } \Delta\mathbf{A} < 0.
\end{aligned} \tag{1}$$

Given the row vector of outputs x′, when the elements of input-coefficient matrix A are smaller, total intermediate input requirements for producing the commodities are lesser in value, i.e., $i'A\hat{x}$, or $i'Z$ is smaller. From the balancing equation $\boldsymbol{x}' = \mathbf{i}'\mathbf{A}\hat{\boldsymbol{x}} + \boldsymbol{V}'$, the value added in each sector must rise such that the new total value added equals the new total final demand, since total final demand equals total value added.

$$\begin{aligned}
&\boldsymbol{x}(\mathrm{t})' = \mathbf{i}'\mathbf{A}(\mathrm{t})\hat{\boldsymbol{x}}(t) + \boldsymbol{V}(\mathrm{t})'\\
&\boldsymbol{x}(\mathrm{t}+1)' = \mathrm{i}'\mathrm{A}(\mathrm{t}+1)\hat{x}(t+1) + \boldsymbol{V}(\mathrm{t}+1)'\\
&\Delta\boldsymbol{x}' = \mathbf{i}'\Delta\mathbf{A}\hat{\boldsymbol{x}}(t) + \mathbf{i}'\mathbf{A}(\mathrm{t}+1)\Delta\hat{\boldsymbol{x}} + \Delta\boldsymbol{V}'\\
&\text{Putting } \Delta\mathbf{x} = 0, \text{we get } \Delta\hat{\boldsymbol{x}} = [0] \text{ and } \Delta\boldsymbol{V}' = -\mathbf{i}'\Delta\mathbf{A}\hat{\boldsymbol{x}}(t) > 0 \text{ since } \Delta\mathbf{A} < 0.
\end{aligned} \tag{2}$$

The row vector of value-added $\boldsymbol{V}'$ is defined as $\boldsymbol{v}'\hat{\boldsymbol{x}}$ where $\boldsymbol{v}'$ is the row vector of value-added coefficients that show the value added per unit of output of each sector and $\hat{\boldsymbol{x}}$ is the diagonal matrix of sector-level outputs. Thus, $\boldsymbol{v}' = \boldsymbol{V}'\hat{\boldsymbol{x}}^{-1}$ and for a given $\boldsymbol{x}'$ we have $\Delta\boldsymbol{v}' = \Delta\boldsymbol{V}'\hat{\boldsymbol{x}}^{-1}$. From the Input–Output table, we obtain the basic macroeconomic identity $\boldsymbol{V}'\mathbf{i} = \boldsymbol{i}'\mathbf{f}$. In the Leontief system, the scalar value of total value added by all sectors together is given as $\mathbf{Y} = \boldsymbol{v}'\boldsymbol{x} = \boldsymbol{\alpha}'\boldsymbol{f}$ where $\boldsymbol{\alpha}' = \boldsymbol{v}'(\mathbf{I} - \mathbf{A})^{-1}$. Since $\mathbf{Y} = \boldsymbol{V}'\mathbf{i} = \mathbf{i}'\boldsymbol{f}$, we have $\boldsymbol{v}'(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{i}'$, so that

$$\mathrm{Y} = \boldsymbol{V}'\mathbf{i} = \boldsymbol{v}'\boldsymbol{x} = \boldsymbol{v}'(\mathbf{I} - \mathbf{A})^{-1}\boldsymbol{f} = \boldsymbol{\alpha}'\boldsymbol{f} = \mathbf{i}'\boldsymbol{f}. \tag{3}$$

The only plausible economic interpretation of this result is that the reduction in the elements of $(\mathbf{I} - \mathbf{A})^{-1}$ is exactly balanced by increase in the elements of $\boldsymbol{v}'$, implying an increase in the total amount of primary inputs to maintain the condition $\boldsymbol{\alpha}' = \mathbf{i}'$, so that one rupee worth of final demand in any sector of the economy makes its way through inter-sector relationships to generate value added of one rupee.

In a purely physical quantity-based Leontief system, primary input requirement (s) such as labor are given as

$$\boldsymbol{V}_R' = \boldsymbol{v}_R'\boldsymbol{x}_R = \boldsymbol{v}_R'(\mathbf{I} - \mathbf{A_R})^{-1}\boldsymbol{f}_R = \boldsymbol{\alpha}_R'\boldsymbol{f}_R \tag{4}$$

where the subscript R indicates quantities. The elements of $\boldsymbol{\alpha}_R'$ are the total direct and indirect primary input requirements for one unit of final demand of the various goods and services so that unlike in Eq. (3) above, $\boldsymbol{\alpha}_R'$ is now no longer a unit row vector. Now due to technological improvements, intermediate inputs are better utilized and the Leontief inverse $(\mathbf{I} - \mathbf{A_R})^{-1}$ becomes smaller. Therefore, the elements of the row vector $\boldsymbol{\alpha}_\mathbf{R}'$ become smaller too, leading to the possibility of a reduction in total primary input requirements. However, if the total output vector in real terms $\boldsymbol{x}_R$ is given, then decreases in the elements of $\boldsymbol{\alpha}_R'$ are exactly balanced by increases in $\boldsymbol{f}_R$ and $\boldsymbol{V}_R$ is unchanged.

The apparent contradiction between Eqs. (3) and (4) is due to the difference between the neoclassical and Leontief systems. In the neoclassical system, resources are fully employed. In contrast, the demand-driven logic of the Leontief system derives primary input requirements from final demand. If lower input coefficients exactly balance higher final demand, employment of primary resources is unaffected. In general, increase in employment of primary inputs is possible only through continuously rising final demand for a given set of technical coefficients. In contrast, the neoclassical system would generate the production possibility frontier $T = R(f_1, f_2, \ldots, f_n) =$ where f_j is the production of the jth commodity available for final use and the total primary resource available in the economy is fully employed by the invisible hand, ruling out any demand deficiency. Therefore, keeping gross output unchanged, the only way to accommodate a reduction in the Leontief inverse $(\mathbf{I} - \mathbf{A})^{-1}$ is to accept an increase in $\boldsymbol{v}'$.

It is instructive to look at the Leontief system in terms of price formulations. The price formulation, which is the dual of the quantity formulation, helps us to tie up the various interpretations discussed in this section neatly. The Leontief price model is given as $\boldsymbol{p}' = \boldsymbol{p}'\mathbf{A_R} + \mathrm{w}\boldsymbol{v}_\mathbf{R}' = \mathrm{w}\boldsymbol{v}_\mathbf{R}'(\mathbf{I} - \mathbf{A_R})^{-1}$, where w is the wage rate. It can be used to show the effects of changes in primary factor prices on commodity prices relative to base year prices. Any change in the technology matrix $\mathbf{A_R}$ and/or primary input coefficients will therefore lead to change in the prices of the commodities, given the unit prices of primary factors of production. Defining the initial price vector as $\boldsymbol{p}(0)'$ and the new price vector as $\boldsymbol{p}(1)'$, we get

$$\begin{aligned}
&\boldsymbol{p}(0)' = \boldsymbol{p}(0)'\mathbf{A_R}(0) + \mathrm{w}\boldsymbol{v}_\mathbf{R}'(0)\\
&\boldsymbol{p}(1)' = \boldsymbol{p}(1)'\boldsymbol{A}_R(1) + \mathrm{w}\boldsymbol{v}_\mathbf{R}'(1)\\
&\Delta\boldsymbol{p}' = \Delta\boldsymbol{p}'.\mathbf{A_R}(1) + \boldsymbol{p}(0)'\Delta\mathbf{A_R} + \mathrm{w}\,\Delta\mathbf{v}_\mathbf{R}' = (\mathbf{I} - \mathbf{A_R}(1))^{-1}\left[\boldsymbol{p}(0)'\Delta\mathbf{A_R} + \mathrm{w}\,\Delta\mathbf{v}_\mathbf{R}'\right].
\end{aligned} \tag{5}$$

A reduction in Input–Output coefficients and/or value-added coefficients therefore leads to a decrease in prices of the commodities, given the primary input prices. The effect of technological change on commodity prices at given primary factor prices has been studied by Duchin and Lange (1995) for the US economy.

Dietzenbacher (1997) has shown the effects of changes in primary input prices on commodity prices. Since $\boldsymbol{x}' = \mathbf{i}'\mathbf{A}\hat{\boldsymbol{x}} + \boldsymbol{V}'$, we have $\boldsymbol{x}'\hat{\boldsymbol{x}}^{-1} = \mathbf{i}'\mathbf{A} + \boldsymbol{v}'$ which implies $\mathbf{i}' = \mathbf{i}'\mathbf{A} + \boldsymbol{v}'$ where $\mathbf{A}$ is the matrix of intermediate inputs per monetary unit of commodity output and $\boldsymbol{v}'$ is the primary input cost per monetary unit of commodity output. Thus, reductions in the elements of matrix $\mathbf{A}$ would lead to lower commodity prices relative to the base year for any given vector of physical final demand quantities. The present paper uses the price formulations to find the effects of a new intermediate input technology on commodity prices relative to base year in the Indian economy, given factor input prices in the following way.

First, by specifying some exogenous changes in the matrix $\mathbf{A}$ for a given vector $\boldsymbol{x}$, the effects on the final demand vector f are determined from Eq. (1). Then, Eq. (5) is used to calculate the effects of change in the Input–Output coefficients on the prices of various commodities and the implications if any on the composition of factor incomes in the economy at unit level of operations. It may be noted that the second set of exercises can be interpreted in light of extensions of the principles of 'inverse important coefficients' and 'fields of influence' as developed by Sonis and Hewings (1989, 1992, 1999).

3 Data

The CSO has very recently published the supply–use tables of the years (2011–12) and (2012–13) for the Indian economy on its Web site (www.mospic.nic).[1] The tables provide data on 140 commodities and 66 industries. The supply table is available in both basic prices and also purchasers' prices, while the use table is available in purchasers' prices. Aggregating the trade and various transport sectors and converting the use table into basic prices by adjusting for indirect taxes less subsidies, trade–transport margins as also imports, a 135-sector commodity-by-commodity Input–Output table was prepared for the year 2011–12[2] broadly along the guidelines suggested by Miller and Blair (2009), using the industry–technology assumption. The basic equations for generating the Input–Output table are

$$\boldsymbol{x} = \mathbf{Ui} + \boldsymbol{f} \quad \text{from the use-table} \tag{6}$$

[1]I am grateful to Professor Kakali Mukhopadhyay of McGill University and GIPE, Pune for bringing this to my notice.

[2]I am also thankful to Professor Kakali Mukhopadhyay for important suggestions regarding the preparation of the Input–Output table.

$$\boldsymbol{q} = \mathbf{Wi} \quad \text{from the supply-table} \tag{7}$$

Combining the two, we get

$$\begin{aligned}\mathbf{x} &= \mathbf{U}\hat{\boldsymbol{q}}^{-1}\boldsymbol{q} + \boldsymbol{f} \\ &= \mathbf{U}\hat{\boldsymbol{q}}^{-1}\mathbf{Wi} + \boldsymbol{f} \\ &= \mathbf{U}\hat{\boldsymbol{q}}^{-1}\mathbf{W}\hat{\boldsymbol{x}}^{-1}\boldsymbol{x} + \boldsymbol{f} \\ &= \mathbf{BD}\boldsymbol{x} + \boldsymbol{f} \\ &= \mathbf{A}\boldsymbol{x} + \boldsymbol{f}\end{aligned}$$

balancing equation (1) mentioned above.

The use table contains disaggregated data on various components of value added such as compensation of employees, operating surplus, net indirect taxes, and consumption of fixed capital. It was used to obtain value added by labor and capital separately and incorporated in the Input–Output table. A note on the construction of the 135-sector commodity-by-commodity Input–Output table is given in Appendix 1.

4 Brief Review of Impact Studies[3]

This section reviews some of the relevant results from studies conducted by ICRISAT and ILO to assess the impacts of PMKSY and PMGSY, respectively, on the agricultural sectors in India. The Pradhan Mantri Krishi Sinchai Yojana has four main components, namely Accelerated Irrigation Benefit Programme, Water For Every Farm (Har Khet Ko Pani), Watershed Development, and Per Drop More Crop or water-use efficiency. Together, these four components are envisaged to lead to a net benefit of Rs. 23 lakh crores in 10 years' time. An investment of Rs. 251,665 crores by the central and state governments together would be required for this program. The total cost including farmers' contribution would be Rs. 466,850 crores with an estimated benefit–cost ratio of 4.95:1 including full cost and a benefit–cost ratio of 9.2:1 including farmers' contribution. The maximum benefit is envisaged from the Watershed Development Program. Enhancing the efficiency of water usage through conjunctive use of soil moisture and irrigation water through micro-irrigation along with the other components of PMKSY is expected to yield good dividends for the agricultural sector in India.

The impact assessment report from ILO on PMGSY mentions several important benefits for agriculture. Improvement in rural road infrastructure was found to have lowered transportation costs and improved agricultural productivity. As a result, production has increased with the use of improved seeds, better fertilizers, pesticides, etc., in the study area. Almost a quarter of the sample farmers households

[3]I sincerely thank the anonymous referee for suggesting the incorporation of this section.

interviewed in the study area reported increased use of fertilizers after construction of rural roads, with the highest change being observed in Uttar Pradesh where almost 47% of the farmers interviewed reported the same. Marginal improvements were also noticed in the agricultural extension services enjoyed by farmers after rural roads were constructed.

These findings suggest that the efficiency of intermediate input usage in Indian agriculture improved due to programs such as PMKSY and PMGSY. The present paper therefore attempts to examine the impacts of increase in intermediate input efficiency through a series of experiments with special reference to India's agricultural sectors. This paper develops nine scenarios or experiments to investigate the effects of improvements in intermediate input efficiency on the final demands, prices, and the distribution of labor and non-labor incomes in the Indian economy with special reference to Indian agriculture. The various experiments, results, and discussions on the same are detailed in the next section.

5 Scenario Development

The first set of exercises was carried out by specifying exogenous changes in the Input–Output coefficients for a given vector of gross outputs. Using the initial matrix **A** and a final demand vector $\boldsymbol{f} = \mathbf{i}$, the gross output was calculated. Then given this gross output vector and the new **A** matrix, the reduction in intermediate inputs was obtained. The same was taken to be the increment in final demand required for maintaining the basic balance Eq. (1). The exogenously specified changes in **A** and the corresponding effects on $\boldsymbol{f}$ were noted. For a 1% decrease in the Input–Output coefficients, the percentage increase in final demand of any sector gives the elasticity of final demand with respect to the corresponding set of inputs. The exercise considered nine scenarios or experiments.

Scenario (i): Efficiency of inputs from the construction sector to the agricultural sectors increased by 1%. Interpretation of this experiment—it shows the effect of reduction in intermediate input from construction sector to the agricultural sectors (1–20), on the final demand for the agricultural sectors' outputs.

Scenario (ii): Efficiency of inputs from the water supply sector to the agricultural sectors increased by 1%. This experiment shows the effect of reduction in intermediate input from water supply sector to the agricultural sectors (1–20), on the final demand for the agricultural sectors' outputs.

Scenario (iii): Efficiency of inputs from the fertilizer and pesticides sector to the agricultural sectors increased by 1%. This scenario was developed since the use of fertilizers and pesticides was expected to improve when the road connectivity in the rural areas improved.

Scenario (iv): Efficiency of all agricultural sectors increased by 1%. This exercise considered a simultaneous improvement in intermediate input usage by all the agricultural sectors (sectors 1–20) of the economy.

Scenario (v): Efficiency of the construction sector increased by 1%. This scenario considered a decrease in the Input–Output coefficients of the construction sector by 1%.

Scenario (vi): Efficiency of the water supply sector by increased 1%. This scenario considered a 1% decrease in the Input–Output coefficients of the water supply sector.

Scenario (vii): All-round increases in the efficiency of all sectors by 1%. In this scenario, a simultaneous decrease in the Input–Output coefficients of all sectors of the economy was considered.

After the above-mentioned scenarios, a second set concerning price effects was developed as follows.

Scenario (viii): Effects on prices. The effects of changes in the Input–Output coefficients on the prices are given by Eq. (5). Considering changes in the inter-industry coefficients only, we get the new price indices after technical change as $\boldsymbol{p}(1)' = \boldsymbol{v}'[\mathbf{I} - \mathbf{A}(1)]^{-\mathbf{1}}$ which is the vector showing the percentage change in price of the various sectors.

Scenario (ix): Effects on employees' compensation relative to operating surplus. In the Leontief Input–Output model, commodity prices are determined for a set of given primary input prices such that price of each commodity is equal to its cost of production. In a simple model with labor as the only primary input, given the value-added coefficients $\boldsymbol{v}'$, the system generates $\mathbf{p}' = \boldsymbol{v}'(\mathbf{I} - \mathbf{A})^{-1}$ as explained earlier in Eq. (5). The economic logic is that production can ultimately be traced back to value added by labor, through the successive rounds of production of commodities that are required to produce a given bill of output. If we now add non-labor primary inputs, then a similar component would be added in the calculation of prices. This would generate information to compare labor and non-labor incomes embedded in prices. Empirically, we obtain employees' compensation and operating surplus as some kind of broad measures of labor and non-labor incomes, respectively, from the Input–Output table. Thus, we can identify two components of value added, namely employees' compensation and operating surplus, as two row vectors $\boldsymbol{v}'_{\mathbf{L}}$ and $\boldsymbol{v}'_{\mathbf{K}}$, respectively. Post-multiplying these by the Leontief inverse gives us components of prices required just to cover the cost of production incurred by these two factors of production. The ratio of prices—one for employees' compensation and the other for operating surplus—can then be treated as a new set of income distribution.

6 Results and Discussions

This section presents and discusses the results of the nine scenarios or experiments mentioned above. It also attempts to explain the results of the various scenarios through two conventional measures of interconnectedness, namely power of dispersion and sensitivity of dispersion, in order to provide an intuitive understanding of the observed results.

Scenario (i): The overall effect was quite small. Three agricultural sectors that showed maximum responsiveness were other food crops, rubber, and kapas, among which the highest elasticity was that of the other food crops sector. But the magnitude of elasticity was found to be 0.02 only.

Scenario (ii): The three sectors that showed maximum responsiveness were wheat, paddy, and sugarcane with elasticity of 0.02, 0.01, and 0.01, respectively. Once again, the overall effects were low.

Scenario (iii): Coarse cereals, other food crops, and other oilseeds were the three sectors with highest responsiveness of final demand. Once again, the magnitude of elasticity was low—it was only 0.01 for coarse cereals and even lower for the rest.

Scenario (iv): The agricultural sector comprised paddy, wheat, coarse cereals, gram, arhar, other pulses, groundnut, rapeseed and mustard, other Oilseeds, kapas, jute, sugarcane, coconut, tobacco, tea, coffee, rubber, fruits, vegetables, and other crops. An increased efficiency of 1% across all agricultural sectors leads to 1.16% increase in the final demand for fertilizers and 1.08% increase in final demand for wheat. The final demand for other food crops also increased by 1.03%. Interestingly, financial services responded with an increase of 0.88%. The increment in paddy and edible oils and fats was 0.67 and 0.65%, respectively. Even petroleum products and other livestock products increased by more than 0.5% each.

It is clear from experiments (i), (ii), and (iii) that higher efficiency of intermediate inputs such as construction, water supply, fertilizers, and pesticides in the production of agricultural sectors has a limited impact. On the other hand, experiment (iv) shows that improved efficiency of all intermediate inputs taken together for agricultural production shows higher elasticity of agricultural output. This leads to the question whether an improvement in the usage of intermediate inputs into the construction, water supply, fertilizers, and pesticides sectors individually from all production of sectors of the economy would show higher elasticity of output of the agricultural sectors.

Scenario (v): A very few sectors of the economy responded to this stimulus. Elasticity of output of other food crops was 0.02, the highest among the agriculture sectors. The maximum effect of 1% increase in efficiency of the construction sector was an increase of 0.44% for iron and steel foundries. Nonmetallic mineral products responded by an increase of 0.24% and real estate sector showed an increase of 0.18%, while cement increased by 0.17%. The other sectors responded even less.

Scenario (vi): Final demand for wheat and paddy increased by 0.02 and 0.01%, respectively, the highest among the agricultural sectors. The highest response was from the trade and transport sector with an increase of 0.28%, while other sectors showed almost no change in their respective final demands. It is evident that the elasticity or sensitivity of agricultural output with respect to improved efficiency of intermediate inputs on the whole is not very high. This leads to the investigation on the effect of all-round increased efficiency of all intermediate inputs in the economy.

Scenario (vii): True to the general equilibrium nature of the Leontief Input–Output system, this stimulus generated striking response. In fact, the elasticity of

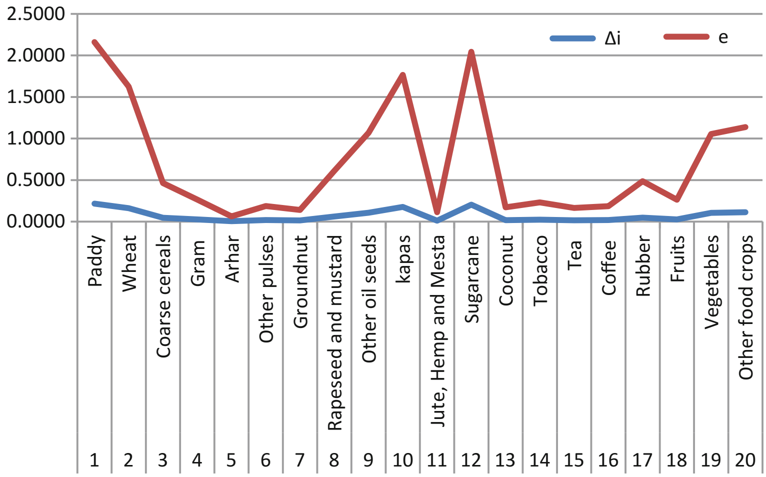


Fig. 1 Quantity effects on agricultural sectors (*Source* Results obtained from the present study)

output of agricultural sectors improved significantly. The change in final demand and the elasticity of agricultural sectors (sectors 1–20 of the Input–Output table) are shown in Fig. 1.

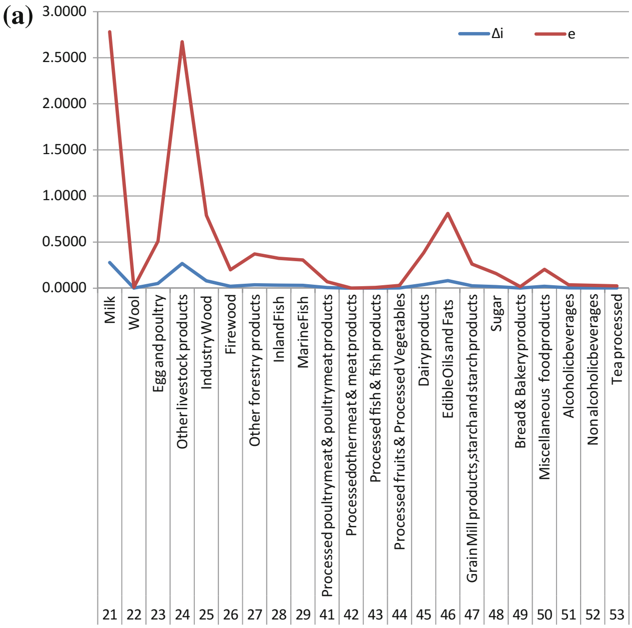
With reference to the agricultural sectors, it is observed that paddy, wheat, other oilseeds, kapas, sugarcane, vegetables, and other food crops showed elasticity greater than 1. Final demand for paddy and wheat increases by 2.16 and 1.62%, respectively. Coarse cereals, gram, arhar, other pulses, and groundnut increase by less than 0.5% each. Other Oilseeds and kapas each show more than 1% increase in final demand. Final demand for sugarcane, vegetables, other food crops, and milk also shows increased final demand by 2.04, 1.06, 1.14, and 2.78%, respectively. Coconut, tobacco, tea, coffee, rubber and fruits respond by less than 5% each.

Apart from the agricultural sectors, there are a large number of agriculture-related sectors in the Indian economy. These are sectors 21–29 and sectors 41–69. The results in these sectors are shown in two groups in Fig. 2a, b, respectively.

Final demand for milk, other livestock products, rubber products as also paper and paper products increases by more than 1% each while those of firewood, other forestry products, inland fish, and marine fish respond by much less than 0.5%.

Elasticity of paper products and newsprint was 1.49 while that of cotton yarn and cotton textiles and synthetic yarn and synthetic textiles was close to 1. Other agriculture-related sectors did not show much sensitivity of final demand.

The response of sectors outside agriculture was more striking. For example, for iron and steel foundries there was 2.9% increase in final demand. Similarly, the final demand for financial services increased by 4.6% and in case of electricity it would result in the augmentation of resources equivalent to 5.12% increase in final demand.



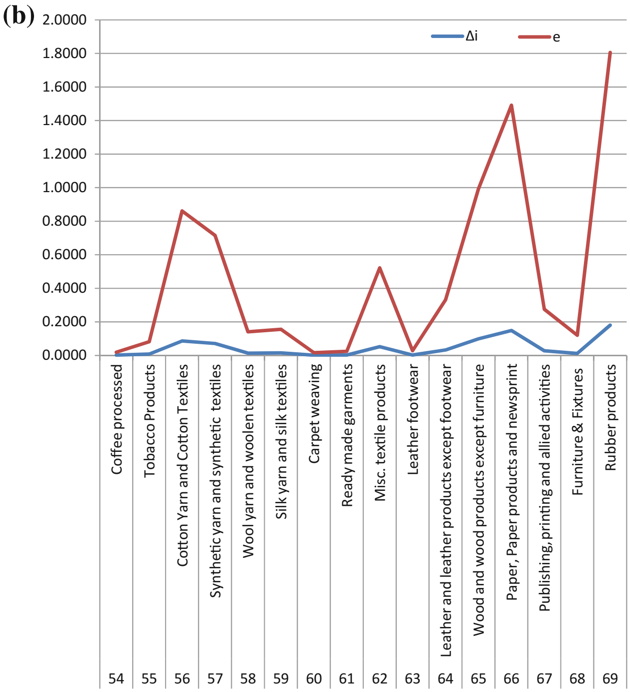


Fig. 2 **a** Quantity effects on agriculture-related sectors, Group (a) (*Source* Results obtained from the present study), **b** quantity effects on agriculture-related sectors, Group (b) (*Source* Results obtained from the present study)

In all, thirty-five sectors responded with more than 1% increase in their respective final demands and another twenty-three sectors showed increases of more than 0.5% each. Both the construction and the water supply sectors show more than 1% increases in final demand. The percentage increase in final demand of all sectors taken together is 10.44%. The overall summary of main results for all sectors of the economy is shown in Appendix 2.

Results of the above-mentioned experiments (i)–(vii) bring out the importance of balanced technological progress in the economy highlighting the extent to which it augments resources available for final demand. For the agricultural sectors as a whole, the increase in final demand was 7.1%. It is clear that most of the sensitive sectors are non-agricultural in nature.

We now turn to the second set of exercises which measure the effects of changes in the matrix *A* on the prices of the various commodities, based on Eq. (5). After an improvement in the efficiency of intermediate input usage, lesser amount of total (direct plus indirect) primary factors would be required, leading to lower requirement of primary factor inputs per unit of final demand. Given the prices of primary inputs, these changes translate into lower total (direct and indirect) primary factor requirements each commodity at unit level of operations. Hence, prices decrease. The following results were observed in this respect.

Scenario (viii): The price effects show a wide range of variation. An interesting result that emerges is the low price sensitivity to agriculture and related sectors. Food grains like paddy, wheat, coarse cereals, gram, arhar, other pulses, groundnut, rapeseed and mustard, other oilseeds show low price sensitivity of around 0.3%. Non-food grain agricultural sectors such as coffee, rubber, tobacco, other food crops, sugarcane, vegetables, kapas, jute hemp, and mesta show similar low sensitivity. However, agriculture-related sectors show more sensitivity of prices. Figures 3 and 4 show the results for the agriculture-related sectors.

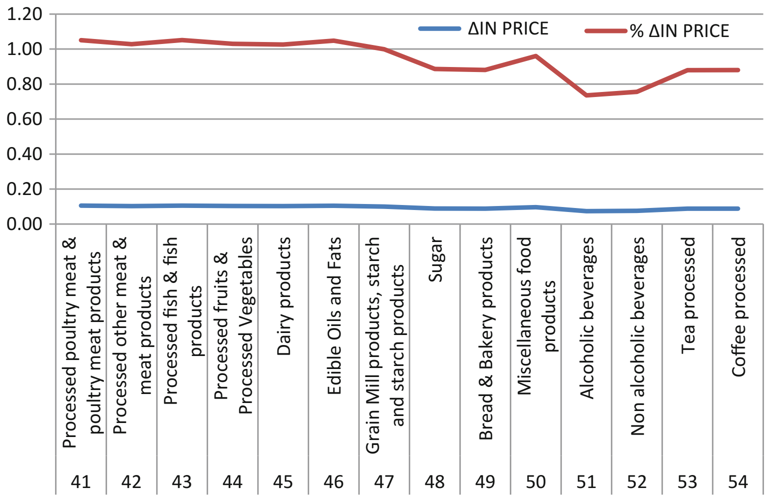


Fig. 3 Price sensitivity of agriculture-related sectors (sectors 41–54) (*Source* Results obtained from the present study)

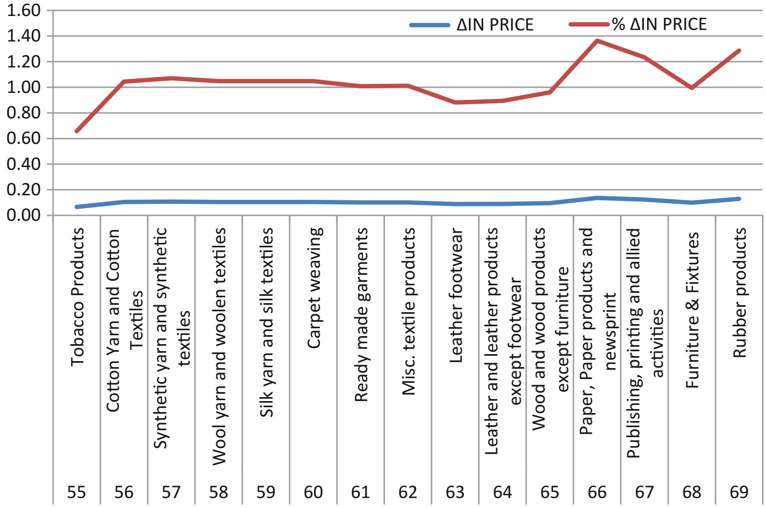


Fig. 4 Price sensitivity of agriculture-related sectors (sectors 55–69) (*Source* Results obtained from the present study)

Some agriculture-related sectors showed price sensitivities greater than 1% but less than 1.15%. These include processed poultry meat and poultry meat products, processed fish and fish products, processed other meat and meat products, processed fruits and processed vegetables, dairy products, cotton yarn and cotton textiles, woolen yarn and woolen textiles, carpet weaving, silk yarn and silk textiles, edible oils and fats, synthetic yarn, synthetic textiles. Inland and marine fish sectors are much less sensitive to technical changes, with about 0.23% change in prices. Milk, wool, eggs and poultry, other livestock products are a little bit more sensitive at around 0.4%. *It should be noted that processed agriculture-related products and processed food products have high price sensitivity as opposed to basic agriculture-related products such as food grains which have very low price sensitivity*.

Appendix 3 summarizes the results on price sensitivities for all sectors of the economy. As many as sixty-five sectors show price sensitivity of more than 1%. Among these sectors, the ones that show maximum effects on prices are gems and jewelry, petroleum products, coal tar products, inorganic chemicals, paints, varnishes, and lacquers, inorganic chemicals, communication equipments, fertilizers, pesticides, organic chemicals, gas, motorcycles and scooters, aircraft and spacecrafts, other electrical machinery, other transport equipment, motor vehicles, soaps cosmetics and glycerin, legal services. Price sensitivity of these sectors varies from 1.4 to 1.74%.

The core manufacturing sectors such as nonferrous basic metals including alloys, iron and steel foundries, miscellaneous manufacturing, iron and steel casting and forging, iron and steel ferroalloys, electrical industrial machinery, electrical cables and wires, electrical appliances, electronic equipment including television, medical precision and optical instruments, paper, paper products and newsprint, ships and boats, rubber products have price sensitivities ranging from 1.29 to 1.38%. Batteries, rail equipment, bicycles and cycle-rickshaws are a little more price sensitive, about 1.39%.

Scenario (ix): The resulting ratio of employees' compensation to operating surplus (CE/OS) is observed to increase in certain sectors and fall in others. The sectors that show an increase in the CE/OS ratio are shown in Appendix 4. The sectors are grouped on the basis of similarities in their nature of production.

It is to be noted that the agricultural sectors do not show any increase in the CE/OS ratio. However, some agriculture-related sectors do show such increase, as listed in Group (a) of Appendix 4. All other sectors in Appendix 4 are non-agricultural in nature. The sectors in Group (h) of Appendix 4, namely public administration and defense, education services, human health and social care services, community, social and personal services, recreation and related activities, have higher coefficients for employees' compensation than for operating surplus. So for these sectors, an increase in the ratio of CE/OS is only natural. However, for the other sectors in Appendix 4, we may consider the increase in the ratio CE/OS to be a sign of reduction of inequality.

Experiments (i)–(ix) show that the effects of improved efficiency of intermediate inputs on the agricultural sector are not very strong. Intuitively, it appears that the agricultural sectors are not very strongly integrated with the economy as a whole. Calculations of the power and sensitivity of dispersion verify this proposition.[4]

Power and Sensitivity of Dispersion

The power of dispersion of any sector is given by the ratio of its backward linkage with the entire economy to the average linkage of all sectors of the economy. It is a measure of the relative strength of the backward linkage of any given sector. On the other hand, the sensitivity of dispersion is a measure of the relative strength of the forward linkage of any given sector and is measured by the ratio of its forward linkage of the entire economy to the average linkage of the all sectors of the economy. Backward and forward linkages in the Leontief system are given, respectively, by the column sums and row sums of the Leontief inverse $(\mathbf{I} - \mathbf{A})^{-1}$. Denoting the Leontief inverse as $[\boldsymbol{l_{ij}}]$, the backward linkage of any sector 'j' is given as $\frac{1}{n}\sum_{i=1}^{n} l_{ij}$, while the forward linkage of any sector 'i' is given as $\frac{1}{n}\sum_{j=1}^{n} l_{ij}$. Therefore, the average linkage for the entire economy is measured by $\frac{1}{n^2}\sum_{j=1}^{n}\sum_{i=1}^{n} l_{ij}$ so that the power of dispersion of any sector 'j' is $\frac{\sum_{i=1}^{n} l_{ij}}{\frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{n} l_{ij}}$ while the sensitivity of dispersion of any sector 'i' is $\frac{\sum_{j=1}^{n} l_{ij}}{\frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{n} l_{ij}}$.

[4]My sincere thanks go to the anonymous referees for suggesting the incorporation of this part of the study.

The power of dispersion was less than unity for each of the twenty agricultural sectors. It means that the backward linkage of the agricultural sectors is less than the average linkage of all sectors of the economy. Similarly, the sensitivity of dispersion of thirteen agricultural sectors was less than unity. These sectors were coarse cereals, arhar, gram, groundnut, other pulses, rapeseed and mustard, coconut, tea, coffee, rubber, tobacco, fruits and jute hemp and mesta. The Seven agricultural sectors showing above-average forward linkage were paddy, wheat, kapas, sugarcane, other food crops, other oilseeds, and vegetables. These seven sectors also showed relatively higher elasticity of output and higher effects on prices in the various experiments discussed above. The rankings of the agricultural sectors based on calculations of the power and sensitivity of dispersion are presented in Appendix 5.

Having seen these results, it is important to note once again that among the nine scenarios developed, in Scenario (vii) where a simultaneous improvement in productivity of all intermediate inputs was considered for the entire economy, out of the 20 agricultural sectors seven (paddy, wheat, other oilseeds, kapas, sugarcane, vegetables, and other food crops) showed greater than unit elasticity while the elasticity of agriculture-related sectors was even more. This is because although the agricultural sectors are not individually very well integrated with the entire economy, there are ripple effects when we consider simultaneous improvement in the efficiency of intermediate inputs across all sectors of the economy, improving the elasticity of all sectors, including the agricultural and agriculture-related sectors. Thus, the benefits of improved intermediate input usage would be harnessed properly when efficiency-increasing programs are adopted across all sectors of the economy.

7 Summary and Conclusions

This paper discusses the concept of technological progress in light of Leontief Input–Output model comparing and contrasting it with the standard neoclassical treatment of technological progress. Empirical application is initiated by constructing India's Input–Output table from the supply and use tables of 2011–12 and using it to calculate the effects of increased efficiency of intermediate inputs with special reference to Indian agriculture.

Water and roadways are among the most vital but scarce resources in Indian agriculture. The Niti Annual Report (2014–15) mentions Pradhan Mantri Krishi Sinchai Yojana (PMKSY) as one of the major activities to be undertaken in promoting Indian agriculture. One of the objectives is to increase efficiency of water used in the irrigation supply chain over a time period of 10 years (2014–2023). In a similar fashion, the Pradhan Mantri Gram Sadak Yojana (PMGSY) has also been launched to build road networks across the country. In the Input–Output framework, efficiency of irrigation and water resource usage will be reflected in a reduction of the intermediate input coefficients. It will lead to lower total direct and indirect input requirements of water. This will augment resources for final use. Similar effects will follow from the PMGSY program. Strengths of these effects are calculated in the Input–Output framework.

Both quantity and price effects of technological progress are calculated, with special reference to the agricultural sectors. Results are extended to show the effects of technological progress on the income distribution as well. On the whole, the responsiveness of agricultural sector outputs and prices to increased efficiency of intermediate inputs is lower as compared to non-agricultural sectors. The effects of increased efficiency of intermediate input usage are more marked when the improvements are spread over all sectors of the economy. Thus, programs like PMKSY and PMGSY would be more effective when executed simultaneously with other programs for increasing efficiency of intermediate inputs across the entire economy.

Appendix 1: Construction of the 135 Sector Commodity × Commodity Input–Output Table

i. *Aggregation of supply table*: The six sectors—trade (117) and railway/land/water/air/supportive transport (120–124)—were aggregated into one sector 'trade and transport.' Accordingly, the aggregated supply table contains 135 commodity sectors.
ii. *Construction of V* matrix: The supply table has dimensions **commodities** × **industries** which is transposed to form the *V* matrix with dimensions **industries** × **commodities**. The column totals of the *V* matrix are total commodity domestically produced, at basic prices.
iii. *Construction of D* matrix: *D* is computed as $V * q(d)^{-1}$ where $q(d)$ is total commodity domestically produced, at basic prices.
iv. *Aggregation of use table*: As in case of the supply table, in the use table also the six sectors—trade (117) and railway/land/water/air/supportive transport (120–124)—were aggregated into one sector 'trade and transport.' Accordingly, the aggregated use table contains 135 commodity sectors. However, the aggregated use table thus formed is at producers' prices. It has to be converted into basic prices. This requires two matrices, namely the matrix of trade and transport margins (TTM) and the matrix of taxes less subsidies (TLS). The aggregated use table at basic prices is formed by subtracting the TTM and TLC from the aggregated use table at producers' prices, with dimensions **commodities** × **industries**. It also contains final demand at basic prices.
v. *Construction of B* matrix: *B* is computed as $U * \hat{x}^{-1}$ where *x* is industry output domestically produced, obtained from the supply table.
vi. Construction of domestic IO table a basic prices: The domestic Input–Output coefficient matrix *A* is constructed as $A = BD$. This gives us the

inter-industry domestic transactions matrix $Z = Ax$. Final use at basic prices was obtained from the aggregated use table at basic prices. Final demand is calculated by subtracting imports from final use.

vii. Summary of workings:

1. The supply table was adjusted for valuation in purchasers' prices, to obtain domestic supply $q(d)$.
2. Accordingly, the domestic industry outputs 'x' were also changed.
3. $B = U * <q(d)> \wedge{-1}$ was calculated.
4. $D = V * <x> \wedge{-1}$ was computed.
5. $A = B * D$ was obtained.
6. The balancing equation $[q(d) = A * q(d) + e - m]$ was checked.

viii. Sectors of India's Input–Output table for 2011–12:

Sector No.	Name	Sector No.	Name
1	Paddy	31	Natural gas
2	Wheat	32	Crude petroleum
3	Coarse cereals	33	Iron ore
4	Gram	34	Manganese ore
5	Arhar	35	Bauxite
6	Other pulses	36	Copper ore
7	Groundnut	37	Other metallic minerals
8	Rapeseed and mustard	38	Limestone
9	Other oilseeds	39	Mica
10	Kapas	40	Other nonmetallic minerals
11	Jute, hemp, and mesta	41	Processed poultry meat and poultry meat products
12	Sugarcane	42	Processed other meat and meat products
13	Coconut	43	Processed fish and fish products
14	Tobacco	44	Processed fruits and processed vegetables
15	Tea	45	Dairy products
16	Coffee	46	Edible oils and fats
17	Rubber	47	Grain mill products, starch, and starch products
18	Fruits	48	Sugar
19	Vegetables	49	Bread and bakery products
20	Other food crops	50	Miscellaneous food products
21	Milk	51	Alcoholic beverages
22	Wool	52	Non-alcoholic beverages
23	Egg and poultry	53	Tea processed
24	Other livestock products	54	Coffee processed

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Sector No.	Name	Sector No.	Name
25	Industry wood	55	Tobacco products
26	Firewood	56	Cotton yarn and cotton textiles
27	Other forestry products	57	Synthetic yarn and synthetic textiles
28	Inland fish	58	Wool yarn and woolen textiles
29	Marine fish	59	Silk yarn and silk textiles
30	Coal and lignite	60	Carpet weaving

Sector No.	Name	Sector No.	Name
61	Ready-made garments	91	Industrial machinery for food and textile industry
62	Misc. textile products	92	Industrial machinery (except food and textile)
63	Leather footwear	93	Machine tools
64	Leather and leather products except footwear	94	Other non-electrical machinery
65	Wood and wood products except furniture	95	Electrical industrial machinery
66	Paper, paper products, and newsprint	96	Electrical cables, wires
67	Publishing, printing, and allied activities	97	Batteries
68	Furniture and fixtures	98	Electrical appliances
69	Rubber products	99	Communication equipment
70	Plastic products	100	Other electrical machinery
71	Petroleum products	101	Electronic equipment including TV
72	Coal tar products	102	Medical precision, optical instrument
73	Inorganic chemicals	103	Watches and clocks
74	Organic chemicals	104	Ships and boats
75	Fertilizers	105	Rail equipment
76	Pesticides	106	Motor vehicles
77	Paints, varnishes, and lacquers	107	Motorcycles and scooters
78	Drugs and medicine	108	Bicycles, cycle-rickshaw
79	Soaps, cosmetics, and glycerin	109	Aircraft and spacecrafts
80	Synthetic fibers, resin	110	Other transport equipment
81	Other chemicals and chemical products	111	Gems and jewelry
82	Cement	112	Miscellaneous manufacturing

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Sector No.	Name	Sector No.	Name
83	Nonmetallic mineral products	113	Construction and construction services
84	Iron and steel ferroalloys	114	Electricity
85	Iron and steel casting and forging	115	Gas
86	Iron and steel foundries	116	Water supply
87	Nonferrous basic metals (including alloys)	117	Trade and transport
88	Hand tools, hardware	118	Repair and maintenance of motor vehicle
89	Miscellaneous metal products	119	Hotels and restaurant
90	Tractors and other agricultural implements	120	Storage and warehousing

Sector No.	Name	Sector No.	Name
121	Communication services	129	Other business services
122	Financial services	130	Computer-related services
123	Insurance services	131	Public administration and defense
124	Ownership of dwellings	132	Education services
125	Real estate services	133	Human health and social care services
126	Renting of machinery and equipment	134	Community, social and personal services
127	Research and development services	135	Recreation, entertainment and radio and TV broadcasting, and other services
128	Legal services		

This commodity × commodity Input–Output table was constructed from the supply and use tables of 2011–12 containing 141 commodity sectors. Trade and transport sector (117) in the above commodity × commodity Input–Output table was obtained by aggregating six commodity sectors of the supply and use tables, namely trade (117) and railway/land/water/air/supportive transport (120–124).

Appendix 2: Final Demand Effects of 1% Increase in Efficiency of Intermediate Inputs in All Sectors

(a) Sectors with more than 1% increase in final demand Agricultural sectors: paddy, sugarcane, wheat, other food crops, kapas, other oilseeds, vegetables Agriculture-based sectors: milk, other livestock products Non-agricultural sectors: crude petroleum, petroleum products, trade and transport, electricity, organic chemicals, inorganic chemicals, financial services, nonferrous basic metals, other chemicals and chemical products, iron and steel casting and forging, coal and lignite, construction and construction services, iron and steel foundries, miscellaneous metal products, plastic products, synthetic fibers and resin, communication services, rubber products, other business services, paper and paper products, iron and steel ferroalloys, fertilizers, gems and jewelry, other nonmetallic minerals, drugs and medicines, hotels and restaurants
(b) Sectors with increase in final demand between 0.9 and 1% Wood and wood products except furniture, iron ore, nonmetallic mineral products
(c) Sectors with increase in final demand between 0.6 and 0.9% Cotton yarn and cotton textiles, natural gas, other non-electrical machinery, edible oils and fats, electrical appliances, real estate services, industry wood, water supply, motor vehicles, synthetic yarn and synthetic textiles, copper ore, electrical industrial machinery, industrial machinery (except food and textiles), renting of machinery and equipment, hand tools hardware, insurance services, rapeseed and mustard
(d) Sectors with increase in final demand between 0.5 and 0.6% Machine tools, miscellaneous textile products, eggs, and poultry

Source Results obtained from the present study

Appendix 3: Price Effects of 1% Increase in Efficiency of Intermediate Inputs in All Sectors

(a) Sectors with more than 1% decrease in price Sensitivity of 1.4 and above: gems and jewelry, petroleum products, coal tar products, inorganic chemicals, paints, varnishes and lacquers, inorganic chemicals, communication equipments, fertilizers, pesticides, organic chemicals, gas, motorcycles and scooters, aircraft and spacecrafts, other electrical machinery, other transport equipment, motor vehicles, soaps cosmetics and glycerin, legal services Sensitivity between 1.30 and 1.39: nonferrous basic metals including alloys, iron and steel foundries, miscellaneous manufacturing, iron and steel casting and forging, iron and steel ferroalloys, electrical industrial machinery, electrical cables and wires, electrical appliances, electronic equipment including television, medical precision and optical instruments, paper, paper products and newsprint, ships and boats, coal and lignite Sensitivity between 1.15 and 1.29: rubber products, storage and warehousing, real estate services, communication services, legal services, construction and construction services, electricity, industrial machinery, tractors and other agricultural implements, publishing, printing and allied activities, miscellaneous metal products, machine tools, other chemicals and chemical

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products, other non-electrical machinery, hand tools, hardware, plastic products, synthetic fibers and resins, communication services
Sensitivity between 1.01 and 1.07: ready-made garments, miscellaneous textile products, drugs and medicine, dairy products, processed other meat and meat products, processed fruits and processed vegetables, cotton yarn and cotton textiles, woolen yarn and woolen textiles, carpet weaving, silk yarn and silk textiles, edible oils and fats, processed poultry meat and poultry meat products, processed fish and fish products, watches and clocks, storage and warehousing, synthetic yarn and synthetic textiles
(b) Sectors with decrease in price between 0.5 and 1%
Sensitivity between 0.45 and 0.72: human health and social care services, insurance services, public administration and defense, other business services, research and development services, financial services, computer-related services, education services
Sensitivity between 0.74 and 1.00: alcoholic and non-alcoholic beverages, firewood, industry wood, other forestry products, crude petroleum and natural gas, sugar, leather and footwear, bread and bakery products, tea and coffee processing, repairs and maintenance of vehicles, recreation entertainment and radio, renting of machinery, manganese ore, bauxite, copper ore, iron ore and other metallic minerals, cement, wood and firewood products, miscellaneous food products, nonmetallic mineral products, furniture and fixtures, grain mill starch and starch products, community social and personal services, trade and transport sector, hotels and restaurants
(c) Sectors with less than 0.5% decrease in price
Paddy, wheat, coarse cereals, gram, arhar, other pulses, groundnut, rapeseed and mustard, other oilseeds, coffee, rubber, tobacco, other food crops, sugarcane, vegetables, kapas, jute hemp and mesta, inland and marine fish sectors, milk, wool, eggs and poultry, other livestock products

Source Results obtained from the present study

Appendix 4: Sectors Showing Increase in the Ratio of Employees' Compensation to Operating Surplus

Group (a)
Processed poultry meat and poultry meat products, processed other meat and meat products, processed fish and fish products, processed fruits and processed vegetables, dairy products, edible oils and fats, grain mill products, starch and starch products, sugar, bread and bakery products, miscellaneous food products, alcoholic beverages, non-alcoholic beverages, tea processed, coffee processed, tobacco products
Group (b)
Coal and lignite, natural gas, crude petroleum
Group (c)
Cotton yarn and cotton textiles, synthetic yarn and synthetic textiles, wool yarn and woolen textiles, silk yarn and silk textiles, carpet weaving, ready-made garments, miscellaneous textile products

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Group (d)
Leather footwear, leather and leather products except footwear, wood and wood products except furniture, paper, paper products and newsprint, furniture and fixtures, rubber products, plastic products
Group (e)
Petroleum products, coal tar products, inorganic chemicals, organic chemicals, fertilizers, pesticides, paints, varnishes and lacquers, drugs and medicine, soaps, cosmetics and glycerin, synthetic fibers, resin
Group (f)
Iron and steel ferroalloys, electrical industrial machinery, electrical cables, wires, batteries, communication equipment, watches and clocks
Group (g)
Construction and construction services, electricity, gas, water supply, storage and warehousing, communication services
Group (h)
Public administration and defense, education services, human health and social care services, community, social and personal services, recreation, entertainment and radio and TV broadcasting, other services

Source Results from the present study

Appendix 5: Ranking of Agricultural Sectors by Power and Sensitivity of Dispersion

S. No.	Name	Ranking out of 135 sectors by power of dispersion	Ranking out of 135 sectors by sensitivity of dispersion
1	Paddy	128	18
2	Wheat	121	25
3	Coarse cereals	113	60
4	Gram	114	75
5	Arhar	122	107
6	Other pulses	118	82
7	Groundnut	126	93
8	Rapeseed and mustard	119	55
9	Other oilseeds	120	33
10	Kapas	129	23
11	Jute, hemp, and mesta	116	99
12	Sugarcane	115	19

(continued)

(continued)

S. No.	Name	Ranking out of 135 sectors by power of dispersion	Ranking out of 135 sectors by sensitivity of dispersion
13	Coconut	123	85
14	Tobacco	131	78
15	Tea	130	87
16	Coffee	124	83
17	Rubber	127	59
18	Fruits	117	76
19	Vegetables	132	34
20	Other food crops	125	32

Notes (i) Power of dispersion of each of the agricultural sectors is less than unity
(ii) Sensitivity of dispersion of agricultural sectors with ranks above 34 is less than unity
Source Results from the present study

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Part II
Manufacturing Sector Modelling

Assessments of ICT Policy Options: The Framework of Input–Output Table Linked with Intangible Knowledge Stock

Masahiro Kuroda, Kenta Ikeuchi, Yasushi Hara and Michael C. Huang

Abstract The 21st century marks the prosperity of cyber systems that drastically reshaped the social economy structure. Confronting the hyper-aging society with shrinking population in Japan, rapid development of ICT/IoT has contributed to social economic change nowadays while evaluating the effectiveness of policy options thus becomes an urgent task for stakeholders. A new type of social economic development with technology substitute of labor deserves more attention to accommodate technology improvement in the society. In order to capture the structural change, we develop a CGE model applying Japan's input–output table from 1995 to 2011 with the disaggregation of 95 sectors. In this model, the capital stock has been distinguished into tangible and intangible capital to better interpret the R&D capital formation and its spillover effect for technology realizations. Based on the mechanism, a user-friendly application called SPIAS-e was developed for policy option evaluation. Finally, the chapter demonstrated simulation results of STI policy options scenarios on how new service platform with ICT would be affected by R&D investments and technological improvement.

Keywords Policy evaluation · CGE · ICT/IoT · R&D · SPIAS-e

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1 Introduction: Toward the Evidence-based Policy Making

The rapid development of cyber-physical systems with the stream of technological change has drastically reshaped the social and economic structures. For this change on the structures, the identification of science, technology, and innovation (STI) policy has become much more challenging than ever before and it is essential to provide more quantitative assessment to reflections on policy engagements to policymakers. For the development of science and technology to cope with societal challenges, it is important that scientists accurately grasp the societal expectation for science, based on observations of the present states of sciences, and show evidence-based alternative policy option to solve the societal problems.

Throughout the transition of economy, the social and economic structural changes have made it necessary to develop policy alternatives to deal with challenges and to conduct prior and ex-post evaluations of policies. At this stage, stakeholders are institutionally required to build policy formation process on a circulated way and advocate the academia to discover societal challenges to identify expectations for science to address challenges on designing policy options and making mutual understanding policy implementation impact assessment and evaluation coping with the challenges. On such evidence-based procession of policymaking, policymakers are suggested to be aquatinted with properties of science in order to deepen the understanding of the properties in the modern sciences and society.

The chapter includes three main sections: In the first section, we introduce the history of science, technology, and innovation development and its implication for the information revolution in the 21st century. In the second section, we specify the concept of R&D capitalized into tangible and intangible asset while using Japan's input–output (IO) table of 1995–2011 for quantitative assessment of the R&D investment. In the third section, we develop a recursive CGE model, SPAIS-e for STI policy impact evaluation. Finally, we set a scenario and demonstrate the simulation results of the changes of GDP, capital price, and employment of new capital service platform. Policy recommendations for the compilation of IO table for R&D for making evidence-based policy assessment are proposed accordingly.

2 The Advancement of Science and Technology and the Structural Change of Society: The History of Industrial Revolutions

The first industrial revolution started from eleventh to thirteenth century while miller power was widely used as primary energy source. At that time, the cast iron and other highly agriculture mechanism technology had substantially improved productivity. The prosperity has activated the urban commercial life and the curiosity thinking with desire of pursuing knowledge, contributing the establishment of university. The first information revolution was activated by the great discovery period of fourteenth to fifteenth century—the invention of compass, gunpowder, and the spread of letterpress printing has contributed to massive knowledge expansion and resulted in popularity of knowledge for the social material foundation in the fifteenth century.

The second industrial revolution in the sixteenth to eighteenth century was stimulated by steam machine and coal energy. Despite that massive production was made possible through mushroomed factories, creating social status of bourgeois as well as urban slum. The boom of democracy spared from America continent to Europe and that the market mechanism had been emphasized. With the discovery and the use of electricity, the science revolution in the late nineteenth century to early twentieth century that made fundamental change on paradigm was achieved through new quantum physics as the third industrial revolution. Later in the fossil energy era, the massive production and consumption have led to a Trans-Science age with information technology boosted by semiconductor, biotechnology with the second information revolution. The fourth industrial revolution with rapid development of Integrated chip (IC), Internet of things (IoT), Artificial intelligence (AI), life science, and cognitive science has risen substantially in the 21st century.

2.1 Japan's Development: From High Economic Growth to Stagflation

The experience of Japan's postwar development is a comprehensive example to witness the entire economic cycle. It could be regarded as one of the successful STI policy instruments that contributed to high economic growth performance during the morden human history. Seventy years after the WWII, Japanese society has experienced a drastic demographic transition from rapid expansion of labor sources due to the demobilization of the soldiers and the repatriates from abroad to aging society with shrinking population since the beginning of the 21st century. After 1945, Japan's industries had been severely damaged during the war, the rapid recovery because of the aid and abundant labor resource from the rural area to urban area. In this period, industrial reconstruction was made in the designated industries. Since the government was very cautious, the fiscal balance between 1948 and 1965 had been cleared and the deficit has rarely been considered by policymakers. Japan had successful experience of economic expansion between 1960 and 1985 except for the oil shocks in 1973 and 1979.

Table 1 Source of average annual economic growth (%)

Indicators/ periods	1965–75	1975–85	1985–95	1995–2000 (%)	2000–05 (%)	2005–10 (%)	2010–14 (%)
Nominal GDP	15.2%	7.6%	4.1%	0.3	−0.2	−0.9	0.2
Real GDP	7.4%	4.0%	3.1%	0.8	1.2	0.3	0.6
Population	1.3%	0.8%	0.4%	0.2	0.1	0.0	−0.5
Labor force	1.0%	1.1%	1.1%	0.3	−0.3	−0.1	−0.1
Tangible capital	n.a.	n.a.	n.a.	1.7	0.4	1.0	0.4
Intangible capital	n.a.	n.a.	n.a.	4.6	6.9	2.3	−0.1

Source National accounts statistics for 2014, population census, etc.

During this period, Japan's government has been continuing the market intervention through Keynesian fiscal policy by prompting public expenditure on infrastructure and industrial rationalization policies for heavey manufactuing industries. Meanwhile, large science with consumer durable consumption electronic appliances such as refrigerator, washing machine, and television appeared to become common in the household. Flying geese paradigm (Akamatsu 1962) has been proven again in the economic linkage among Japan and other newly industrial economies like South Korea, Singapore, and Taiwan. Vogel's *Japan As Number One* (1979) had been one of the best sellers and lessons for successful economy.

In 1985, Japan was forced to adapt the agreement of the Plaza Accord. Afterward, the exchange rate of the Japanese Yen versus US dollar appreciated by 51% from 1985 to 1987. Consequently, Japan suffered from the bubble economy while its economic growth had reached its limitation with the coming of stagflation in the burst of bubble. Since the 1990s, the feature of Japan's economy had changed from massive consumption market to hobby and high-quality demand along with the expansion of fiscal burden, social insurance, medical care, education expenditure. The damage of Kobe earthquake in 1995 and Asian financial crisis in 1997 had again deterred the confidence, resulting into a more cautious and hesitation for investment and that had frustrated several economic stimulus plans.

Table 1 shows that Japan had positive economic performance till 2000, and on contrary, the stagflation, decrease in population and labor force became severer subsequently. Japan had stepped into hyper-aging society since 2006, with the purpose of leading to sustainable development, and Japan realized that the key solution for aging society, shrinking population, and reduction of fiscal deficit might depend on the knowledge and experiments between science and technology responding to societal problems.

2.2 The Fluctuation of Modernism and STI

From the twentieth to twenty-first century, with the advancement of science and technology, huge issues have been embraced by the entire society. The modernistic social regulations have been undergoing a fluctuation in democracy, market mechanism, and scientific philosophy. Meanwhile, the diminution of energy and resource has been advocating the society to switch from fossil energy to sustainable energy. The globalization led by information technology has somehow inferior the income gap and disparity, while populism has experienced great expansion along with the development of Social Networking System (SNS).

The productivity gain stimulated by aggressive STI spending policy throughout the structural change of society on science and technology. However, the stimulus plans are obligated to follow government's budgetary concerns with efficiency and feasibility. This may contain the expectation and confidence in the public for STI policy that may satisfy the transparency and the understanding of the public by putting policymaker's reflections on policy engagements. Traditionally, the policymaking mechanism could be derived into PDCA cycle, referring as "plan-do-check-act" four-step management method used in business for the control and continual improvement of processes and products. Such process has been widely used as a scientific method of implementing STI policy for solving normative approach. The revolutionary development in the information science and technology since the beginning of twentieth century had enormous impacts on all of the science fields including life, material physics, and environmental science methodologically and conceptually. Deepening the properties and the structure of trans-scientific relationships among various sciences is essential to manage the promotion of the STI and apply their results on the policies in order to solve complex problems in modern society.

2.3 The Objective of Science for Science Policy and Policy for Science to Achieve the Co-improvement

STI has been highly expected to cope with societal challenges to appropriately respond to growing economic and social structural changes. Deepening the understanding for the properties in the modern science and society relies on the interpretation of the relation between the technology and modern socio-economy. Moreover, trans-scientific issues which arise in the course of the interaction between science, technology, and society remained unsolved. In order to solve such complicated issues, reliable collaborations among scientists, citizens, and politicians are indispensable in order to fulfill their responsibility.

The development of new trans-sciences has not only brought a variety of benefit, but also unpredictable impacts, disasters, and damages on environment of earth and public controversy. These mean that such impacts could be fairly difficult to understand for their fragile and complex characteristics. A solid and effective collaboration among various science including natural sciences and humanities is strongly recommended with the aim of analyzing their phenomenon scientifically and finds efficient policy instruments as a STI policy.

2.4 Pyramid Hierarchy and the Categories of Industrial Structure

The development of ICT has changed the way of life prevailing from ownership to the right to use. Such transition has made the physical input such as land, building, or merchandise no longer necessary conditions for economic activities. The shared value economy (Fig. 1) may gradually replace the traditional economic mechanism while the material input for production is only secondary and what really matters is the service provided through the newly created platform based on the Internet and SNS that link the demand and supply on their most efficient and least costly pathway. Cases like Uber, Airbnb, YouTube, and other e-commerce have redesigned the nowadays consumption style with sharp advice for the existing IO analysis and its compilation.

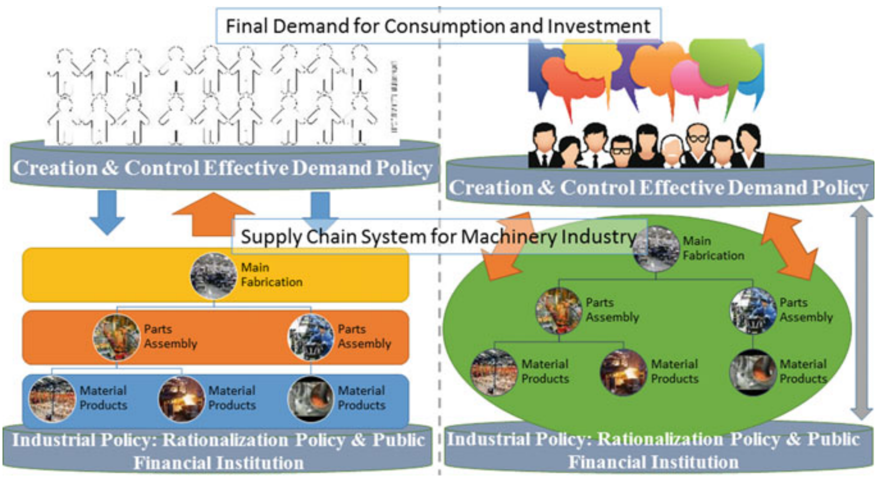

Fig. 1 Transition for consumption and investment. *Source* GRIPS SciREX Center

3 Quantitative Modeling for Science and Technology

The impact assessment of STI policy requires the development of adequate modeling frameworks in order to capture the specific characteristics of research and innovation. Their structural equations are estimated econometrically very rich in economic details. Tsujimura et al. (1981) decomposed Japanese economy structure with analyzing economic policy with the interpretation of their general interdependence. Based on the analysis of different periods of Japanese economic development, they presented quantitative theory of price and built a CGE empirical model for quantitative approach. The base of recursive CGE models relies on markets equilibrium balancing supply and demand through the system of prices. Policies that alter the equilibrium are considered shocks that induce new equilibria in the interaction between consumers and producers in the different markets.

There is a general consensus among economists and policymakers that R&D activities play a decisive role in fostering productivity growth. Aulin-Ahmavaara (1999) uses dynamic IO model to examine the effective rates and prices of the inputs treated as produced. The conclusion indicated that such rates are determined by production technology. For recent R&D expenditure studies, Kristkova (2013) indicates that the public R&D sector is not involved in the production of capital varieties, whereas the production of general knowledge is contained in the production processes of both public and private R&D as a specific factor. Comite and Kancs (2015) compares several macroeconomic models, in which they pointed out that modeling public intervention in R&D as a free productive input as determination of optimal policy, or a type of subsidy may be underprovided by the market because of positive spillover across firms. They also suggest that determination of the parameters capturing this effect in the economy should be carefully examined with evidence. The redesign of the STI policy assessment is suggested in order to enable the reconstruction on planning and the implementation of the STI policy, and further, to have such methodology developed as one branch of science. Deepening the understanding of the processes could be operated by involving STI and visualizing their social and economic impacts of STI policy. While the results of these alternative policy options could be examined with scientific evidences, such process is emphasized and regarded effectively with the intention of ensuring transparency in decision-making and provision of accountability to the general public.

3.1 The Capture of Capital Stock Flow

For the assessment of R&D expenditure impact on productivity, we propose a framework of measurement to show the effectiveness of the impacts on the production activities by the accumulation of the knowledge stock through the R&D investment based on Kuroda and Nomura (2004). We try to capitalize the R&D

expenditure as an intangible asset from sources of investments for R&D activities provided both from the public and the private by government and private industry. The investments assume to create the knowledge for science and technology, in which the science fields are divided into several fields of sciences. R&D activities are introduced by public and private research institutes like university and affiliated research institutes, independent research institutes as private enterprises, and intra-enterprise R&D activity affiliated by private enterprises. The R&D products and services created by these agencies are accumulated into the knowledge as intangible assets in each agency.

R&D investments are introduced separately investments by government and nonprofit organizations, research institute by private institutions and intra-research activities within the private firm. While introducing the R&D activities into the IO framework explicitly, we could show the theoretical frame to measure how the accumulated intangible assets (knowledge stock) could create the efficiency of the production activities. It is assumed that each R&D investment is accumulated as intangible assets and the capital service flows as technological knowledge are created by the accumulated intangible assets. Capital stock is estimated by perpetual inventory method in tangible and intangible assets by activity in each industry. The real quantity of investment by activity is induced by the nominal investment deflated by price index of investment by activity. The real quantity of investment in time series is utilized to estimate the capital stock by activity in the perpetual inventory method.

Langlois (2002) indicates that if intra-firm R&D activities are assumed to increase the gross output, final demand, and value added shall be explicitly estimated as new concepts. In the current Japanese IO table, intra-firm R&D activity has been taken account of the activity as one independent activity although all of intra-firm R&D activity is aggregated in one activity. The output is transferred into the users as intermediate inputs, but not in the capital formation except capital depreciation allowance. In our analysis, the intra-firm R&D activity could be treated as one of activities in each sector, by which each firm assumed to be able to create new knowledge as one of intangible assets. Furthermore, the capital service flow accumulated in the intangible knowledge stock is assumed to be transferred to the firm main production activity as a type of capital input, but not intermediate input.

3.2 From 1993SNA to 2008SNA

Transaction of knowledge service which is created by knowledge stock is a vital issue. In the 1993 System of National Accounts (SNA), R&D expenditure has been treated as intermediate inputs (United Nations 1993; OECD 2002). Research activities by market producers have been accounted in the gross output in the old SNA in Japan. However, they have not been treated as the transactions in the final demand, but in intermediate transactions. In the revision of JSNA in 2016, the capitalization of the R&D expenditure was regarded in the macroaggregated level as a type of intangible assets. It is treated as one of intangible investment goods, but not as intermediate goods (Cabinet Office of Japan 2017). Since the R&D Expenditure includes total labor cost for R&D, intermediate inputs as well as tangible and intangible capital inputs in public and private research and development activities include university, public, and private research institutes.

The treating the entity of patents and licensing service of patents is also important. Transactions of knowledge service which are creating from knowledge stock by capitalization of R&D activity, most of all, treatments of entity of patents, and transactions of licensing service, should be treated explicitly in SNA and input–output statistics (OECD 2010). The 2008SNA regards entity of patents as fixed productive capital formation; licensing fees of patents as output of the licensing service; and their transactions are treated as intermediate demand or fixed capital formation. However, in Japanese IO table, patent service is not specialized as an industrial sector. Therefore, net transaction of licensing fee of patents are including in the property income in each industrial sector. In the aggregate of the nation-wide, transaction of licensing fee among domestic sectors is canceled out and taken account of the net outside transaction.

The JSNA has revised accordingly with the amendment on R&D from the intermediate inputs to final demand as investment of intangible assets in 2016. The 2015 IO table in Japan will be revised into 2008SNA with inclusion of final demand as capital formation adding to new items of the value added as business surplus and capital depreciation allowance (Kobayashi 2016). On the other hand, intra-firm R&D activities by market producers have not been taken accounts of output measures, but in the business surplus implicitly. Treatment of the capitalization of R&D expenditure based on SNA2008 has been employed in many countries such as Australia (2009), Canada (2012), USA (2013), Korea (2014), and UK (2014), respectively.

3.3 Data Structure

For the sake of making coevolutionary relationship among scientists, citizens, and politicians, and activating STI capabilities for value capture in the society, we aim to construct a policy simulator to give evidence-based policy options. We compose the following data framework for our objectives. In the measurement of private or public R&D expenditure, such investment activity in capital stock should be regarded from dimensions of tangible and intangible knowledge capital stock. As suggested by 2008SNA, the R&D investment should be taken as intangible knowledge stock formation. Such compilation has been done in Japan's 2016 national accounts as an aggregated measure but not yet the IO table of 2011 (released in 2015). The data used in our model (Fig. 2) were sourced from Japan's IO tables and with extended estimation (red blocks) to distinguish tangible and intangible capital investments by 95 sectors (Table 3), considering long-/short-run

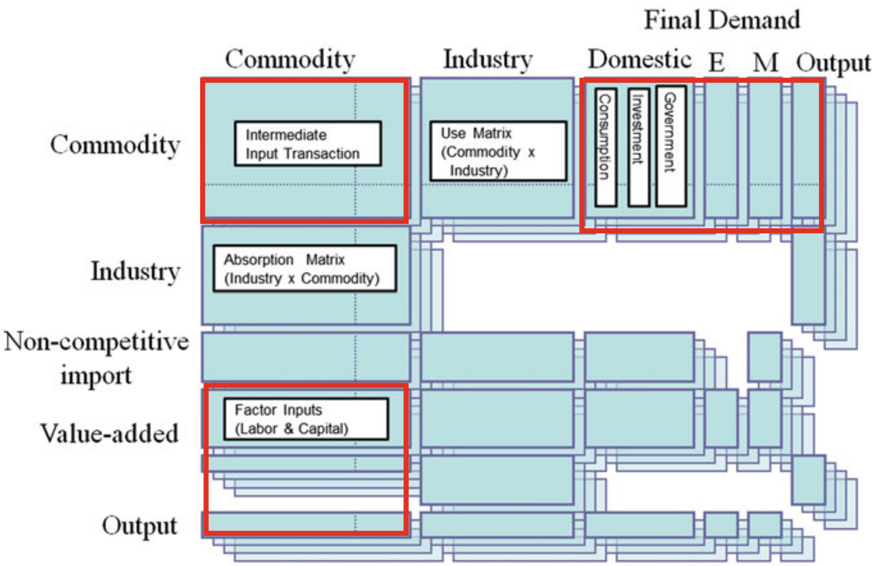

Fig. 2 Structure of input–output data layers. *Source* Kuroda et al. (2016)

block, labor market modeling, value added and wage determinant, government balance sheet, and the final demand block.

In advance, here we try to revise the Japanese IO Tables to be capitalized the R&D investment during the year 1995–2011. The production activity at the year *t* depends upon the tangible and intangible capital assets accumulated at the prior years and embodied the technological properties at the time when they were invested. Through investment, accumulated productive capital is composed of the capital goods from prior periods. The idea could evaluate the contribution of knowledge stock which is accumulated by the R&D investment as intangible assets. We assume that the knowledge of science and technology is accumulated and deepened by the R&D activities with R&D investment. Then we assume that the R&D investment is accumulated as intangible assets and intangible asset creates knowledge proportionally to the amount of intangible capital stock.

In our IO table, R&D activities are assumed to be separately identified as intra-firm R&D activity, independent public and nonprofit private R&D activities including government institutes and nonprofit institutions and independent private R&D industrial activity. In each industrial sector excluding the above R&D activities with the assumption to be divided into the production activity of main products and infra-industry R&D activity. We also assume that independent public and nonprofit private R&D activity and private R&D industrial activity are divided into several fields by science and technology.

Figure 3 shows that sectors except research institutes by government and industry are divided into the following three categories: (a) main product;

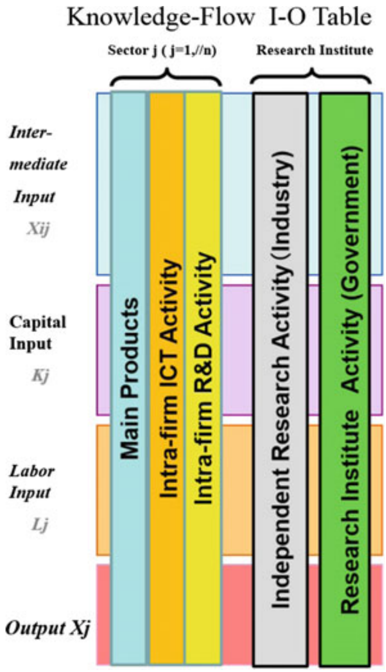

Fig. 3 Data framework—production activity by sector. *Source* GRIPS SciREX Center

(b) intra-firm ICT activity; and (c) intra-firm R&D activity. Under such disaggregation, we may obtain a systematic view of capital service flow facilitated by the ICT/IoT implementation for information allocation and processioning to accelerate its productivity for manufacturing. The R&D activities by industry and government as independent research institute are divided into ten research fields of ICT, environment, materials, energy, space, oceanography, other natural sciences and social sciences and humanity.

In order to analyze the impacts of the development of the knowledge in science and technology on the economy and society, it is necessary to establish the analytical tool to observe the impacts theoretically and empirically. Capital stock matrix both in tangible and intangible assets assumes to be estimated by the perpetual inventory method with given economic rate of replacement. We can define capital coefficients by tangible and intangible assets as the ratio by capital stock and output in main products and R&D activities, respectively.

The intra-R&D activity and intra-information activity including software development in-house from the main productive activity in the enterprise are classified separately. The knowledge services created inside of the enterprise are counted as capital formation of intangible assets and accumulated to the intangible assets. On the other hand, the fixed capitals which are used in the intra-activity of R&D and software development are counted at the fixed capital formation as investment and they are accumulated to the tangible assets in these two activities. In our model, these factor inputs represent the capitalization of intangible assets so that such capital inputs are measured by quantity and price of the capital services which were imputed from capital stock and capital cost. The capital stocks and capital cost are measured consistently with IO tables as for tangible and intangible assets while the intangible assets are separately estimated by software and knowledge stock in research fields. Finally, the capital formation matrices by flow and stock for tangible and intangible assets were estimated annually while labor inputs by sector and activity are separately estimated.

4 The Mechanism of Policy Formation and Its Evaluation

For activating science and technology capabilities for value capture in the society, we constructed a recursive CGE model (Kuroda et al. 2016) that illustrates the new business platforms reflecting the investment on R&D for facilitating capital service flow (Fig. 4). The model is expected to shed lights on implication of total factor productivity (TFP) for its process change on the demand side while the productivity improvement in information provision service sector that enlarges the platform business, assisting manufacturing sectors to create new market and variate the international production networking structure.

On such platform, scientists need to move from Science for Science's sake to Science for Society while policymakers want to design an evidence-based STI policy scientifically to realize the capability of science and technology toward the value captured, while the predetermined endogenous variable such as capital stock

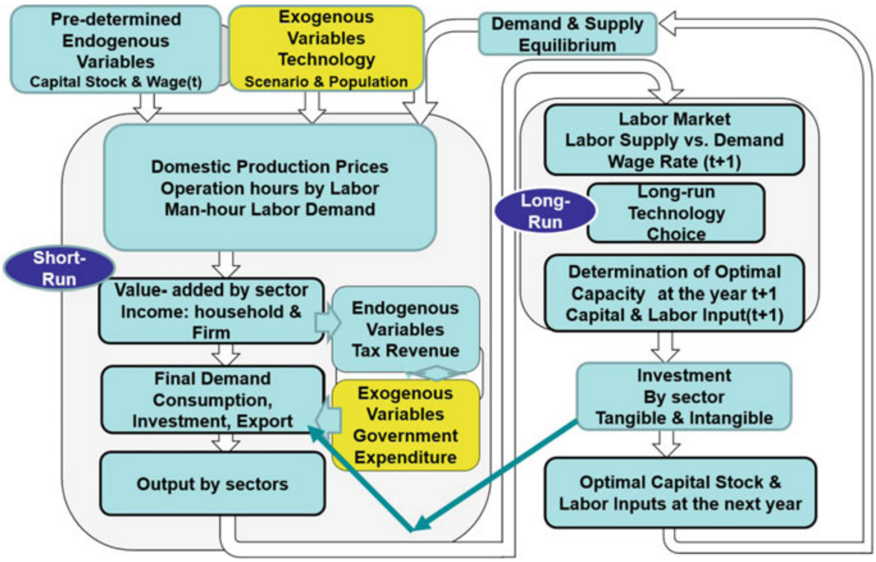

Fig. 4 Recursive CGE model structure. *Source* GRIPS SciREX Center

and wage interacted with exogenous variable of technology and population generates the output of short-run equilibrium and determines new equilibrium as the predetermined variables for the next time period.

Moreover, the information management could benefit from outsourcing and externalization while the cross-sectional platform of information management may thus be established. The simulation results showed the change on employment and production division along with the ICT/IoT advancement of its short-/long-run effect.

4.1 The SciREX Policy Intelligence Assistance System—Economic Simulator (SPIAS-e)

In this process, the change of capital service and labor service could be observed, indicating the gap of income and capital formation. There are different level of procession/production efficiency and are set technology parameters in the activity divisions of marketing, planning, R&D, procurement, operation and sales, maintenance will be calibrated through a database system—SciREX Policy Assistance Intelligence System (SPIAS) containing research grants, academic performance based on scientific papers, patents, and news releases.

Based on the structure of the recursive CGE model, we develop a user-friendly simulator "SPIAS-e" affiliated in our SPIAS platform. The key parameters and the volume of government R&D investment could be easily controlled with the visualized results of the year 2005–2050 comparing the business as usual (BAU) path on GDP growth, impact, changes on indicators and stock in visualized graphs of policy options (Appendixes).

4.2 Scenarios

Two scenarios are made to examine the impact of R&D investment on medical service sector (Table 2). The BAU scenario gives us the overview of the baseline economic and social trend until 2050 from the year 2005. The R&D investment (tangible and intangible) made by government remained the same and no improvement of technology production while the structural changes of the population by age and gender are assumed exogenously. The ICT+R&D scenario referred to more R&D investment in ICT and other science R&D fields, with higher efficiency to be actualized from the year 2020 in production efficiency led by more R&D investment in the designated sectors such as semiconductor, software, Internet, information management, and communication service-related sectors. The knowledge stock accumulated by the government R&D expenditure is assumed to

Table 2 Scenarios and parameter setting

	Business as usual (BAU)	ICT+R&D
Life science R&D investment[a]	1	1
ICT & communication R&D investment[a]	1	1.5 times
Material science R&D investment[a]	1	1
Energy science R&D investment[a]	1	1
Other sciences R&D investment[a]	1	1.5 times
Production efficiency improvement from 2020[b]	1	1.2 times

[a]Comparing with 2005 level
[b]In semiconductor, ICT, software, Internet and information-related sectors

have an impact on the productivity increases in the private sectors as public goods thanks to the patent released.

4.3 Assumptions on Exogenous Policy Variables for the Baseline Scenario

We have set assumptions for Baseline scenario of the Japanese economy during the future years 2020–2050 as following: (i) Government R&D expenditure scale remains the same during 2005–2050; (ii) Constant tax rates including personal income tax, corporate income tax, consumption tax, indirect tax and property for the 2005 level; (iii) Government consumption expenditure will be assumed to be constant to nominal GDP endogenously; (iv) Government capital formation for tangible and intangible assets will be fixed at the 2005 level nominally; and (v) Structure of the population will be assumed to be given by the projections with fertility medium-variant case by National Institute of Population and Social Security Research.

4.4 Simulation Results

When R&D investment policy options of government R&D expenditure and assumed productivity efficiency improvement are inserted in the SPIAS-e, the system on Webpage generates the projection of economic performance and indicators 2005–2050 (while the results from 2005 to 2011 are the actual data) as alternative policy option assessment. The GDP growth (upper panel) and percentage change (middle panel) and the breakdown of GDP growth contributed by value add (lower panel) are displayed in Fig. 5. (Abbreviations could be referred to Table 4.)

Simulation results showed that ICT+R&D scenario will lead to higher real GDP since 2020 and gradually increase its growth path. The GDP change seemed to fluctuate from the BAU but remained on positive scale. While the production

Fig. 5 GDP change and contribution by value add (unit: million JPY, %). *Source* GRIPS SciREX Center SPIAS-e

efficiency improvement was actualized in 2020, the GDP growth reached its peak by 0.8% and decrease due to its marginal effect diminishing. In the breakdown of the contribution, it could be found that the share of OS (operation surplus) and DEPK (tangible capital depreciation provision) kept increasing and served as the growth engine with its spillover pull for the economy.

4.5 Employment Change

The employment by gender and age has also been an important concern as the economic indicator and assessment. The employment projection on three representing sectors of selected capital service platforms is (Fig. 6): Information and Communication, Software and Information Management Service.

Overall speaking, the aging society and shrinking population seem to be inevitable while the employment in the three sectors showed a continuous drop.

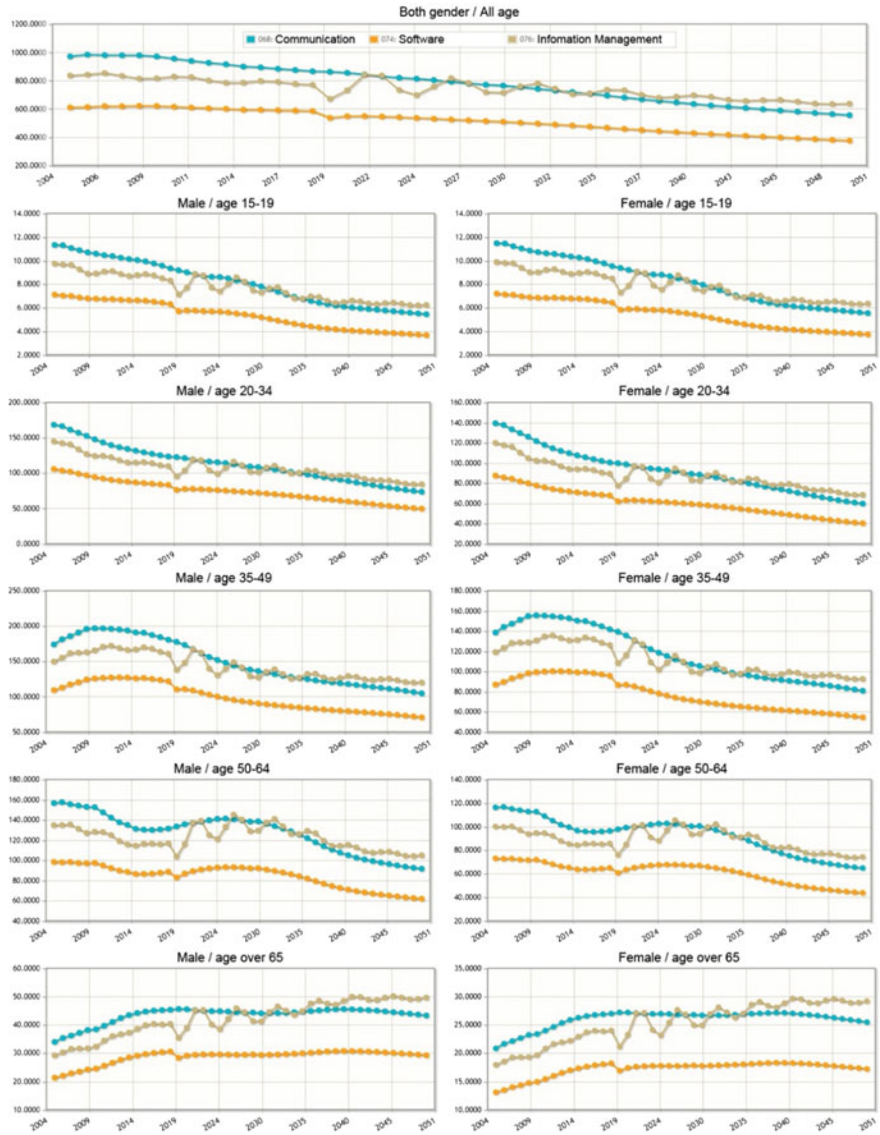

Fig. 6 Sectoral employment change (unit: person). *Source* GRIPS SciREX Center SPIAS-e

In the group of younger age 15–34, the trend has been decreasing mainly due to the shrinking population; whereas in categories of age over 65-year old, the share of employment continue to growth, implying that the ICT and R&D investment could stimulate the employment for the whole generation and sustain the employment till their silver age. The information management service overtook the information and communication sectors in a longer term.

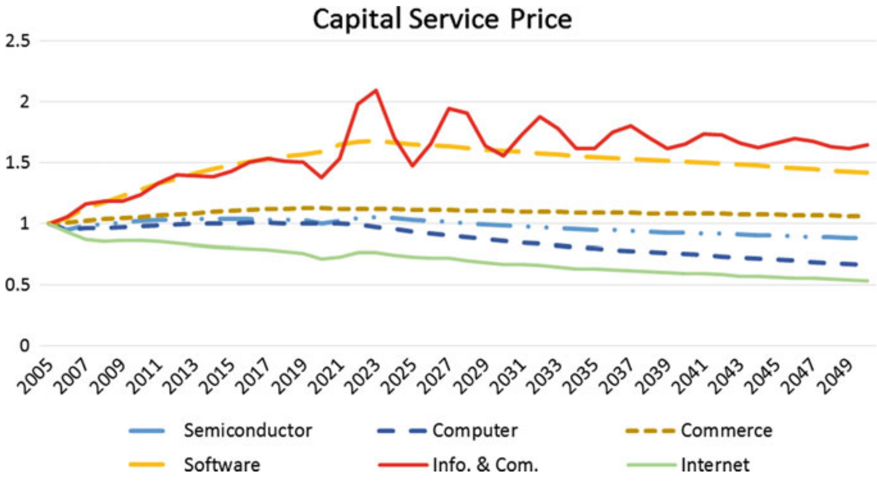

Fig. 7 Capital service price index. *Source* GRIPS SciREX Center SPIAS-e

Comparing the capital service price among six sectors that highly related to the ICT/IoT (Fig. 7), sectors such as Software and Information and Communication showed a vibrant growth while computer and semiconductor revealed decrease, most of all in Internet sector. On other hand, commerce remained steady with only very slight improvement. This comparison showed that the new platform created in the new society will be mainly led by information revolution while software and information management service will have most significant role. These newly boomed sectors may overtake the traditional commercial mode; nevertheless, they may well face drastic business cycle, which actually reflecting the current situation of SNS platform. In spite of its essential role supporting the new platform base, the Internet sector will just become a basic provision and thus no more additional surplus granted.

4.6 Disguised Unemployment and Work Sharing

Under the current model structural and predetermined inter-temporal formula, with the assumption of fully employment. The declining labor supply, especially in working hour may imply that much labor-intensive chores, could be done by senior citizen with the support of ICT and robot. The fact of less working hour and the substitute of man labor by ICT and event robot for "working sharing," creating another phenomenon of "disguised unemployment."

By comparing the divisions of employment multiplying real hourly wage between BAU and policy option, Fig. 8 shows the trend of disguised unemployment in the three categories. The declining number of intra-ICT indicated the

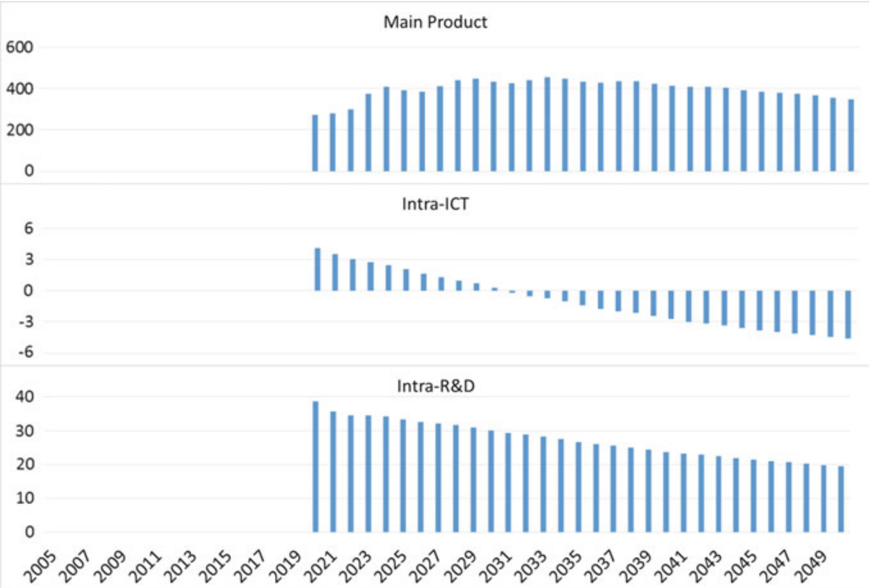

Fig. 8 Disguised unemployment in three categories (unit: thousand people). *Source* GRIPS SciREX Center SPIAS-e

massive demand of employment in such sector, while main product and intra-R&D only decrease in a mild pace.

Up to date in 2018, a decent job regarded a reasonable work is 8 h a day (40 h weekly or 1775 h annually). With higher production efficiency led by the technology advancement, declining working hour is foreseeable in the very near future, just as the implementation of two-day weekend and holiday system in the twentieth century. The simulation results provided the motivation by social needs and through innovation that provides feedback to current social economy and leads new social economy. With less working and more leisure time, leaving human being more freedom to consider complicated issues for achieving a sustainable socio-economy under more newly established service platforms. The improvement of work and life balance could contribute to quality of life (QoL) improvement.

5 Concluding Remarks

The impact assessment and evaluation of STI policy options have been regarded top priority for Japanese government to allocate its budget efficiently and effectively. The simulation results calculated by SPIAS-e illustrate a possible picture of Japan's development under a society of aging and shrinking population. It is implied that various system and reforms should be established to cope with the change of social structure as well as the new service platforms. The SPIAS-e is not only an evidence-based, user-friendly tool but mostly it demonstrates a platform to understand the process and socioeconomic change among “good translational relationship” between natural and social and humanity sciences.

Based on the 2008SNA, the new IO table compilation of R&D will help to make more accurate STI policy recommendations. With the development of the system and more precise calibrations on the technologies, the quantified and visualized results could assist policymaking. An important and necessary condition is to create “policy options” with consistency and accountability to redesign the new social and economic structures. SPIAS-e is expected to help policymakers better understand the substitution between machine and unskilled labor, and the expansion of income differences domestically and internationally.

While the recent rapid improvement of *AI* and *Big-Data* is contributing to the effective collection of data that will help us redefining neoclassical economics for obtaining sustainable development. Confronting the challenges of aging society with shrieking population, the lack of effective demand should be solved by continuously created platform of knowledge-based open innovation so that such unstable conflicts among countries with perception gaps could be observed and overcome.

Appendixes

Appendix 1: SPIAS-e Architecture

SPIAS-e is a Web-based system consisting of (1) economic model module by Java languages and (2) front-end/visualization module by Python 3.x Language. The data are stored in MySQL (compatible MariaDB) Database and running in Linux/ Windows OS environment.

Initially, user could set policy parameter (a) R&D expenditure in six categories for both public and private sectors and (b) short-term and long-term sectoral productivity (classified in Table 3) through Web browser and other exogenous variables are stored in *csv* format. After initialization, front-end modules call economic model module in parallel with policy parameter.

In the simulation process, economic model module stores macro-data into MySQL database, and front-end module fetches yearly GDP data. After completion of economic simulation, economic model module returns simulated endogenous and exogenous variables (listed in Appendix 2) and those are stored into MySQL DB (Fig. 9).

Table 3 Sector classification

No.	Sector	No.	Sector
1	Agriculture (main products, ICT activity)	49	Robot (intra-firm R&D activity)
2	Agriculture (intra-firm R&D activity)	50	Precise machinery (main products)
3	Mining (main products, ICT activity)	51	Precise machinery (intra-firm ICT activity)
4	Mining (intra-firm R&D activity)	52	Precise machinery (intra-firm R&D activity)
5	Food (main products)	53	Petroleum, coal (main products)
6	Food (intra-firm ICT activity)	54	Petroleum, coal (intra-firm ICT activity)
7	Food (intra-firm R&D activity)	55	Petroleum, coal (intra-firm R&D activity)
8	Synthetic (main products)	56	Miscellaneous manufacturing (main products)
9	Synthetic (intra-firm ICT activity)	57	Miscellaneous manufacturing (intra-firm ICT activity)
10	Synthetic (intra-firm R&D activity)	58	Miscellaneous manufacturing (intra-firm R&D activity)
11	Pulp, paper (main products)	59	Energy manufacturing (main products)
12	Pulp, paper (intra-firm ICT activity)	60	Energy manufacturing (intra-firm ICT activity)
13	Pulp, paper (intra-firm R&D activity)	61	Energy manufacturing (intra-firm R&D activity)
14	Chemical (main products)	62	Construction (main products)
15	Chemical (intra-firm ICT activity)	63	Construction (intra-firm ICT activity)
16	Chemical (intra-firm R&D activity)	64	Construction (intra-firm R&D activity)
17	Material (main products)	65	Transportation (main products)
18	Material (intra-firm ICT activity)	66	Transportation (intra-firm ICT activity)
19	Material (intra-firm R&D activity)	67	Transportation (intra-firm R&D activity)
20	Machinery (main products)	68	Communication (main products)
21	Machinery (intra-firm ICT activity)	69	Communication (intra-firm ICT activity)
22	Machinery (intra-firm R&D activity)	70	Communication (intra-firm R&D activity)
23	Electronic devices (main products)	71	Commerce (main products)
24	Electronic devices (intra-firm ICT activity)	72	Commerce (intra-firm ICT activity)
25	Electronic devices (intra-firm R&D activity)	73	Commerce (intra-firm R&D activity)

(continued)

Table 3 (continued)

No.	Sector	No.	Sector
26	Fiber-optical cable (main products)	74	Software (main products)
27	Fiber-optical cable (intra-firm ICT activity)	75	Software (intra-firm R&D activity)
28	Fiber-optical cable (intra-firm R&D activity)	76	Info. mgmt. (main products)
29	Semiconductor manufacturing (main products)	77	Info. mgmt. (intra-firm R&D activity)
30	Semiconductor manufacturing (intra-firm ICT activity)	78	Internet (main products)
31	Semiconductor manufacturing (intra-firm R&D activity)	79	Internet (intra-firm R&D activity)
32	Communication devices (main products)	80	Medical, welfare services (main products)
33	Communication devices (intra-firm ICT activity)	81	Medical, welfare services (intra-firm R&D activity)
34	Communication devices (intra-firm R&D activity)	82	Education (main products)
35	Computing equipment (main products)	83	Education (intra-firm R&D activity)
36	Computing equipment (intra-firm ICT activity)	84	R&D life science (Public, nonprofit)
37	Computing equipment (intra-firm R&D activity)	85	R&D information communication (public, nonprofit)
38	Semiconductor devices (main products)	86	R&D materials (public, nonprofit)
39	Semiconductor devices (intra-firm ICT activity)	87	R&D ecology, energy (public, nonprofit)
40	Semiconductor devices (intra-firm R&D activity)	88	R&D miscellaneous (industry)
41	Electronic component (main products)	89	R&D life science (industry)
42	Electronic component (intra-firm ICT activity)	90	R&D information communication (industry)
43	Electronic component (intra-firm R&D activity)	91	R&D materials (industry)
44	Heavy machinery, transportation equipment (main products)	92	R&D ecology, energy (industry)
45	Heavy machinery, transportation equipment (intra-firm ICT activity)	93	R&D miscellaneous (industry)
46	Heavy machinery, transportation equipment (intra-firm R&D activity)	94	Miscellaneous service (main products)
47	Robot (main products)	95	Miscellaneous service (intra-firm R&D activity)
48	Robot (intra-firm ICT activity)		

Table 4 Breakdown of value add

Abbreviation	Content
BCT	Household expenditure in *t*-period
YE	Total employer income
YSEFW	Income of employer and family workers
OS	Potential output
DEPK	Tangible capital depreciation provision
DEPKN	Intangible capital depreciation provision
DEPKITE	Tangible capital depreciation provision on ICT activity
DEPKRDE	Intangible capital depreciation provision on R&D activity
DEPKPI	Tangible capital depreciation provision on main product activity
DEPKNITE	Intangible capital depreciation provision on ICT activity
DEPKNRDE	Tangible capital depreciation provision on R&D activity
DEPKNPI	Intangible capital depreciation provision on main product activity
TKAN	Indirect tax
HOJO	Operation surplus

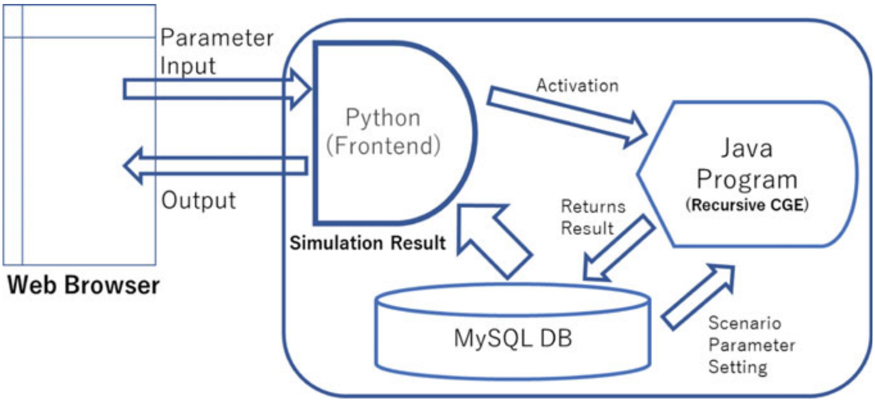

Fig. 9 Structure and illustration of MySQL DB

Appendix 2: List of Variables

Variable Subscripts

$a(1, \ldots, 5)$: age range
1: 15–19, 2: 20–34, 3: 35–5, 4: 51–64, 5: over 65.
i, j $(1, \ldots, 93)$: Product
$o(1, \ldots, 3)$: Category of intra-firm activity
1: Main products, 2: Intra-firm ICT activity, 3: Intra-firm R&D activity.

Agriculture and fishery, mining, software, information management and service, Internet, other service, intra-firm ICT activity including two kinds of product, the public R&D activity without occupation classification

$s(M, F)$: M: male, F: female
t (1, …, T): period
$\theta(1, \ldots, 5)$: R&D classification of purpose.
Public R&D activity is classified into five sectors as well as private R&D sector.

Exogenous Variables

a_{ij}^{DINVK}: j-sector, o = 1 (main products) nominal input share of i-capital goods

a_{ij}^{MINVK}: j-sector, o = 1 (main products) nominal input share of i-capital goods

$a_{ij}^{DINVKITE}$: j-sector, o = 2 (intra-firm ICT activity) nominal input share of i-capital goods

$a_{ij}^{MINVKITE}$: j-sector, o = 2 (intra-firm ICT activity) nominal input share of i-capital goods

$a_{ij}^{DINVKRDE}$: j-sector, o = 2 (intra-firm ICT activity) nominal input share of i-capital goods

$a_{ij}^{MINVKRDE}$: j-sector, o = 2 (intra-firm ICT activity) nominal input share of i-capital goods
e: Exchange rate (¥/$)
h^*: Regular working hour

IM_i^{CIF}: Import

$Kj^{GN\theta t}$: Intangible capital stock of public R&D activity in t-period (classified in θ purpose)
LC_j: Current compensation
LC_{SEYj}: Self-employed income
LC_{FWYj}: Income of family worker

LC^R: Income of oversea employee
N^t: Population
PC^R: Net asset income from oversea

$P^{BCTt}BC_T^t$: Nominal household expenditure in t-period
$P_i^{Ex}\ Ex_i$: Export (final demand block)

$P^{GC}C^G$: Government expenditure

$P^{GDEP}GDEP_T$: Social cost depreciation

$P^{GI}I^G$: Public tangible capital formation (excluding R&D investment)

$P_j^{INVKG}KG_j$: Public R&D activity investment (Classified in θ purpose)

$P_j^{INVKG\theta}\ K_j$: Public tangible capital formation R&D activity (Classified in θ purpose)

$P_j^{INVKN\theta}$ KNG_j: Public intangible capital formation R&D activity (Classified in θ purpose)

$P_\theta^{INVKNGt}$ KNG_θ^t: Public nominal R&D investment in t-period (Classified in θ purpose)

$P_\theta^{INVKNEt}$ KNE_θ^t: Private nominal R&D investment in t-period (Classified in θ purpose)

P_i^M M_i: Import (final demand block)

P_i^m: Price of intermediate import goods of i-sector

P_j^{mt+1}: Price of import goods from j-sector

P_j^{MIT}: Price function of aggregate intermediate import goods of intra-firm ICT activity in j-sector

P_j^{MRD}: Price function of aggregate intermediate import goods of intra-firm R&D activity in j-sector

P_T^Z Z_T: Net capital stock

r^*: Average interest rate in capital market
SS^{GP}: Personal social insurance premium by age
SS^{PG}: Personal social insurance payment by age
T^M: Custom tax, tariff
TRC^{PG}: Capital transfer from private to public
TRC^{RP}: Capital transfer from oversea to individual
TRE^{GP}: Net current transfer from public to individual
TRE^{GR}: Net current transfer from public to oversea
TRE^{PR}: Net current transfer from individual to oversea
TRE^{RG}: Net capital transfer from oversea to public
TRE^{RP}: Net capital transfer from oversea to individual
W: World trade volume

weight_j^{Et*}: Cost share of employee wage on j-sector at the start of t-period

weight_j^{SEFWt*}: Cost share of self-employed and family worker wage on j-sector at the start of t-period

X_j^{*t+1}: Assumed demand of j-sector
Y: Assumed gross output
Z: Net capital stock (nominal)
δ_j: Capital depreciation on main products of j-sector

δ_j^{KIT}: Capital depreciation on intra-firm ICT activity of j-sector

δ_j^{KPE}: Capital depreciation on intra-firm R&D activity of j-sector

δ_j^{KN}: Intangible Capital depreciation of j-sector

τ^C: Consumption tax rate
τ^I: Net indirect tax rate

τ^K: Capital income tax rate (investment revenue tax rate) on tangible capital (main product)

τ^{KIT}: Capital income tax rate (investment revenue tax rate) on tangible capital (intra-firm ICT activity)

τ^{KPE}: Capital income tax rate (investment revenue tax rate) on tangible capital (intra-firm R&D activity)

τ^{KN}: Capital income tax rate (investment revenue tax rate) on intangible capital (main product)

τ^{SKPIN}: Capital income tax rate (investment revenue tax rate) on intangible capital (intra-firm ICT activity)

τ^{KNE}: Capital income tax rate (investment revenue tax rate) on intangible capital (intra-firm R&D activity)

τ^L: Personal income tax rate

τ_i^M: Custom tax, tariff rate

τ^P: Fixed asset tax rate

τ^{PKN}: Fixed asset tax rate on tangible capital (main products)
τ^{PIT}: Fixed asset tax rate on tangible capital (intra-firm ICT activity)
τ^{PPE}: Fixed asset tax rate on tangible capital (intra-firm R&D activity)

Endogenous Variables

a_{ij}^d: Input share of nominal domestic intermediate *i*-goods on *j*-sector at the beginning

a_{ij}^m: Input share of nominal import intermediate *i*-goods on *j*-sector at the beginning

a_j^{DD}: Input share of nominal domestic intermediate goods on *j*-sector at the beginning

a_j^{MM}: Input share of nominal import intermediate goods on *j*-sector at the beginning

a_{ij}^{d*}: Input coefficient of intermediate input on domestic goods

a_{ij}^{m*}: Input coefficient of intermediate input on import goods

AN^t: Labor force
AN_{as}^t: Labor force by age (a = 1, …, 5), gender (Survey on employment structure[1])
Labor force = Employed person + Job seeker (among unemployed person)
Employed person = Full-time employee + Part-time employee
Unemployed person = Work applicant (job seeker) + Non-work applicant
BC_j: Household expenditure
BS_j: Capital cost of *j*-sector

[1]Based on the population distribution of Japan's Employment Status Survey. http://www.stat.go.jp/english/data/shugyou/

C_j^*: Long-term cost function of *j*-sector

C_j^{L*}: Total employment cost of *j*-sector

DEP_j: Capital depreciation provision of *j*-sector

DEP_j^{KITE}: Tangible capital depreciation provision on intra-firm ICT activity of *j*-sector

DEP_j^{KNITE}: Intangible capital depreciation provision on intra-firm ICT activity of *j*-sector

DEP_j^{KNRDE}: Tangible capital depreciation provision on intra-firm R&D activity of *j*-sector

DEP_j^{KRDE}: Intangible capital depreciation provision on intra-firm R&D activity of *j*-sector

DEP_j^{PK}: Tangible capital depreciation provision of *j*-sector

DIV_j: Dividends of *j*-sector

ED_{jas}^t: Demand for employment of *j*-sector by age, gender in *t*-year

ES_{as}^t: Supply of employment by age, gender in *t*-year[2]
FW_{as}^t: Family workers by age and gender in *t*-year

$g(\cdot)$: Formula of technology improvement
h_j: Working hours on *j*-sector
h_j: Actual working hour
$INVK_j$: Tangible capital formation on *j*-sector (real)
$INVKN_j$: Intangible capital formation on *j*-sector (real)
IY_{jSEFW}^t: Self-employed, family worker income per person
K_j: Tangible capital stock of main product of *j*-sector is endogenous at the start of time period as long-term selection. In the main product sectors, the tangible capital stock is endogenous. From tangible capital to capital service, the capital stock ratio is following the assumption of $SK_j^t = K_j^t$
KC_j: Capital revenue
KG_j: Sectoral public tangible capital stock, public R&D sectors (j = 82–86)
KPI_j: Private R&D on tangible capital stock of *j*-sector

$KNG^{\theta t}$, $KNPI^{\theta t}$: Intangible public and private capital stock on R&D sector (by θ purpose) at the start of *t*-period
$KNITE_j$: Intangible capital stock of intra-firm ICT activity of *j*-sector
$KNRDE_j$: Intangible capital stock of intra-firm R&D activity of *j*-sector
$KNPI_j$: Private intangible capital stock of intra-firm R&D activity of *j*-sector
L_j: Number of employment in *j*-sector
$LITE_j$: Number of ICT-related employment in *j*-sector

[2]It is given exogenously. While in the Employment Status Survey, the distribution of employer is sourced from the employment matrix of input–output table by product sector. In addition, the number of employer is accessible from the distribution table in the Employment Status Survey.

$LRDE_j$: Number of R&D-related employment in j-sector
L_j^*: Labor input of j-sector predetermined by long-term production block
MITE: Aggregate of domestic and import intermediate goods of intra-firm ICT activity
MNE: Aggregate of domestic and import intermediate goods of intra-firm R&D activity
MR_j: Marginal short-term income of j-sector
N_{as}: Population by age (a = 0, 1,…, 5) and gender (s = M, F)
P: Current price level
P^{BCT}: Price of household expenditure
P_T^C: Price function of aggregate consumption goods

P_j^d: Price of domestic goods of j-sector in current period

P_i^{dc}: Price after consumption tax

P_{ij}^{DMt}: Price of good and service determined by the equilibrium of short-term good and service market. In the assumption of competitive input–output table, the import price P_i^{mt} of i-sector is set as exogenous variable.

P^{Et}: Aggregate price of employed labor service by gender and age of current period. The price of labor service is determined by the technology choice of the next time period as well as the equilibrium of labor market; with the technology choice, the price of labor service is predetermined at the start of current period.

P_j^{Et}: Labor service price employed in j-sector at current period, predetermined endogenously. The price gaps exist in sectors such as agriculture, mining, manufacturing (main product, organizational, ICT activity, intra-firm R&D activity), energy, service (main product, organization, ICT activity, intra-firm R&D activity), public, private R&D.

P_{jas}^{Et}: Wage by age (a = 1,…, 5) and gender (s = M, F) of j-sector

P_j^{INVK}: Price of capital investment good of tangible capital formation of j-sector. Aggregated from the share weight of investment price (aggregate price of domestic and import good) in the matrix of tangible capital. The price of investment good of tangible capital formation of public R&D j-sector () and private R&D sector is also calculated according to share weight of tangible capital matrix, as well as determined by the short-term equilibrium of good and service market.

P_j^{INVKIT}: Price of capital investment good in tangible capital formation of intra-firm ICT activity of j-sector

P_j^{INVKPE}: Price of capital investment good in tangible capital formation of intra-firm R&D activity of j-sector

P_j^{INVKNE}, $P_j^{INVKNG\theta t}$, $P_j^{INVKNPIt}$: Price of intangible capital investment good of price intra-firm R&D activity, public R&D sector (θ), private R&D sector (θ), determined by short-term equilibrium of goods and service market.

P_j^{DIT}: Aggregate price function of domestic intermediate goods of intra-firm ICT activity of j-sector

P_j^{DRD}: Aggregate price function of domestic intermediate goods of intra-firm R&D activity of j-sector

P_j^{MIT}: Aggregate price function of import intermediate goods of intra-firm ICT activity of j-sector

P_j^{MRD}: Aggregate price function of import intermediate goods of intra-firm R&D activity of j-sector

P_j^{DMIT}: Aggregate price function of intermediate input of intra-firm ICT activity of j-sector

P_j^{DMRD}: Aggregate price function of intermediate input of intra-firm R&D activity of j-sector

P_j^{L}: Price of labor service of j-sector

P_j^{LIT}: Price of labor service of intra-firm ICT activity of j-sector

P_j^{LNG*}: Price of labor service predetermined by long-term production block of j-sector

P_j^{LRD}: Price of labor service of intra-firm R&D activity of j-sector

P_i^{mc}: Import price after consumption tax

P_j^{Mt}: Price of intermediate good determined by the process of short-term equilibrium in goods and service market of j-sector in current period

P_j^{Set}: Average income per employer of j-sector in current period

P_j^{Set}: Average income per family worker of j-sector in current period

P_j^{SEFWt*}: Price of labor service per employer or family worker of j-sector in t-year ($IY^t_{jSEFW/}\, h^*$)

P_j^{SK}: Price of tangible capital service of j-sector

P_j^{SKt}, $P_j^{SKG\theta t}$, $P_j^{SKPI\theta t}$: Price of tangible capital service of j-sector. The price is derived from the tangible capital investment price, function of rate of return/ depreciation of capital. Among them, the price of tangible capital service of public R&D sector (θ) and private R&D sector (θ) is corresponded with special purpose R&D activity (θ).

P_j^{SKIPI}: Price of tangible capital service in private R&D of j-sector

P_j^{SKIT}: Price of tangible capital service of intra-firm ICT activity of j-sector

P_j^{SKK}: Price of tangible capital service input (SK_j+ $SKPE_j$) of j-sector

P_j^{SKNE}: Price of intangible capital service in intra-firm R&D of j-sector

$P_\theta^{SKNE\mathrm{t}}$, $P_\theta^{SNG\mathrm{t},}$ $P_\theta^{SKNPI\mathrm{t}}$: Price of intangible capital service of intra-firm R&D activity, public R&D sector (θ), and private R&D sector (θ). With the respect to the intangible capital stock in the different R&D activity, the capital service price is derived from the intangible capital investment price, function of rate of return/ depreciation of capital.

P_j^{SKNG}: Price of intangible capital service in public R&D of j-sector

P_j^{SKNPI}: Price of intangible capital service in private R&D of j-sector

P_j^{SKPE}: Price of tangible capital service of intra-firm R&D activity of j-sector

Q_j: Potential output of j-sector in the period

r_j^K: Rate of capital return on tangible capital (main products and organizational activity)

r_j^{KIT}: Rate of capital return on tangible capital (intra-firm ICT activity)

r_j^{KNE}: Rate of capital return on tangible capital (intra-firm R&D activity)

r_j^{KPI}: Rate of capital return on private R&D tangible capital

r_j^{KNPI}: Rate of capital return on private R&D intangible capital

r_j^{KG}: Rate of capital return on public R&D tangible capital

r_j^{KNG}: Rate of capital return on public R&D intangible capital

r_j^{KN}: Rate of capital return on intangible capital (main product and organizational activity)

r_j^{SKPINN}: Rate of capital return on intangible capital (intra-firm ICT activity)

S^G: Public saving

S^P: Private gross saving

S^PN: Private net saving

SE_{as}^t: Number of employer by age and gender in t-year
SK_j: Tangible capital service of j-sector
SKG_j: Tangible capital service of public R&D of j-sector
SKI_j: Tangible capital service of private R&D of j-sector
SKK_j: Tangible capital service input of j-sector (SK_j+ $SKPE_j$)
$SKITE_j$: Tangible capital service of intra-firm ICT activity of j-sector
$SKNE_j$: Intangible capital service of intra-firm R&D activity of j-sector
$SKNITE_j$: Intangible capital service of intra-firm ICT activity of j-sector
$SKNRDE_j$: Intangible capital service of intra-firm R&D of j-sector
$SKPE_j$: Tangible capital service of intra-firm R&D of j-sector
$SKNG_j$: Intangible capital service of public R&D of j-sector
T^C: Consumption tax revenue
T^G: Gross tax revenue on public sector
T^I: Net indirect tax revenue
T^K: Capital income tax revenue
T^L: Personal tax revenue
T^P: Tax revenue on fixed asset
v_j^K: Cost share function on capital

v_j^L: Cost share function on labor

v_j^M: Cost share function on intermediate input

v_j^X: Cost share function on output

X_j: Output of j-sector

x_{ij}^{DINVK}: Domestic capital investment in original product tangible capital formation of j-sector

x_{ij}^{MINVK}: Import capital investment in original product tangible capital formation of j-sector

$x_{ij}^{DINVKIT}$: Domestic capital investment in intra-firm ICT activity tangible capital formation of j-sector

$x_{ij}^{MINVKIT}$: Import capital investment in intra-firm ICT activity tangible capital formation of j-sector

$x_{ij}^{DINVKPE}$: Domestic capital investment in intra-firm R&D activity tangible capital formation of j-sector

$x_{ij}^{MINVKPE}$: Import capital investment in intra-firm R&D activity tangible capital formation of j-sector

Y: Personal disposable income

Y_{jFW}^t: Income per person of family worker of j-sector at the start of t-year

Y_{jSE}^t: Income per person of employer of j-sector at the start of t-year

YE_j^t: Total employer income of j-sector in t-year

$YSEFW_j^t$: Income of employer and family workers of j-sector in t-year

ΔBP^R: Current gap from oversea (nominal)

ΔIS^G: Fiscal gap of government (nominal)

ΔIS^P: Gap on national saving

${\lambda_{ANas}}^t$: Ratio labor force of age and gender over total labor force in t-year
λ_{ANas}^t= Labor force of age and gender (AN_{as}^t)/Total labor force (AN^t)
λ_{ESas}^t: Ratio of employment by age and gender in t-year
λ_{SEas}^t: Ratio of employer by age and gender in t-year[3]
λ_{SEas}^t= Number of employer (SE_{as}^t)/ labor force (AN_{as}^t)
λ_{FWas}^t: Ratio of family workers by age and gender in t-year
λ_{FWas}^t= Family workers (FW_{as}^t)/Total labor force (AN_{as}^t)
Supply of employment = Employed person + Job seeker
μ_{ESas}^t: Rate of employed person by age and gender ($ES_{as}^{t)}$/Labor force by age and gender (AN_{as}^t)

[3]It is given exogenously. While in the Employment Status Survey, the distribution of family workers is sourced from the employment matrix of input–output table by product sector. In addition, the number of family workers is accessible from the distribution table in the Employment Status Survey.

Appendix 3: Model Formula Structure

The formula structure of the model is derived as follows:
Goods and service demand market (t-period)
j-sector domestic goods and production

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right]\left[\left(\sum_{(i\neq j)} P_i^d a_{ij}^d + \sum_i P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[L_j P_j^L P_j^{L0}/\left\{\alpha_j\left(a_j K_j^{bj} KNITE_j^{cj} KNRDE_j^{dj} KNG_\theta^{ej} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right]\cdot X_j^{(1-\alpha j)/\alpha j}\right] \quad (1)$$

- Intra-firm ICT activity

$$P_j^d\left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right]\left[\left(\sum_{(i\neq j)} P_i^d a_{ij}^d + \sum_i P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[LITE_j P_j^{LITE} P_j^{LITE0}/\left\{\alpha_j\left(a_j KITE_j^{bj} KNITE_j^{cj} KNG_{(\theta=1)}^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right]\cdot X_j^{(1-\alpha j)/\alpha j}\right] \quad (2)$$

- Intra-firm R&D activity

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right]\cdot\left[\sum_{(i\neq j)}\left(P_i^d a_{ij}^d + P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[LRDE_j P_j^{LN} P_j^{LN0}/\left\{\alpha_j\left(a_j KRDE_j^{bj} KNRDE_j^{cj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right]\cdot X_j^{(1-\alpha j)/\alpha j}\right] \quad (3)$$

- Private sector R&D activity

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right]\left[\sum_{(i\neq j)}\left(P_i^d a_{ij}^d + P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[LRDE_j P_j^L P_j^{L0}/\left\{\alpha_j\left(a_j KPI_j^{bj} KNPI_j^{cj} KNRDE_j^{dj} KNG_\theta^{ej} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right]\cdot X_j^{(1-\alpha j)/\alpha j}\right] \quad (4)$$

- Public R&D activity

$$P_j^d = C_j/X_j = \left[\left\{\left(1+\tau_j^I\right)/\left(1-\left(1+\tau_j^I\right)a_{jj}^d\right)\right\}\right] \cdot \left[\sum_{(i \neq j)} P_i^d a_{ij}^d + \sum_i P_i^m a_{ij}^m \right.$$
$$\left. + \left(LNG_j h_j P_j^{LNGt} P_j^{LNG0} + KG_j^t P_j^{SKGt} P_j^{SKG0} + KNG_j^t P_j^{SKNGt} P_j^{SKNG0}\right)/X_j\right] \tag{5}$$

- ICT activity

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right]\left[\left(\sum_{(i \neq j)} P_i^d a_{ij}^d + \sum_i P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[L_j P_j^L P_j^{L0}/\left\{\alpha_j\left(a_j K_j^{bj} KNRDE_j^{cj} KNRDE_j^{dj} KNG_\theta^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right] \cdot X_j^{(1-\alpha j)/\alpha j}\right] \tag{6}$$

- ICT R&D activity

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right] \cdot \left[\sum_{(i \neq j)}\left(P_i^d a_{ij}^d + P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[LRDE_j P_j^{LN} P_j^{LN0}/\left\{\alpha_j\left(a_j KRDE_j^{bj} KNRDE_j^{cj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right] \cdot X_j^{(1-\alpha j)/\alpha j}\right. \tag{7}$$

- Other product activity

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right] \cdot \left[\left(\sum_{(i \neq j)} P_i^d a_{ij}^d + \sum_i P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[L_j P_j^L P_j^{L0}/\left\{\alpha_j\left(a_j K_j^{bj} KNRDE_j^{cj} KNG_\theta^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right] \cdot X_j^{(1-\alpha j)/\alpha j}\right] \tag{8}$$

- Other R&D activity

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\left\{\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right\}\right] \cdot \left[\sum_{(i \neq j)}\left(P_i^d a_{ij}^d + P_i^m a_{ij}^m\right)\right.$$
$$\left. + \left[LN_j P_j^{LN} P_j^{LN0} \Big/ \left\{\alpha_j\left(a_j KRDE_j^{bj} KNRDE_j^{cj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right] \cdot X_j^{(1-\alpha j)/\alpha j}\right] \tag{9}$$

Value-added block
Labor income

$$YE_j^t = E_j^t h_j P_j^{Et} P_j^{E0} \tag{10}$$

$$YSEFW_j^t = IY_{jSEFW}^t\left(SE_j^t + FW_j^t\right) \tag{11}$$

Capital income

$$BS_j^t + DEP_j = P_j^d X_j/\left(1+\tau_j^I\right) - \Sigma_i P_i^d a_{ij}^d X_j - \Sigma_i P_i^m a_{ij}^d X_j - BC_j - LC_j \tag{12}$$

$$P_j^{SK} = (1-\tau^K) r_j^K P_j^{INVKt-1} + \delta_j P_j^{INVKt} - \left(P_j^{INVKt} - P_j^{INVKt-1}\right) + \tau^P P_j^{INVKt-1} \tag{13}$$

$$P_j^{SKITt} = \left(1-\tau^{KIT}\right) r_j^K P_j^{INVKITt-1} + \delta_j P_j^{INVKITt} - \left(P_j^{INVKITt} - P_j^{INVKITt-1}\right) + \tau^{PIT} P_j^{INVKITt-1} \tag{14}$$

$$P_j^{SKPEt} = \left(1-\tau^{KPE}\right) r_j^K P_j^{INVKPEt-1} + \delta_j P_j^{INVKPEt} - \left(P_j^{INVKPEt} - P_j^{INVKPEt-1}\right) + \tau^{PPE} P_j^{INVKPEt-1} \tag{15}$$

$$P_j^{SKN} = (1-\tau^K) r_j^{KN} P_j^{INVKNt-1} + \delta_j^{KN} P_j^{INVKNt} - \left(P_j^{INVKNt} - P_j^{INVKNt-1}\right) + \tau^P P_j^{INVKNt-1} \tag{16}$$

$$P_j^{SKPINt} = \left(1-\tau^{SKPIN}\right) r_j^{SKPINN} P_j^{INVSKPISNt-1} + \delta_j^{KN} P_j^{INVSKPINt} - \left(P_j^{INVSKPINt} - P_j^{INVSKPINt}\right) + \tau^{SKPIN} P_j^{INVSKPINt-1} \tag{17}$$

$$P_j^{SKNE} = \left(1-\tau^K\right) r_j^{KNE} P_j^{INVKNEt-1} + \delta_j^{KNE} P_j^{INVKNEt} - \left(P_j^{INVKNEt} - P_j^{INVKNEt-1}\right) + \tau^P P_j^{INVKNEt-1} \tag{18}$$

$$\begin{aligned} BS_j &= SK_j P_j^{SK} + SKN_j P_j^{SKN} + SKNE_j P_j^{SKE} \\ &= K_j\left\{\left(1-\tau^K\right) r_j^K P_j^{INVKt-1} + \delta_j P_j^{INVKt} - \left(P_j^{INVKt} - P_j^{INVKt-1}\right) + \tau^P P_j^{INVKt-1}\right\} \\ &\quad + KN_j\left\{\left(1-\tau^K\right) r_j^{KN} P_j^{INVKNt-1} + \delta_j^{KN} P_j^{INVKNt} - \left(P_j^{INVKNt} - P_j^{INVKNt-1}\right) + \tau^P P_j^{INVKNt-1}\right\} \\ &\quad + KNE_j\left\{\left(1-\tau^K\right) r_j^{KNE} P_j^{INVKNEt-1} + \delta_j^{KNE} P_j^{INVKNEt} - \left(P_j^{INVKNEt} - P_j^{INVKNEt-1}\right) + \tau^P P_j^{INVKNEt}\right\} \end{aligned} \tag{19}$$

Sectoral capital depreciation

$$DEP_j^{INVK} = \delta_j P^{INVK} K_j \tag{20}$$

$$DEP_j^{INVKN} = \delta_j P^{INVKN} KN_j \tag{21}$$

$$DEP_j^{INVKNE} = \delta_j P^{INVKNE} KNE_j \tag{22}$$

$$DEP_j^{INVKG} = \delta_j P^{INVKG} KG_j \tag{23}$$

$$DEP_j^{INVKGN} = \delta_j P^{INVKGN} KGN_j \tag{24}$$

Sectoral dividends

$$DIV_j = \left(1 - \tau^K\right) BS_j - \tau^P P_j^{INVK} K_j - \tau^P P_j^{INVKN} KN_j - \tau^P P_j^{INVKNE} KNE_j \tag{25}$$

Individual disposable income

$$\begin{aligned} Y &= \left(1 - \tau^L\right) \Sigma_j \left(LC_j + LC_{SEYj} + LC_{FWYj}\right) + \left(1 - \tau^L\right) LC^R \\ &\quad + \Sigma_{j\varepsilon} DIV_j + \left(1 - \tau^P\right) PC^R + TRE^{GP} - TRE^{PR} + SS^{GP} - SS^{PG} + TRC^{RP} - TRC^{PG} \end{aligned} \tag{26}$$

Gross saving and net saving

$$S^P = \left(Y - TRC^{RP} + TRC^{PG}\right) - P^C C \tag{27}$$

$$S^{PN} = S^P - \Sigma_{(j\varepsilon IND)} DEP_j^P \tag{28}$$

$$\begin{aligned} \Delta IS^P &= S^P - \left(\sum_j P_j^{INVK} INVK_j + \sum_j P_j^{INVKN} + INVKN_j + \sum_j P_j^{INVKNE} INVKNE_j\right) \\ &\quad - Z + TRC^{RP} + TRC^{PG} = \Delta BP^R \Delta IS^G \end{aligned} \tag{29}$$

Government block

$$T^L = \tau^L \left\{ \sum_j \left(LC_j + LC_{SEYj} + LC_{FWYj} \right) + LC^R \right\} \tag{30}$$

$$T^K = \tau^K \sum_j KC_j \tag{31}$$

$$T^P = \tau^P \left(\sum_j P_j^{INVK} K_j + PC^R \right) \tag{32}$$

$$T^I = \sum_j \left\{ \left(\tau_j^I / \left(1 + \tau_j^I \right) P_j^d X_j \right) \right\} \tag{33}$$

$$T^C = \left(1 + \tau^C \right) \sum_i P_i^C C_i \tag{34}$$

$$T^M = \sum_i \tau_i^M IM_i^{CIF} \tag{35}$$

$$T^G = T^L + T^K + T^P + T^I + T^C + T^M \tag{36}$$

$$S^G = T^G - TRE^{GP} - TRE^{GR} - P^{GC} C^G - SS^{GP} + SS^{PG} \tag{37}$$

$$\begin{aligned} \Delta IS^G = {} & S^G + TRC^{PG} + TRC^{RG} \\ & - \left(P^{GI} I^G + \sum_{j=82-86} P_j^{INVK} INVK_j + \sum_{j=82-86} P_j^{INVKN} INVKN_j \right) \end{aligned} \tag{38}$$

Product

$$X_i = \sum_j a_{ij}^d X_j + BC_T + CK_i + GC_T + GDEP_T \tag{39}$$

$$\boldsymbol{X} = [\boldsymbol{I} - \boldsymbol{A_d}]^{-1} \boldsymbol{F_d} \tag{40}$$

Product calculation

$$\begin{aligned} X_i = {} & \sum_j a_{ij}^d X_j + BC_T + CK_i + GC_T + GDEP_T + INVKG_i + INVKGN_i \\ & + INVK_i + INVKITE_i + INVKRDE_i + INVKPI_i + INVKN_i + INVKNITE_i \\ & + INVKNRDE_i + INVKNPI_i + Z_T + EX_i + M_i \end{aligned} \tag{41}$$

$$\boldsymbol{X} = [\boldsymbol{I} - \boldsymbol{A_d}]^{-1}\boldsymbol{F_d} \tag{42}$$

Long-term product block
Price function of intermediate goods

$$\ln P_j^{DIT} = \Sigma_i a_j^{dIT} \ln P_i^d \tag{43}$$

$$\ln P_j^{DRD} = \Sigma_i a_{ij}^{dRD} \ln P_i^d \tag{44}$$

$$\ln P_j^{MIT} = \Sigma_i a_{ij}^{mIT} \ln P_i^m \tag{45}$$

$$\ln P_j^{MRD} = \Sigma_i a_{ij}^{mRD} \ln P_i^m \tag{46}$$

$$\ln P_j^{DMIT} = a_j^{DDIT} \ln P_j^{DIT} + a_j^{MMIT} \ln P_j^{MIT} \tag{47}$$

$$\ln P_j^{DMRD} = a_j^{DDRD} \ln P_j^{DRD} + a_j^{MMRD} \ln P_j^{MRD} \tag{48}$$

Price function of aggregate tangible capital and intangible investment goods

$$\ln P_j^{INVK} = \Sigma_i a_i^{DINVK} \ln P_i^d + \Sigma_i a_{ij}^{MINVK} \ln P_i^m \tag{49}$$

$$\ln P_j^{INVKIT} = \Sigma_i a_i^{DINVKIT} \ln P_i^d + \Sigma_i a_{ij}^{MINVKIT} \ln P_i^m \tag{50}$$

$$\ln P_j^{INVKPE} = \Sigma_i a_i^{DINVKPE} \ln P_i^d + \Sigma_i a_{ij}^{MINVKPE} \ln P_i^m \tag{51}$$

$$a_{ij}^{DINVK} = P_i^d x_{ij}^{DINVK} / \left(\Sigma_i P_i^d x_{ij}^{DINVK} + \Sigma_i P_i^m x_{ij}^{MINVK}\right) \tag{52}$$

$$a_{ij}^{MINVK} = P_i^m x_{ij}^{MINVK} / \left(\Sigma_i P_i^d x_{ij}^{DINVK} + \Sigma_i P_i^m x_{ij}^{MINVK}\right) \tag{53}$$

$$a_{ij}^{DINVKIT} = P_i^d x_{ij}^{DINVKIT} / \left(\Sigma_i P_i^d x_{ij}^{DINVKIT} + \Sigma_i P_i^m x_{ij}^{MINVKIT}\right) \tag{54}$$

$$a_{ij}^{MINVKIT} = P_i^m x_{ij}^{MINVKIT} / \left(\Sigma_i P_i^d x_{ij}^{DINVKIT} + \Sigma_i P_i^m x_{ij}^{MINVKIT}\right) \tag{55}$$

$$a_{ij}^{DINVKPE} = P_i^d x_{ij}^{DINVKPE} / \left(\Sigma_i P_i^d x_{ij}^{DINVKPE} + \Sigma_i P_i^m x_{ij}^{MINVKPE}\right) \tag{56}$$

$$a_{ij}^{MINVKPE} = P_i^m x_{ij}^{MINVKPE} / \left(\Sigma_i P_i^d x_{ij}^{DINVKPE} + \Sigma_i P_i^m x_{ij}^{MINVKPE}\right) \tag{57}$$

Price function of aggregate labor service

$$P_j^{Lt+1} = F\left(P_j^L, P_j^{LNPE}, P_j^{LNG}, P_j^{LNPI}\right) \tag{58}$$

Long-term cost function

$$\begin{aligned}\ln \mathrm{C}_j^{*ITE} &= \alpha_j^{ITE0} + \sum_k \alpha_j^{ITEk} \ln P_j^{k*} + \alpha_j^{ITEx} \ln X_j^* + \alpha_j^{ITEt} g\left(KNG_{j(j=83)}^t\right) + (1/2) \sum_k \sum_l \ln \beta_j^{ITEkl} \ln P_j^{k*} \ln P_j^{l*} \\ &+ \sum_k \beta^{ITEkx} \ln P_j^{k*} \ln X_j^* + \sum_k \beta_j^{ITEkt} \ln P_j^{k*} g\left(KNG_{j(j=83)}^t, P\text{-Index}(k)\right)\end{aligned} \tag{59}$$

$$\begin{aligned}\ln \mathrm{C}_j^{RDE*} &= \alpha_j^{RDE0} + \sum_k \alpha_j^{RDEk} \ln P_j^{k*} + \alpha_j^{RDEx} \ln X_j^* + \beta_j^{RDEt} g\left(KNG_j^t\right) + (1/2) \sum_k \sum_l \ln \beta_j^{RDEkl} \ln P_j^{k*} \ln P_j^{l*} \\ &+ \sum_k \beta^{RDEkx} \ln P_j^{k*} \ln X_j^* + \sum_k \beta_j^{RDEkt} \ln P_j^{k*} g\left(KNG_j^t, P\text{-Index}(k)\right)\end{aligned} \tag{60}$$

$$\begin{aligned}\ln \mathrm{C}_j^* = \alpha_j^0 + \sum_k \alpha_j^k \ln P_j^{k*} + \alpha_j^x \ln X_j^* + \alpha_j^t g\left(SKNG_\theta^t, SKNE_j^t\right) + (1/2) \sum_k \sum_l \ln \beta_j^{kl} \ln P_j^{k*} \ln P_j^{l*} \\ + \sum_k \beta^{kx} \ln P_j^{k*} \ln X_j^* + \sum_k \beta_j^{kt} \ln P_j^{k*} g\left(SKNG_\theta^t, SKNE_j^t\right)\end{aligned} \tag{61}$$

Function of technology improvement

$$g\left(SKNG_\theta^t, SKNE_j^t\right) = \mu_j(SKNG_\theta^t + SKNE_j^t)/\{1 + \mu_j(SKNG_\theta^t + SKNE_j^t)\} \tag{62}$$

Share function

$$v_j^K = \partial \ln C_j^* / \partial \ln P_j^{k*} = a_j^k + \sum_i \beta_j^{ki} \ln P_j^{i*} + \beta_j^{kX} \ln X_j^* + \beta_j^{kT} g\left(SKNG_\theta^t, SKNE_j^t\right) \tag{63}$$

$$v_j^L = \partial \ln C_j^* / \partial \ln P_j^{L*} = a_j^L + \sum_i \beta_j^{Li} \ln P_j^{i*} + \beta_j^{LX} \ln X_j^* + \beta_j^{LT} g\left(SKNG_\theta^t, SKNE_j^t\right) \tag{64}$$

$$v_j^M = \partial \ln C_j^* / \partial \ln P_j^{M*} = a_j^M + \sum_i \beta_j^{Mi} \ln P_j^i + \beta_j^{MX} \ln X_j^* + \beta_j^{kT} g\left(SKNG_\theta^t, SKNE_j^t\right) (i = K, L, M) \tag{65}$$

$$v_j^X = \partial \ln C_j^* / \partial \ln X_j^{k*} = \alpha_j^X + \Sigma_i \beta_j^{kX} \ln P_j^i + \beta_j^{XX} \ln X_j^* + \beta_j^{XT} g\left(K^{GNt+1}\right) \tag{66}$$

Output

$$K_j^* = v_j^K \left(C_j^* / \left(P_j^{K*} P_j^{K0} \right) \right) (j = 1, \ldots, n) \tag{67}$$

$$L_j^* = v_j^L \left(C_j^* / \left(P_j^{L*} P_j^{L0} \right) \right) / h_j^* (j = 1, \ldots, n) \tag{68}$$

$$a_{ij}^d = V_{ij}^d P_j^d / P_i^d \quad (i, j = 1, \ldots, n) \tag{69}$$

$$a_{ij}^m = V_{ij}^m P_j^d / P_i^m \quad (i, j = 1, \ldots, n) \tag{70}$$

Current rate of return

$$r_j^K = \left[\frac{BS_j - \left\{ \left\{ \begin{array}{c} K_j\left\{ \delta_j P_j^{INVKt} - \left(P_j^{INVKt} - P_j^{INVKt-1} \right) + \tau^P P^{INVKt-1} \right\} \\ + KRDE_j \left\{ \delta_j^{KRDE} P_j^{INVKRDEt} - \left(P_j^{INVKRDEt} - P_j^{INVKRDEt-1} \right) + \tau^{PKRDE} P^{INVKRDEt-1} \right\} \\ + KITE_j \left\{ \delta_j^{KITE} P_j^{INVKITEt} - \left(P_j^{INVKITEt} - P_j^{INVKITEt-1} \right) + \tau^{PKITE} P^{INVKITEt-1} \right\} \\ + KN_j \left\{ \delta_j^{KN} P_j^{INVKNt} - \left(P_j^{INVKNt} - P_j^{INVKNt-1} \right) + \tau^{PKN} P^{INVKNt-1} \right\} \\ + KNRDE_j \left\{ \delta_j^{KNRDE} P_j^{INVKNRDEt} - \left(P_j^{INVKNRDEt} - P_j^{INVKNRDEt-1} \right) + \tau^{PKNRDE} P^{INVKNRDEt-1} \right\} \\ + KNITE_j \left\{ \delta_j^{KNITE} P_j^{INVKNITEt} - \left(P_j^{INVKNITEt} - P_j^{INVKNITEt-1} \right) + \tau^{PKNITE} P^{INVKNITEt-1} \right\} \end{array} \right\} \right\}}{\begin{array}{c} K_j (1 - \tau^K) P_j^{INVKt-1} \\ + KRDE_j (1 - \tau^{KRDE}) P_j^{INVKRDEt-1} \\ + KITE_j (1 - \tau^{KITE}) P_j^{INVKITEt-1} \\ + KN_j (1 - \tau^{KN}) P_j^{INVKNt-1} \\ + KNRDE_j (1 - \tau^{KNRDE}) P_j^{INVKRDEt-1} \\ + KNITE_j (1 - \tau^{KNITE}) P_j^{INVKNITEt-1} \end{array}} \right] \tag{71}$$

Expected rate of return of next period

$$r_j^{*K} = f\left(r, r_j^K \right) \tag{72}$$

Price function of aggregate capital service

$$PSK_j^t = F\left(P_j^{SKt} \cdot P_j^{SKNPlt} \right) \tag{73}$$

$$P_j^{SKt} = \left(1 - \tau^K\right) r_j^K P_J^{INVKt-1} + \delta_j P_j^{INVKt} - \left(P_j^{INVKt} - P_j^{INVKt-1} \right) + \tau^P P^{INVKt-1} \tag{74}$$

$$P_j^{SKITEt} = \left(1 - \tau^{KITE}\right) r_j^K P_J^{INVKITEt-1} + \delta_j P_j^{INVKITEt} - \left(P_j^{INVKITEt} - P_j^{INVKITEt-1}\right) + \tau^{PITE} P^{INVKITEt-1} \quad (75)$$

$$P_j^{SKRDEt} = \left(1 - \tau^{KRDE}\right) r_j^{KRDE} P_J^{INVKRDEt-1} + \delta_j P_j^{INVKRDEt} - \left(P_j^{INVKRDEt} - P_j^{INVKRDEt-1}\right) + \tau^{PRDE} P^{INVRDEt-1} \quad (76)$$

$$P_j^{SKNt} = \left(1 - \tau^{KN}\right) r_j^K P_J^{INVKNt-1} + \delta_j P_j^{INVKNt} - \left(P_j^{INVKNt} - P_j^{INVKNt-1}\right) + \tau^{PKN} P^{INVKNt-1} \quad (77)$$

$$P_j^{SKNITEt} = \left(1 - \tau^{KNITE}\right) r_j^{KNITE} P_J^{INVKNITEt-1} + \delta_j^{KNITE} P_j^{INVKNITEt} - \left(P_j^{INVKNITEt} - P_j^{INVKNITEt-1}\right) + \tau^{PKNITE} P^{INVKNITEt-1} \quad (78)$$

$$P_j^{SKNRDEt} = \left(1 - \tau^{KNRDE}\right) r_j^{KNRDE} P_J^{INVKNRDEt-1} + \delta_j^{KNRDE} P_j^{INVKNRDEt} - \left(P_j^{INVKNRDEt} - P_j^{INVKNRDEt-1}\right) + \tau^{PSKNRDE} P^{INVSKNRDEt-1} \quad (79)$$

Capital cost

$$\begin{aligned} BSj &= SKjPSKj + SKPEjPSKPEj + SKITjPSKITj + SKNEjPSKNEj \\ &= K_j\left\{(1-\tau^K) r_j^K P_j^{INVKt-1} + \delta_j P_j^{INVKt} - \left(P_j^{INVKt} - P_j^{INVKt-1}\right) + \tau^P P^{INVKt-1}\right\} \\ &+ KPE_j\left\{\left(1-\tau^{KPE}\right) r_j^K P_j^{INVKPEt-1} + \delta_j^{KPE} P_j^{INVKPEt} - \left(P_j^{INVKPEt} - P_j^{INVKPEt-1}\right) + \tau^{PKPE} P^{IKVKPEt-1}\right\} \\ &+ KIT_j\left\{\left(1-\tau^{KIT}\right) r_j^K P_j^{INVKITt-1} + \delta_j^{KIT} P_j^{INVKITt} - \left(P_j^{INVKITt} - P_j^{INVKITt-1}\right) + \tau^{PKIT} P^{IKVKITt-1}\right\} \\ &+ KNE_j\left\{\left(1-\tau^{KNE}\right) r_j^K P_j^{INVKNEt-1} + \delta_j^{KNE} P_j^{INVKNEt} - \left(P_j^{INVKNEt} - P_j^{INVKNEt-1} + \tau^{PKNE} P^{INVKNEt-1}\right)\right\} \end{aligned} \quad (80)$$

Short-term supply of goods and service

j-sector product

$$C_j = P_j^d X_j = \left(1 + \tau_j^I\right)\left\{\Sigma_i P_i^d a_{ij}^d X_j + \Sigma_i P_i^m a_{ij}^m X_j + L_j h_j P_j^{Et} P_j^{E0} + IY_{jSEFW}^t (SE_j^t + FW_j^t) + \left(K_j^t + KPE_j^t\right) P_j^{SKKt} P_j^{SKK0}\right\} \quad (81)$$

$$P_j^d X_j / P = \alpha_j^s Y + \beta_j^s W + \gamma_j^s \left(P_j^d / P\right) + \eta_j^s \quad (82)$$

$$MR_j = -P_j^d \left(\gamma_j^s / \left(X_j - \gamma_j^s\right)\right) \quad (83)$$

$$X_j = Q_j h_j^* \left(h_j / h_j^*\right)^{\alpha j} \quad (84)$$

$$Q_j = a_j\left(K_j + KPE_j\right)^{bj} KNE_j^{cj} KNG_\theta^{dj} \tag{85}$$

$$h_j = \left(X_j / a_j\left(K_j + KPE_j\right)^{bj} KNE_j^{cj} KN_\theta^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)} \tag{86}$$

$$\begin{aligned} P_j^d = & \left[\left\{\left(X_j - \gamma_j^s\right)\left(1 + \tau_j^I\right)\right\} / \gamma_j^s\left(\left(1 + \tau_j^I\right) a_{jj}^d - 1\right)\right] \cdot \left[\left(\Sigma_{(i \neq j)} P_i^d a_{ij}^d + \Sigma_i P_i^m a_{ij}^m\right)\right. \\ & \left. + \{L_j P_j^L P_j^{L0} / \left\{\alpha_j\left(a_j\left(K_j + KPE_j\right)^{bj} KNE_j^{cj} KN_\theta^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\} \cdot X_j^{(1-\alpha j)/\alpha j}\right] \end{aligned} \tag{87}$$

Intra-firm ICT activity

$$\begin{aligned} C_j &= P_j^d X_j \\ &= \left(1 + \tau_j^I\right)\{\Sigma_i P_i^d a_{ij}^d X_j + \Sigma_i P_i^m a_{ij}^m X_j + (LIT_j h_j P_j^{LITt} P_j^{LIT0} + KIT_j^t P_j^{SKITt} P_j^{SKIT0}\} \end{aligned} \tag{88}$$

$$P_j^d X_j / P = \alpha_j^s Y + \beta_j^s W + \gamma_j^s\left(P_j^d / P\right) + \eta_j^s \tag{89}$$

$$MR_j = -P_j^d\left(\gamma_j^s / \left(X_j - \gamma_j^s\right)\right) \tag{90}$$

$$X_j = Q_j h_j^*\left(h_j / h_j^*\right)^{\alpha j} \tag{91}$$

$$Q_j = a_j KIT^{bj} KNG_{(\theta=1)}^{dj} \tag{92}$$

$$h_j = \left(X_j / a_j KIT_j^{bj} KNG_j^{cj}{}_{(\theta=1)}^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)} \tag{93}$$

$$\begin{aligned} P_j^d = & \left[\left\{\left(X_j - \gamma_j^s\right)\left(1 + \tau_j^I\right)\right\} / \gamma_j^s\left(\left(1 + \tau_j^I\right) a_{jj}^d - 1\right)\right] \cdot \left[\left(\Sigma_{(i \neq j)} P_i^d a_{jj}^d + \Sigma_i P_i^m a_{jj}^m\right)\right. \\ & \left. + \{LIT_j P_j^{LIT} P_j^{LIT0} / \left\{\alpha_j\left(a_j KIT_j^{bj} KNG_{j(\theta=1)}^{cj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\} \cdot X_j^{(1-\alpha j)/\alpha j}\right] \end{aligned} \tag{94}$$

Intra-firm R&D activity

$$\begin{aligned} C_j = P_j^d X_j = & \left(1 + \tau_j^I\right)\left\{\Sigma_i P_i^d a_{ij}^d X_j + \Sigma_i P_i^m a_{ij}^m X_j + LN_j h_j P_j^{Et} P_j^{E0}\right. \\ & \left. + IY_{jSEFW}^t\left(SE_j^t + FW_j^t\right) + KPE_j^t P_j^{SKPEt} P_j^{SKPE0} + KNE_j^t P_j^{SKNEt} P_j^{SKNE0}\right\} \end{aligned} \tag{95}$$

$$X_j = Q_j h_j^*\left(h_j / h_j^*\right)^{\alpha j} \tag{96}$$

$$Q_j = a_j KNE_j^{bj} \tag{97}$$

$$h_j = \left(X_j / a_j KNE_j^{bj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)} \tag{98}$$

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right.$$
$$\left.\cdot\left[\Sigma_{(i\neq j)}\left(P_i^d a_{ij}^d + P_i^m a_{ij}^m\right) + \left\{LN_j P_j^{LN} P_j^{LN0}/\alpha_j\left(a_j KNE_j^b h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right] X_j^{(1-\alpha j)/\alpha j} a\right] \tag{99}$$

Private R&D activity (STI category)

$$C_j = P_j^d X_j = \left(1+\tau_j^I\right)\left\{\Sigma_i P_i^d a_{ij}^d X_j + \Sigma_i P_i^m a_{ij}^m X_j + E_j h_j P_j^{Et} P_j^{E0}\right.$$
$$\left. + IY_{jSEFW}^t\left(SE_j^t + FW_j^t\right) + KPI_j^t P_j^{SKPIt} P_j^{SKPI0} + KNPI_j^t P_j^{SKNPIt} P_j^{SKNPI0}\right\} \tag{100}$$

$$X_j = Q_j h_j^*\left(h_j / h_j^*\right)^{\alpha j} \tag{101}$$

$$Q_j = a_j KPI_j^{bj} KNPI_j^{dj} \tag{102}$$

$$h_j = \left(X_j / a_j KPI_j^{bj} KNPI_j^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)} \tag{103}$$

$$P_j^d = \left[\left\{\left(X_j - \gamma_j^s\right)\left(1+\tau_j^I\right)\right\}/\gamma_j^s\left(\left(1+\tau_j^I\right)a_{jj}^d - 1\right)\right.$$
$$\left.\cdot\left[_{(i\neq j)}\left(P_i^d a_{ij}^d + P_i^m a_{ij}^m\right) + \left\{E_j P_j^E P_j^{E0}/\alpha_j\left(a_j KPI_j^{bj} KNPI_j^{dj} h^{*(1-\alpha j)}\right)^{(1/\alpha j)}\right\}\right] X_j^{(1-\alpha j)/\alpha j}\right] \tag{104}$$

Public R&D sector (STI category)

$$C_j = P_j^d X_j = \left(1+\tau_j^I\right)\{\Sigma_i P_i^d a_{ij}^d X_j + \Sigma_i P_i^m a_{ij}^m X_j$$
$$+ \left(LN_j^G h_j P_j^{LNGt} P_j^{LNG0} + KG_j^t P_j^{SKGt} P_j^{SKG0} + KNG_j^t P_j^{SKNGt} P_j^{SKNG0}\right) \tag{105}$$

$$P_j^d = C_j / X_j = \left\{\left(1+\tau_j^I\right)/\left(1-\left(1+\tau_j^I\right)a_{jj}^d\right)\right\}\cdot\left[\Sigma_{(i\neq j)} P_i^d a_{ij}^d + \Sigma_i P_i^m a_{ij}^m + (LN_j^G h_j P_j^{LNGt} P_j^{LNG0} +\right.$$
$$\left. + KG_j^t P_j^{SKGt} P_j^{SKG0} + KNG_j^t P_j^{SKNGt} P_j^{SKNG0})/X_j\right] \tag{106}$$

Labor block
Labor force

$$AN_{as}^{t+1} = \lambda_{ANas}^{t+1} \times N_{as}^{t+1} \tag{107}$$

$$SE_{as}^{t+1} = \lambda_{SEas}^{t+1} \times AN_{as}^{t+1} \tag{108}$$

$$FW_{as}^{t+1} = \lambda_{FWeas}^{t+1} \times AN_{as}^{t+1} \tag{109}$$

$$ES_{as}^{t+1} = \left(1 - \lambda_{SEas}^{t+1} - \lambda_{FWeas}^{t+1}\right) \times AN_{as}^{t+1} \tag{110}$$

$$ES_{as}^{t} = \lambda_{ESas}^{t} \times ES_{as}^{t}(a = 1, \ldots, 5), (s = M, F) \text{ while } \lambda_{ESas}^{t} = 1 - \lambda_{SEas}^{t} - \lambda_{FWeas}^{t} \tag{111}$$

Price of labor service

$$P^{Et} = \Sigma_j \Sigma_a \Sigma_s \text{weight}_{jas}^{t} P_{jas}^{Et} \tag{112}$$

$$\text{weight}_{jas}^{t} = P_{jas}^{Et} ED_{jas}^{t} / \Sigma_j \Sigma_a \Sigma_s P_{jas}^{Et} ED_{jas}^{t} \tag{113}$$

$$P_j^{SEFWt*} = IY_{jSEFW}^{t} / h^* = F\left(P^{Et}*\right) \tag{114}$$

Labor wage

$$\begin{aligned} \ln C_j^* = {} & \alpha_j^0 + \Sigma_k \alpha_j^k \ln P_j^{k*} + \alpha_j^x \ln X_j^* + \alpha_j^t g\left(K_j^{GNt+1}\right) + (1/2)\Sigma_k \Sigma_l \ln \beta_j^{kl} \ln P_j^{k*} \ln P_j^{l*} \\ & + \Sigma_k \ln P_j^{k*} \ln X_j^* + \Sigma_k \beta_j^{kt} \ln P_j^{k*} g(K^{GNt+1}) \end{aligned} \tag{115}$$

$$v_j^L = \partial \ln C_j^* / \partial \ln P_j^{Lt*} = \alpha_j^L + \Sigma_l \beta_j^{Ll} \ln P_j^{l*} + \beta_j^{LX} \ln X*_j + \beta_j^{Lx} g(K^{GNt+1}) \tag{116}$$

$$P_j^{Lt*} = weight_j^{Et*} P_j^{Et*} + weight_j^{SEFEt*} P_j^{SEFWt*} \tag{117}$$

$$C_j^{L*} = v_j^L \times C_j^* \tag{118}$$

Wage gap of labor service by gender, age, and occupation

$$P_{jaso}^{Et+1*} = \theta_{Jaso}^{Et+1*} P^{Et*} \tag{119}$$

Determinant of wage and employment level in the next period

$$v_j^L = \partial \ln C_j^* / \partial \ln P_j^{L*} = \alpha_j^L + \Sigma_i \beta_j^{Li} \ln P_j^i + \beta_j^{LX} \ln X_j^* + \beta_j^{LT} g\left(SK^{GNt+1}\right) \tag{120}$$

$$P_j^{Lt+1*} = P_j^{Lt} \tag{121}$$

$$P_j^{Et+1*} = P_j^{Et} \tag{122}$$

$$P_j^{SEFWt+1*} = P_j^{SEFWt} \tag{123}$$

$$P_j^{SKt*} = P_j^{SKt\blacktriangle} \tag{124}$$

$$P_j^{DMt*} = P_j^{DMt\blacktriangle} \tag{125}$$

$$ED_{jas}^{t+1*} = v_{jas}^{L*} \times Y_{jE}^{*t+1} / (P_{jas}^{Et+1*} \cdot h^*) \tag{126}$$

Formula of occupation and industry

$$\ln C_j^* = \alpha_j^0 + \Sigma_k \alpha_j^k \ln P_j^{k*} + \alpha_j^x \ln X_j^* + \alpha_j^t g\left(K_j^{GNt+1}\right) + (1/2)\Sigma_k \Sigma_l \ln \beta_j^{kl} \ln P_j^{k*} \ln P_j^{l*} + \Sigma_k \ln P_j^{k*} \ln X_j^* + \Sigma_k \beta_j^{kt} \ln P_j^{k*} g\left(K^{GNt+1}\right) \tag{127}$$

$$P_j^{SKt*} = \Sigma_o weight_j^{ot} P_j^{oSKt} \tag{128}$$

$$\text{weight}_j^{ot} = P_j^{oSKt} SK_j^{ot} / \Sigma_o P_j^{oSKt} SK_j^{ot} \tag{129}$$

$$P_j^{SKNt*} = \Sigma_o \text{weight}_j^{ot} P_j^{oSKNt} \tag{130}$$

$$\text{weight}_j^{ot} = P_j^{oSKNt} SKN_j^{oNt} / \Sigma_o P_j^{oSKNt} SKN_j^{oNt} \tag{131}$$

$$P_j^{Mt} = \Sigma_o \text{weight}_j^{ot} P_j^{oMt*} \tag{132}$$

$$\text{weight}_j^{ot} = P_j^{oM*} M_j^{oMt} / \Sigma_o P_j^{oM*} M_j^{oMt} \tag{133}$$

$$P_j^{Lt*} = \Sigma_o \text{weight}_j^{ot} P_j^{oLt*} \tag{134}$$

$$\text{weight}_j^{ot} = P_j^{oL*} L_j^{oLt} / \Sigma_o P_j^{oLt*} L_j^{oLt} \tag{135}$$

$$v_j^L = \partial \ln C_j^* / \partial \ln P_j^{Lt*} = \alpha_j^L + \Sigma_l \beta_j^{Ll} \ln P_j^{l*} + \beta_j^{LX} \ln X*_j + \beta_j^{Lx} g\left(K^{GNt+1}\right) \tag{136}$$

$$ED_{as}^{t+1*} = \Sigma_j ED_{jas}^{t+1*} \tag{137}$$

Optimal capital stock in t + 1 period

$$INVK_j = K_j^* - \left(1 - \delta_j^K\right) K_j \tag{138}$$

$$INVKITE_j = KITE_j^* - \left(1 - \delta^{KITE}\right) KITE_j \tag{139}$$

$$INVKRDE_j = KRDE_j^* - \left(1 - \delta^{KRDE}\right) KRDE_j \tag{140}$$

$$INVKPI_j = KPI_j^* - \left(1 - \delta_j^{KPI}\right) KPI_j \tag{141}$$

$$INVKN_j = KN_j^* - \left(1 - \delta_j^{KN}\right) KN_j \tag{142}$$

$$INVKNITE_j = KNITE_j^* - \left(1 - \delta^{KNITE}\right) KNITE_j \tag{143}$$

$$INVKNRDE_j = KNRDE_j^* - \left(1 - \delta^{KNRDE}\right) KNRDE_j \tag{144}$$

$$INVKNPI_j = KNPI_j^* - \left(1 - \delta_j^{KNPI}\right) KNPI_j \tag{145}$$

Investment demand

$$INVK_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVK} P_j^{INVK} INVK_j}{P_i^d} \tag{146}$$

$$INVKITE_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKITE} P_j^{INVKITE} INVKITE_j}{P_i^d} \tag{147}$$

$$INVKRDE_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKRDE} P_j^{INVKRDE} INVKRDE_j}{P_i^d} \tag{148}$$

$$INVKPI_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKPI} P_j^{INVKPI} INVKPI_j}{P_i^d} \tag{149}$$

$$INVKN_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKN} P_j^{INVKN} INVKN_j}{P_i^d} \tag{150}$$

$$INVKNITE_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKNITE} P_j^{INVKNITE} INVKNITE_j}{P_i^d} \tag{151}$$

$$INVKNRDE_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKNRDE} P_j^{INVKNRDE} INVKNRDE_j}{P_i^d} \tag{152}$$

$$INVKNPI_i = \frac{\sum_{j \in IND} \omega_{ij}^{INVKNPI} P_j^{INVKNPI} INVKNPI_j}{P_i^d} \quad (153)$$

Foreign block

$$\Delta IS^R = \Sigma_{(\varepsilon IND)} P_i^d Ex_i - \Sigma_{(I \varepsilon IND)} \left(1 - \tau_i^M\right) IM_i^{CIF} + LC^R + PC^R - TRE^{GR} - TRE^{PR} \quad (154)$$

$$\Delta B^R = \Delta IS^R + TRC^{RC} + TRC^{RP} \quad (155)$$

Final demand block

$$P_i^{dc} = (1 + \tau^C) P_i^d \quad (156)$$

$$P_i^{mc} = (1 + \tau^C) P_i^m \quad (157)$$

$$\ln P_T^C = \Sigma_i \alpha_i^{dC} \ln P_i^{dc} + \Sigma_i \alpha_i^{mC} \ln P_i^{mc} \quad (158)$$

$$C_T = \alpha_c + \beta_c (Y / P_T^C) \quad (159)$$

$$\begin{aligned} F^D &= BC^T + C^T + GC^T + GDEP^T + INVKG^T + INVK^T \\ &\quad + INVKGN^T + INVKVN^T + INVKNE^T + Z^T \end{aligned} \quad (160)$$

$$X^D = \left(I - A + M^D\right)^{-1} (F^D + E^T) \quad (161)$$

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Part III
Service Sector Modelling

The Impact of Presence and Hypothetical Absence of Tourism in Indian Economy

An Input–Output Analysis

Poonam Munjal

Abstract This paper attempts to derive the backward and forward linkages of tourism sector for India, despite the fact that tourism, unlike other sectors, does not fall in the SNA or I-O framework owing to its demand-driven nature of activity. For the first time, tourism is endogenized in the I-O framework using the results of tourism satellite accounts to derive its linkages. Further importance of tourism is explored by presenting these linkages in the system from which tourism is completely extracted or made to disappear. This is done using the hypothetical extraction method (HEM).

Keywords Tourism satellite account · Input–output table · Multiplier analysis Backward and forward linkages · Hypothetical extraction method

JEL Classification L830 · C670 · D570

1 Introduction

Tourism is an important social and economic activity in many countries, some countries depending almost entirely on tourism. It not only earns export revenue but is instrumental in a nation's infrastructure development and also creates jobs and enterprises. Tourism's economic impacts are therefore an important consideration in state, regional and community planning and economic development (Stynes 1997).

However, measuring tourism and its contribution to the national economy are a difficult task since tourism is not defined separately in the standard international industry or product classifications or in the accounting framework of national accounts, which focuses on accounting of economic activities undertaken in the country according to standard international classifications (Kolli et al. 2014). This is

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because of the nature of activity that tourism is. Unlike other producer sectors in the system of national accounts (SNA), tourism is not defined as a producer of a good or service but is defined as a sector whose output is its demand by its purchaser, that is, a tourist. Therefore, tourism sector is not presented explicitly in the national accounts and in the supply and use tables, although its elements are embedded in other sectors of national accounts, like hotels, transport services, food and beverages.

This paper, for the first time, attempts to put tourism as a separate sector in the framework of the supply and use tables and subsequently in the input–output tables using the relevant ratios obtained from the tourism satellite account (TSA) of the economy. By doing this, the interlinkages of tourism sector with other sectors of the economy can be assessed and hence the impact—both direct and indirect—of tourism sector on the economy can be quantified. Also, for the first time for Indian economy, the impact of hypothetical "disappearance" of this sector is realized through the input–output models.

The present paper is structured as follows. Section 2 reviews the literature Sect. 3 presents a brief description of satellite accounts in general and tourism satellite account (TSA) in particular. Section 4 summarizes the methodology adopted in putting the tourism sector into the framework of the input–output table using the outcomes of the TSA and presents its linkages with other sectors of the economy by way of multipliers. Section 6 presents the impact of hypothetical "disappearance" of tourism from the economy. The concluding remarks present the key findings and are given in the last section of the paper.

2 Review of Literature

A number of studies have been undertaken to estimate the economic impact of tourism using various techniques like input–output model, computable general equilibrium (CGE) approach, social accounting matrix, regression analysis. The bulletin paper, "Economic Impacts of Tourism" by Stynes (1997), presents a systematic introduction to economic impact concepts and methods. Many studies also focus on the multiplier impact of tourism. Archer's (1976) input–output model is used for investigating the multiplier effects of tourism expenditure. We know that an input–output analysis provides a method of examining the effect of changes in final demand on the economy's output and its impact on income and employment. Applying the same input–output model in tourism impact study, Archer's model takes tourism sector's total demand as the vector of final demand. A study by Var and Quayson (1985) examines the multiplier impact of tourism in the Okanagan region (British Columbia, Canada) using the Archer tourism multiplier methodology. Other studies measuring the contribution of tourism using the input–output methods for computing tourism multipliers are by Summary (1987), which estimates the tourism's contribution to the economy of Kenya using input–output analysis.

Sugiyarto et al. (2003) in their research article “Tourism and Globalization—Economic Impact in Indonesia” attempted to measure the economic impact of tourism in Indonesia using computable general equilibrium (CGE) approach. The aim of this study is to examine the impact of tourism within the macroeconomic context of globalization in the form of increasing trade liberalization, as well as in the context of lower domestic taxation. Another study that measures economic impacts from tourism using CGE modelling, as well as I-O analysis, is authored by Zhou et al. (1997), in their research paper titled “Estimating Economic Impacts from Tourism”.

One of the first studies to analyse the economic impact of tourism using a social accounting matrix (SAM) was carried out by Wagner (1997). In a discussion paper by Blake et al. (2001), the tourism sector is analysed using the CGE modelling techniques and the tourism satellite accounts (TSAs) are used as the basic data input. A research paper by Raveendran and Saluja (1992), titled “The Economic Impact of Tourism in India”, estimates the impact of tourism on national income and employment. It also estimates the indirect impacts and multiplier effect. But in this study, estimates are obtained without going into details of preparing Tourism Satellite Account.

There is no dearth of literature on measurement of contribution of tourism industry to the economy as a whole. Its impact has also been estimated at large extent. Various techniques have been used to estimate this impact. The input–output analysis has also been used extensively, as discussed in the previous sections. But these studies were carried out mostly on economies other than India. This provided enough motivation to attempt to study the impact of tourism on Indian economy. Apart from this, another motivation was to study the impact of tourism by putting it within the framework of input–output table, and considering it as one of the other production sectors of the economy. In other similar studies, mentioned above, tourism multipliers were obtained using the tourism expenditure as an exogenous account. It was treated as vector of final demand. In contrast, in this study, the tourism sector is endogenized in the input–output framework. The interdependencies of tourism with other sectors can be brought out if tourism is incorporated within the input–output table as a separate entity. It can then be noted how tourism impacts other sectors and how other sectors impact tourism. A similar study (Munjal 2013) was based on India’s first TSA which followed the earlier TSA methodology recommended by UNWTO (2001).

3 Tourism Satellite Account

Satellite accounts help in recasting the national accounts framework in rigorously controlled structures, in order to better understand and analyse special aspects of the economy that may transcend the traditional notion of industries. While the national accounts represent “the books” of the nation’s economy, the satellite accounts are designed to expand the capacity of the national accounts and present the detailed information of the sectors. It focusses on the particular area of interest such as tourism, environment, education, health, transportation.

The tourism satellite account (TSA) is an accounting procedure designed to measure goods and services associated with tourism according to international standards, concepts, classifications and definitions. Hence, the estimates using the TSA framework have the advantage of being credible with the methodology widely accepted and internationally comparable. It is a unique tool to document the direct gross domestic product (GDP) and employment contributions of tourism to national economies. Among the various purposes that can be served by TSA, some are as follows:

- Develop quantitative estimates of tourism value added and tourism employment and, thus, analyse the importance of tourism in the economy;
- Offer a framework for developing impact models of tourism on economic activity and employment by identifying relationships between tourism industries and the rest of the economy;
- Identify capital base of tourism industries;
- Measure productivity within tourism and compare it with other industries.

In order to enable international comparison, the World Tourism Organisation (UNWTO) developed successive sets of international recommendations on tourism statistics. The International Recommendations for Tourism Statistics 2008 (IRTS 2008) provides the basic concepts and definitions concerning the different aspects of tourism by which countries are encouraged to develop their tourism statistics in line with the compilation practices of other economic statistics which are aligned with the Systems of National Accounts 1993. Besides, the tourism satellite account: recommended methodological framework 2008 (TSA: RMF 2008) provides an additional resource to link tourism statistics to the standard tables of SNA 2008.

According to the TSA: RMF 2008, TSA comprises a set of accounts and tables that provides tourism-related macroeconomic aggregates, principal among them being the gross value added of tourism industry (GVATI), tourism direct gross value added (TDGVA) and tourism direct gross domestic product (TDGDP). This helps in assessing the size and contribution of tourism to the economy.

The need for preparing a satellite account for tourism arises particularly because of the demand-based nature of this sector. Tourism sector, unlike other sectors of the system of national accounts, is not defined as an industry by the characteristic of the product it makes as an output but rather by the characteristic of the purchaser demanding the products. To the extent tourism is an economic phenomenon; many aspects of it are already embedded in the system of national accounts.

4 Tourism Interlinkages with Other Sectors of the Economy Through the Input–Output Framework

4.1 Input–Output Table

Input–output (I-O) table is the matrix representation of a nation's economy and is used to analyse the inter-industry relations in an economy, depicting how the output of one industry is used as input in other industries, thereby making each industry dependent on other industries both as the user and as supplier.

The standard I-O table can be viewed as consisting of four major components (also known as blocks or quadrants). Each of these blocks consists of a series of rows and columns. A row in an I-O table shows the values in which an economic sector provides inputs to various other sectors and final uses. Final use refers to the sector's sales to households and government as their consumption expenditure; sector's use in fixed investment; and its net exports. On the other hand, a column shows the sector's inputs from other sectors and its primary inputs consisting of taxes less subsidies on production and the gross value added comprising payments for labour, capital, land and imported inputs. The row total and the column total of a sector give its total value of output and hence are equal.

Input–output tables, now prepared by most of the economies, are powerful tools and are applied for various purposes. The primary advantage of input–output tables is the generation of multipliers—output multipliers and employment multipliers. Unlike economic base multipliers, which calculate only one multiplier, input–output multipliers are calculated for all the industries. It is able to reveal the impact of growth or decline in one industry on all the other industries of the economy. Similarly, it generates employment multipliers for all the sectors.

4.2 Tourism as One of the I-O Sectors

Any economic activity of a region has both direct and indirect economic benefits. These are captured by the I-O tables and the I-O model based on these tables. Tourism also has a number of such benefits but since it is not a separate sector in the system of national accounts or in the I-O tables, its indirect benefits are difficult to quantify while some estimates of direct benefits can be obtained using other available tourism statistics or through tourism-related primary data.

The direct benefits go to the industries that provide their goods and services directly to the tourists, e.g. accommodation providing industries, transport operators, travel agents. But there are certain indirect beneficiaries too, e.g., shops, banks, medical and health centres. The money spent by the tourists in an area is re-circulated and re-spent in the local economy, thereby generating extra income and output. The actual economic benefit, therefore, to the area is greater than the original amount spent by the tourists.

The model based on I-O table helps to capture this additional generation of income and output by tracking the interlinkages within the sectors of an economy. With the quantification of these interlinkages, it is interesting to see how, an additional demand in tourism sector effects other sectors of the economy through its backward linkages and vice versa through the forward linkages.

For this, tourism sector has to be included as a separate sector in the I-O table. As mentioned earlier, its aspects are embedded in other sectors of the I-O table. These sectors can be classified as tourism-characteristic (those which cease to exist in the absence of tourism), tourism-related (those which are not entirely dependent on tourism but do relate strongly with the sector) and non-tourism sectors. These sectors, broadly identified by the UNWTO in TSA: RMF 2008 and specifically categorized for Indian tourism, are as follows:

Tourism-characteristic industries

1. Accommodation services
2. Food and beverage serving services
3. Railway passenger transport services
4. Road passenger transport services
5. Water passenger transport services
6. Air passenger transport services
7. Transport equipment rental services
8. Travel agencies and other reservation services
9. Cultural and religious services
10. Sports and other recreational services
11. Health and medical-related services

Tourism-related industries

12. Readymade garments
13. Processed food
14. Tobacco products
15. Beverages
16. Travel-related consumer goods
17. Footwear
18. Soaps, cosmetics and glycerine
19. Gems and jewellery
20. Books, journals, magazines, stationery, etc.

Non-tourism industries

21. Agriculture
22. Mining and other non-tourism-specific manufacturing
23. Trade
24. Transport freight services
25. Other non-tourism-specific services

Using this classification of industries, India's second tourism satellite account (TSA) was prepared for the year 2009–10, which is the latest till now. The TSA, through its set of tables and accounts that bring together the demand-side and supply-side data for these industries, evaluates the two most important outcomes, that is, tourism industry ratios (TIRs) and tourism product ratios (TPRs) for each of these industries/products.

We have these ratios separately for industries as well as products as TSA is based on the framework of the supply and use table (SUT), which are the matrices of transactions between the products and industries, with products presented in its rows and industries in columns.[1] The TIR and TPR ratios refer to the proportion of the total value added of an industry/product which is related to tourism. Table 1 presents the TIRs and TPRs as obtained in India's TSA.

Thus, a TIR of 51.1% for accommodation services implies that 51.1% of total value added generated by this industry is on account of tourism activity. It may be noted that TSA, due to its SUT framework, brings out the interlinkages among the sectors of the economy, and hence, some of the non-tourism industries/products also show some element of tourism in their value added.

The objective of this study is to put tourism as a separate sector in the I-O table, and I-O table is compiled through the SUTs. As mentioned earlier, in the SUTs, products are presented in rows and industries in columns. Hence, we start with putting Tourism as a separate industry and as a separate product in India's SUT, which originally is a matrix of 130 products and industries but is aggregated, for this study, to have 25 products and industries as are listed above. The TIRs of these 25 industries are used to extract the tourism component from each of the column industries so that tourism becomes an additional 26th industry column, which is an aggregation of the extracted components. Similarly, TPRs are used to extract the tourism component from each of the row products which results in tourism being an additional 26th product row. This is done in both supply and use tables.

Further, these SUTs are converted to the symmetric I-O tables, which are basis to the I-O analysis and the generation of multipliers. Unlike SUTs, which are product × industry matrices, I-O tables are either product × product or industry × industry matrices. The I-O table is compiled by merging the fully balanced SUTs by application of technology assumptions and transformation models. This process results in the creation of a product × product I-O table which has 26 product (or sector) rows and columns, Tourism being one of them. With tourism, now included as a separate sector in I-O table, it is possible to study its linkages with other sectors of the economy and its direct as well as indirect impact on economy through the generation of output multipliers.

[1]SUTs are the basis for the construction of symmetric I-O tables. I-O tables cannot be compiled without passing through the supply and use stage. Symmetric I-O tables are the basis for input–output analysis. The supply table presents the details of goods produced by each industry in the form of their main product or by-products. Use table gives the product-wise input requirement for each industry.

Table 1 Tourism product ratios and tourism industry ratios

Industries/products	Tourism product ratios	Tourism industry ratios
Agriculture	0.00	0.00
Mining and other non-tourism-specific manufacturing	0.00	0.00
Trade	0.00	0.66
Transport freight services	0.00	2.25
Other non-tourism-specific services	2.29	2.29
Processed food	3.12	0.00
Beverages	5.65	0.02
Tobacco products	3.76	0.00
Readymade garments	24.39	0.00
Books, journals, magazines, stationery, etc.	6.16	0.00
Leather footwear	13.95	0.00
Travel-related consumer goods	70.66	0.00
Soaps and cosmetics	0.55	0.00
Gems and jewellery	6.22	0.00
Railway passenger transport services	57.63	57.63
Land passenger transport services	57.40	54.42
Water passenger transport services	12.10	12.10
Air passenger transport services	77.20	77.20
Travel agencies and other reservation services	72.36	72.36
Accommodation services	64.76	51.09
Food serving services	16.10	16.37
Health and medical-related services	30.05	30.05
Transport equipment rental services	28.82	28.82
Cultural and religious services	17.06	17.06
Sporting and recreational services	3.84	3.84

4.3 Input–Output Analysis

The I-O analysis helps to track and quantify the interlinkages of tourism industry with other industries of the economy. With the quantification of these interlinkages, it is interesting to see how, an additional demand in tourism industry effects other industries of the economy through its backward linkages and vice versa through the forward linkages.

The multipliers help in analysing the overall—direct and indirect—impact of exogenous changes in the economy, referred to as external shocks. The multipliers represent a quantitative expression of the extent to which some initial, “exogenous” force or change is expected to generate additional effects through the interdependencies associated with some assumed and/or empirically established, “endogenous” linkage system.

Table 2 A three-sector I-O table

	Sectors				
Sectors	1	2	3	Final demand	Gross value of output
1	X_{11}	X_{12}	X_{13}	F_1	X_1
2	X_{21}	X_{22}	X_{23}	F_2	X_2
3	X_{31}	X_{32}	X_{33}	F_3	X_3
Primary inputs	P_1	P_2	P_3		
Gross value of output	X_1	X_2	X_3		

The I-O table, on which the I-O model is based, is the matrix representation of a nation's economy and depicts how the output of one industry is used as input in other industries, thereby making each industry dependent on other industries both as the user and as supplier. The I-O table with, say, three sectors is shown in Table 2.

The above matrix represents the following set of six balance equations, three representing the sector's sales to other sectors and final users and three representing its purchases from other sectors and primary inputs:

$$\begin{aligned} x_{11} + x_{12} + x_{13} + F_1 &= X_1 \\ x_{21} + x_{22} + x_{23} + F_2 &= X_2 \\ x_{31} + x_{32} + x_{33} + F_3 &= X_3 \end{aligned} \tag{1}$$

$$\begin{aligned} x_{11} + x_{21} + x_{31} + P_1 &= X_1 \\ x_{12} + x_{22} + x_{23} + P_2 &= X_2 \\ x_{13} + x_{23} + x_{33} + P_3 &= X_3 \end{aligned} \tag{2}$$

where F_i is the final use or final demand and P_i is the Primary Input.

Further, if a_{ij} is the input coefficient and is denoted by x_{ij}/X_j, we get,

$$\begin{aligned} a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + F_1 &= X_1 \\ a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + F_2 &= X_2 \\ a_{31}X_1 + a_{32}X_2 + a_{33}X_3 + F_3 &= X_3 \end{aligned} \tag{3}$$

And, if b_{ij} is the output coefficient and is denoted by x_{ij}/X_i, we get,

$$\begin{aligned} b_{11}X_1 + b_{21}X_2 + b_{31}X_3 + P_1 &= X_1 \\ b_{12}X_1 + b_{22}X_2 + b_{32}X_3 + P_2 &= X_2 \\ b_{13}X_1 + b_{23}X_2 + b_{33}X_3 + P_3 &= X_3 \end{aligned} \tag{4}$$

Equation (3) can be written in matrix notations as

$$\begin{aligned} &AX + F = X \\ &\text{or}(I - A)X = F \\ &\text{or}\, X = (I - A)^{-1}F \end{aligned} \tag{5}$$

Similarly, Eq. (4) can be written in matrix notations as

$$\begin{aligned} &B'X + P = X \\ &\text{or}(I - B')X = P \\ &\text{or}\, X = (I - B')^{-1}P \end{aligned} \tag{6}$$

The inverse matrices of Eqs. (5) and (6) are called Leontief inverse matrices after W. Leontief who introduced Input–Output Analysis. These matrices reflect the direct and indirect effects of inter-industry linkages.

To be specific, in the framework of input–output analysis, production by a particular sector has two kinds of effects on other sectors in the economy. If a sector *j* increases its output due to additional demand, more inputs (purchases) are required including more intermediates from other sectors. Such interconnection of a particular sector to other sectors from which it purchases inputs (demand side) is termed as “backward linkage”. Also called “output multiplier”, this is the column sum of inverse matrix given in Eq. (5) and can be interpreted as the cumulative increase in the output of the economy which is induced by one additional unit of final demand of a certain sector. The higher the multipliers, the larger are the effects on the input–output system of the economy.

On the other hand, increased output of sector *j* indicates that additional amounts of products are available to be used as inputs by other sectors. There will be increased supplies from sector *j* for sectors which use product *j* in their production (supply side). This interconnection of a particular sector to those to which it sells its output is termed as “forward linkages”. These are obtained from the column sum of inverse matrix given in Eq. (6) and can be interpreted as the cumulative increase in the output of the economy which is induced by one additional unit of primary inputs of a certain sector. While backward linkages are the relationship between the activity in a sector and its purchases, forward linkages are the relationship between the activity in a sector and its sales.

For the present study, Leontief inverse matrices are obtained from the I-O table in which tourism sector is now a separate sector. These inverse matrices help in deriving the backward (output multiplier) and forward (input multiplier) linkages of all the 26 economic sectors, including tourism. These linkages or multipliers, arranged in descending order of their values, are presented in Tables 3 and 4.

The tables suggest that tourism has reasonably good backward and forward linkages with other sectors of the economy. The output multiplier of tourism sector is 1.83, bringing the sector to 14th position among the 26 sectors. Hence, its

Table 3 Backward linkages (or output multiplier) of sectors

		Backward linkage
1	Gems and jewellery	2.50
2	Processed food	2.33
3	Beverages	2.31
4	Leather footwear	2.26
5	Soaps and cosmetics	2.26
6	Books, journals, magazines, stationery, etc.	2.25
7	Mining and other non-tourism-specific manufacturing	2.19
8	Travel-related consumer goods	2.16
9	Food serving services	2.14
10	Readymade garments	2.09
11	Transport freight services	2.09
12	Tobacco products	1.93
13	Land passenger transport services	1.85
14	**Tourism**	**1.83**
15	Air passenger transport services	1.81
16	Travel agencies and other reservation services	1.78
17	Accommodation services	1.75
18	Railway passenger transport services	1.72
19	Health and medical-related services	1.69
20	Water passenger transport services	1.68
21	Sporting and recreational services	1.61
22	Agriculture	1.47
23	Transport equipment rental services	1.43
24	Trade	1.31
25	Cultural and religious services	1.29
26	Other non-tourism-specific services	1.23

capacity to induce production activity in the economy is higher than that of 12 other sectors. In terms of the value of its multiplier, a unit increase in final demand of tourism sector is expected to trigger the overall production of 1.83 units in the entire economy. On the other hand, tourism occupies 13th position with respect to the input multiplier, its own being 1.45. Hence, the expansion of this sector generates a powerful stimulus in other sectors, by way of absorbing its output as inputs to other sectors.

Table 4 Forward linkages (or input multiplier) of sectors

		Forward linkage
1	Transport equipment rental services	2.09
2	Mining and other non-tourism-specific manufacturing	2.05
3	Trade	1.99
4	Transport freight services	1.99
5	Agriculture	1.94
6	Food serving services	1.89
7	Accommodation services	1.89
8	Cultural and religious services	1.62
9	Air passenger transport services	1.60
10	Travel-related consumer goods	1.51
11	Processed food	1.48
12	Land passenger transport services	1.45
13	**Tourism**	**1.45**
14	Other non-tourism-specific services	1.41
15	Railway passenger transport services	1.41
16	Gems and jewellery	1.35
17	Sporting and recreational services	1.34
18	Books, journals, magazines, stationery, etc.	1.30
19	Beverages	1.28
20	Readymade garments	1.21
21	Soaps and cosmetics	1.21
22	Tobacco products	1.15
23	Health and medical-related services	1.07
24	Leather footwear	1.05
25	Travel agencies and other reservation services	1.04
26	Water passenger transport services	1.01

5 Importance of Tourism in Indian Economy

It is evident from the previous sections that tourism is an important economic activity in India. Due to the country's diversity in regions, culture, geographies and natural resources, India attracts all kinds of tourists whose preferences to travel range from visiting historical monuments to religious places or from scenic mountains to exotic sea beaches.

Tourism's economic value to India is also apparent from the extent of revenue that a large inflow of tourists generates in the economy. According to the Ministry of Tourism's latest annual publication "India Tourism Statistics—2017", a total of 8.8 million foreign tourists visited India in 2016, resulting in the foreign exchange earnings to the tune of US$ 22.9 billion. The number of tourist arrivals registered an annual growth of 9.7% while foreign exchange earnings grew by 8.8% in 2016.

India's second tourism satellite account (TSA) from 2009–10, also the latest so far, suggests that tourism sector contributes 3.7% to the Indian GDP. This is the sector's direct contribution. However, as seen in the previous sections, the sector has strong interlinkages with other sectors of the economy and hence accounts for a significant indirect contribution too. Putting together, tourism's direct and indirect contribution amounted to 6.8% to India's GDP in 2009–10. This owes to the tourism output multiplier of 1.8518.

Tourism sector is also an important employment generator. As per TSA 2009–10, the direct share of tourism-related employment in total employment was 4.4%. Its employment multiplier is even higher than its output multiplier, suggesting that the indirect impact on employment is much higher than the impact on GDP. With the employment multiplier of 2.3256, the sector's direct and indirect share to total employment was 10.2%.

Clearly, expansion of tourism sector will not only generate more activity and employment in the tourism and tourism-related sectors, but due to the strong linkages with other sectors, it will also trigger economic activity and generate employment in other sectors due to the spill-over effects.

Notably, the contribution of tourism to Indian economy is comparable and even exceeds its contribution to other economies. This can be inferred by comparing the results of Indian TSA with TSAs of other countries for the similar period. For example, tourism contributed a total of 5.2% to Australian economy (GDP) in 2010, putting together the direct and indirect impact. The same for Brazilian economy was 8.6% in 2011. For New Zealand, this share was 8.7% in 2010.

6 Hypothetical Extraction of Tourism

The hypothetical extraction method (HEM) was initially suggested by Paelinck et al. (1965), Strassert (1968) and Schultz (1977) and was later reformulated by Meller and Marfán (1981) and Clements (1990). This method, one of the applications of I-O model, measures the importance of a sector by hypothetically extracting that sector from the I-O system. In other words, the method analyses the role of a sector by deriving the loss that an economy might incur if that sector completely "disappears" from the economy. While such hypothetical situation might be unimaginable for many sectors like manufacturing or several service-providing sectors but this cannot be completely ruled out in the case of tourism. Many countries or regions which depend largely on tourism activities, suffer huge losses if the country reels under some extreme circumstances like terrorist attack or natural calamities.

Using HEM, the importance of a sector can be felt through both backward and forward linkages. In the I-O table, a sector is made to "disappear" by nullifying its row and column from the A-Matrix (for impact through backward linkage) and B-Matrix (for impact through forward linkage). The output difference between the "with" and "without" that sector quantifies its importance in the economy.

In the full n-sector model, output X_n is defined as $(I - A_n)^{-1} * F_n$, as given in Eq. 5 of previous section. In the reduced (n−1)-sector model, output X_{n-1} corresponds to $(I - A_{n-1})^{-1} * F_{n-1}$, where A_{n-1} is the coefficient matrix in which all the elements of the rows and columns of "hypothetically disappeared" sector are replaced by zeroes and F_{n-1} is the corresponding reduced final demand vector. So, the difference between X_n and X_{n-1} is the aggregate measure of the economy's loss (decrease in output) if that sector disappears. Normalization through division by gross output and multiplication by 100 produces an estimate of the percentage decrease in total economic activity.

The percent loss suffered by the sectors of the economy resulting from the extraction of tourism sector from the system is given in Table 5

Hence, while tourism sector helps in multiplying the overall output of the economy by a factor of 1.83 units when its demand increases by 1 unit, its

Table 5 Measure of loss to economy after extracting "tourism"

		Percent loss
1	Agriculture	−5.65
2	Mining and other non-tourism-specific manufacturing	−3.26
3	Trade	−3.94
4	Transport freight services	−3.94
5	Other non-tourism-specific services	−1.36
6	Processed food	−2.71
7	Beverages	−2.53
8	Tobacco products	−0.56
9	Readymade garments	−1.38
10	Books, journals, magazines, stationery, etc.	−1.24
11	Leather footwear	−0.15
12	Travel-related consumer goods	−2.61
13	Soaps and cosmetics	−0.63
14	Gems and jewellery	−2.04
15	Railway passenger transport services	−1.37
16	Land passenger transport services	−1.52
17	Water passenger transport services	−0.05
18	Air passenger transport services	−1.45
19	Travel agencies and other reservation services	−0.14
20	Accommodation services	−8.31
21	Food serving services	−8.31
22	Health and medical-related services	−0.34
23	Transport equipment rental services	−6.97
24	Cultural and religious services	−2.31
25	Sporting and recreational services	−1.09
	Total	−7.15

"disappearance" causes the output to fall by 7.15%. The most significantly impacted sectors are "Hotels" and "Restaurants", whose output are expected to shrink by 8.31% each.

7 Concluding Remarks

The present study clearly validates and quantifies the importance of tourism sector in an economy. While the tourism satellite account brings out the direct contribution of tourism in India's economy, the I-O model reveals its direct as well as indirect impact. According to India's TSA from 2009–10, tourism directly contributes 3.7% to India's GDP. The I-O analysis suggests that tourism's output multiplier is 1.83. Its mathematical implication is that tourism sector's overall contribution (direct as well as indirect) is 1.83 times the direct contribution; therefore, it goes up to 6.8% of GDP after multiplying 3.7 with 1.83. The tourism sector has strong forward linkages too which is reflected in its input multiplier of 1.45.

Further, the analysis based on hypothetical extraction method reveals that the disappearance of tourism from the Indian economy is expected to result in the contraction of GDP by 7.2%, as its direct and indirect impact. Hence, while tourism contributes 6.8% to GDP, its absence brings GDP down by 7.2%. Both the estimates point towards the significance of the sector in the economy. This is an important takeaway for the policymakers and provides enough reason to promote the tourism activity and the investment in its development.

Appendix

See Tables 6 and 7.

Table 6 Inverse matrix for backward linkage

S. No.	Industries	1	2	3	4	5	6	7
1	Agriculture	1.2021	0.1099	0.0241	0.1039	0.0187	0.6824	0.3442
2	Mining and other n-tourism-sp. manu	0.1309	1.7701	0.1316	0.6115	0.0939	0.2540	0.4145
3	Trade	0.0645	0.1307	1.0243	0.1081	0.0175	0.1938	0.1635
4	Transport freight services	0.0283	0.0574	0.0107	1.0475	0.0077	0.0852	0.0719
5	Other n-tourism-sp. serv	0.0234	0.0785	0.0640	0.0854	1.0589	0.0508	0.0559
6	Processed food	0.0062	0.0078	0.0017	0.0059	0.0013	1.0317	0.1764
7	Beverages	0.0001	0.0007	0.0002	0.0008	0.0002	0.0005	1.0428
8	Tobacco products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0001
9	Readymade garments	0.0003	0.0025	0.0004	0.0015	0.0006	0.0006	0.0008
10	Books, journals, magazines, stationery, etc.	0.0003	0.0007	0.0022	0.0018	0.0006	0.0007	0.0006
11	Leather footwear	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000
12	Travel-related consumer goods	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001
13	Soaps and cosmetics	0.0001	0.0008	0.0002	0.0004	0.0001	0.0002	0.0008
14	Gems and jewellery	0.0001	0.0007	0.0009	0.0006	0.0001	0.0003	0.0004
15	Railway passenger transport services	0.0001	0.0006	0.0001	0.0005	0.0004	0.0003	0.0003
16	Land passenger transport services	0.0026	0.0055	0.0124	0.0064	0.0028	0.0046	0.0043
17	Water passenger transport services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Air passenger transport services	0.0000	0.0004	0.0001	0.0002	0.0002	0.0001	0.0002
19	Travel agencies and other reservation services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Accommodation services	0.0005	0.0009	0.0018	0.0086	0.0017	0.0012	0.0010
21	Food serving services	0.0038	0.0066	0.0125	0.0605	0.0119	0.0083	0.0073
22	Health and medical-related services	0.0001	0.0002	0.0002	0.0013	0.0020	0.0002	0.0002
23	Transport equipment rental services	0.0000	0.0001	0.0000	0.0003	0.0000	0.0000	0.0001
24	Cultural and religious services	0.0001	0.0006	0.0001	0.0004	0.0003	0.0002	0.0002
25	Sporting and recreational services	0.0006	0.0019	0.0003	0.0011	0.0004	0.0007	0.0008
26	Tourism	0.0063	0.0171	0.0235	0.0393	0.0127	0.0132	0.0217
Output multiplier		1.4705	2.1940	1.3112	2.0863	1.2321	2.3297	2.3081

(continued)

Table 6 (continued)

S. No.	Industries	8	9	10	11	12	13	14
1	Agriculture	0.2299	0.0628	0.0660	0.1139	0.1086	0.1011	0.0603
2	Mining and other n-tourism-sp. manu	0.1996	0.6977	0.8315	0.7504	0.7209	0.7183	0.6684
3	Trade	0.1206	0.1110	0.1333	0.1338	0.1255	0.1289	0.1185
4	Transport freight services	0.0530	0.0488	0.0586	0.0588	0.0552	0.0567	0.0521
5	Other n-tourism-sp. serv	0.0613	0.0995	0.0887	0.1008	0.0803	0.0977	0.1781
6	Processed food	0.0652	0.0046	0.0079	0.0172	0.0094	0.0320	0.0040
7	Beverages	0.0002	0.0004	0.0004	0.0005	0.0006	0.0019	0.0004
8	Tobacco products	1.1381	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000
9	Readymade garments	0.0004	1.0191	0.0025	0.0063	0.0044	0.0012	0.0012
10	Books, journals, magazines, stationery, etc.	0.0005	0.0005	1.0229	0.0006	0.0006	0.0008	0.0006
11	Leather footwear	0.0000	0.0000	0.0000	1.0016	0.0003	0.0000	0.0000
12	Travel-related consumer goods	0.0000	0.0003	0.0002	0.0070	1.0040	0.0001	0.0003
13	Soaps and cosmetics	0.0085	0.0029	0.0013	0.0005	0.0008	1.0795	0.0004
14	Gems and jewellery	0.0004	0.0005	0.0005	0.0008	0.0009	0.0005	1.3019
15	Railway passenger transport services	0.0020	0.0009	0.0007	0.0020	0.0008	0.0007	0.0025
16	Land passenger transport services	0.0072	0.0050	0.0065	0.0073	0.0055	0.0068	0.0255
17	Water passenger transport services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004
18	Air passenger transport services	0.0004	0.0003	0.0004	0.0003	0.0004	0.0007	0.0015
19	Travel agencies and other reservation services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Accommodation services	0.0009	0.0008	0.0009	0.0011	0.0009	0.0009	0.0013
21	Food serving services	0.0060	0.0059	0.0066	0.0074	0.0066	0.0065	0.0088
22	Health and medical-related services	0.0002	0.0003	0.0002	0.0003	0.0002	0.0003	0.0005
23	Transport equipment rental services	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
24	Cultural and religious services	0.0002	0.0017	0.0010	0.0004	0.0006	0.0007	0.0022

(continued)

Table 6 (continued)

S. No.	Industries	8	9	10	11	12	13	14
25	Sporting and recreational services	0.0076	0.0025	0.0015	0.0040	0.0025	0.0026	0.0018
26	Tourism	0.0296	0.0222	0.0206	0.0471	0.0313	0.0218	0.0740
Output multiplier		1.9321	2.0879	2.2525	2.2621	2.1606	2.2604	2.5048

S. No.	Industries	15	16	17	18	19	20
1	Agriculture	0.1186	0.1853	0.0656	0.1526	0.1543	0.2617
2	Mining and other n-tourism-sp. manu	0.3765	0.3927	0.3751	0.3897	0.3171	0.2465
3	Trade	0.0792	0.0968	0.0673	0.0893	0.0804	0.0961
4	Transport freight services	0.0348	0.0425	0.0296	0.0393	0.0353	0.0422
5	Other n-tourism-sp. serv	0.0477	0.0499	0.0632	0.0584	0.0681	0.0365
6	Processed food	0.0063	0.0072	0.0045	0.0081	0.0084	0.0188
7	Beverages	0.0011	0.0011	0.0007	0.0014	0.0015	0.0037
8	Tobacco products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	Readymade garments	0.0013	0.0013	0.0063	0.0030	0.0015	0.0021
10	Books, journals, magazines, stationery, etc.	0.0007	0.0009	0.0008	0.0009	0.0029	0.0007
11	Leather footwear	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	Travel-related consumer goods	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
13	Soaps and cosmetics	0.0004	0.0004	0.0003	0.0019	0.0005	0.0006
14	Gems and jewellery	0.0003	0.0004	0.0004	0.0004	0.0005	0.0003
15	Railway passenger transport services	1.0003	0.0003	0.0003	0.0003	0.0007	0.0002
16	Land passenger transport services	0.0037	1.0038	0.0144	0.0073	0.0136	0.0034
17	Water passenger transport services	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
18	Air passenger transport services	0.0001	0.0001	0.0001	1.0001	0.0001	0.0001
19	Travel agencies and other reservation services	0.0000	0.0000	0.0000	0.0000	1.0001	0.0000
20	Accommodation services	0.0029	0.0055	0.0026	0.0040	0.0067	1.0029
21	Food serving services	0.0204	0.0384	0.0179	0.0280	0.0468	0.0204
22	Health and medical-related services	0.0042	0.0005	0.0003	0.0007	0.0007	0.0004
23	Transport equipment rental services	0.0007	0.0002	0.0003	0.0002	0.0002	0.0001
24	Cultural and religious services	0.0002	0.0003	0.0002	0.0003	0.0005	0.0002

(continued)

Table 6 (continued)

S. No.	Industries	15	16	17	18	19	20
25	Sporting and recreational services	0.0008	0.0009	0.0010	0.0010	0.0009	0.0007
26	Tourism	0.0185	0.0246	0.0311	0.0258	0.0420	0.0167
Output multiplier		1.7189	1.8532	1.6820	1.8128	1.7830	1.7542
S. No.	Industries	21	22	23	24	25	26
1	Agriculture	0.5186	0.1095	0.0687	0.0384	0.0291	0.1767
2	Mining and other n-tourism-sp. manu	0.2529	0.3391	0.1848	0.1278	0.2351	0.3685
3	Trade	0.1588	0.0723	0.0418	0.0265	0.0391	0.0927
4	Transport freight services	0.0698	0.0318	0.0184	0.0117	0.0172	0.0407
5	Other n-tourism-sp. serv	0.0384	0.0408	0.0656	0.0631	0.1965	0.0571
6	Processed food	0.0419	0.0055	0.0061	0.0021	0.0018	0.0106
7	Beverages	0.0084	0.0009	0.0012	0.0004	0.0002	0.0018
8	Tobacco products	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004
9	Readymade garments	0.0026	0.0039	0.0007	0.0004	0.0007	0.0030
10	Books, journals, magazines, stationery, etc.	0.0007	0.0010	0.0003	0.0004	0.0007	0.0009
11	Leather footwear	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	Travel-related consumer goods	0.0000	0.0001	0.0000	0.0001	0.0001	0.0002
13	Soaps and cosmetics	0.0004	0.0003	0.0002	0.0001	0.0006	0.0007
14	Gems and jewellery	0.0003	0.0004	0.0002	0.0001	0.0002	0.0085
15	Railway passenger transport services	0.0002	0.0003	0.0001	0.0001	0.0003	0.0004
16	Land passenger transport services	0.0039	0.0046	0.0029	0.0012	0.0018	0.0048
17	Water passenger transport services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Air passenger transport services	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002
19	Travel agencies and other reservation services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Accommodation services	0.0026	0.0061	0.0024	0.0013	0.0008	0.0040
21	Food serving services	1.0184	0.0430	0.0171	0.0092	0.0056	0.0278
22	Health and medical-related services	0.0003	1.0003	0.0003	0.0002	0.0004	0.0008
23	Transport equipment rental services	0.0001	0.0001	1.0002	0.0000	0.0031	0.0002
24	Cultural and religious services	0.0002	0.0003	0.0005	1.0014	0.0059	0.0005
25	Sporting and recreational services	0.0007	0.0008	0.0005	0.0005	1.0582	0.0012
26	Tourism	0.0178	0.0279	0.0141	0.0085	0.0168	1.0239
Output multiplier		2.1372	1.6890	1.4264	1.2937	1.6142	1.8254

Table 7 Inverse matrix for forward linkage

S. No.	Industries	1	2	3	4	5	6	7
1	Agriculture	1.2021	0.0362	0.0857	0.0857	0.0174	0.0495	0.0049
2	Mining and other n-tourism-sp. manu	0.3971	1.7701	0.6275	0.6275	0.2110	0.2241	0.1086
3	Trade	0.0181	0.0274	1.0243	0.0243	0.0358	0.0102	0.0079
4	Transport freight services	0.0343	0.0560	0.0475	1.0475	0.0210	0.0156	0.0124
5	Other n-tourism-sp. serv	0.0252	0.0349	0.0312	0.0312	1.0589	0.0136	0.0148
6	Processed food	0.0854	0.0088	0.0322	0.0322	0.0047	1.0317	0.0030
7	Beverages	0.0077	0.0026	0.0049	0.0049	0.0009	0.0317	1.0428
8	Tobacco products	0.0050	0.0012	0.0035	0.0035	0.0010	0.0113	0.0002
9	Readymade garments	0.0043	0.0132	0.0101	0.0101	0.0051	0.0025	0.0012
10	Books, journals, magazines, stationery, etc.	0.0016	0.0055	0.0043	0.0043	0.0016	0.0015	0.0004
11	Leather footwear	0.0008	0.0015	0.0013	0.0013	0.0005	0.0010	0.0001
12	Travel-related consumer goods	0.0002	0.0004	0.0004	0.0004	0.0001	0.0002	0.0001
13	Soaps and cosmetics	0.0035	0.0069	0.0059	0.0059	0.0025	0.0088	0.0029
14	Gems and jewellery	0.0081	0.0248	0.0211	0.0211	0.0178	0.0042	0.0026
15	Railway passenger transport services	0.0011	0.0010	0.0010	0.0010	0.0003	0.0005	0.0004
16	Land passenger transport services	0.0188	0.0110	0.0130	0.0130	0.0038	0.0058	0.0052
17	Water passenger transport services	0.0004	0.0007	0.0006	0.0006	0.0003	0.0002	0.0002
18	Air passenger transport services	0.0006	0.0004	0.0004	0.0004	0.0002	0.0002	0.0002
19	Travel agencies and other reservation services	0.0003	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001
20	Accommodation services	0.0040	0.0010	0.0020	0.0020	0.0004	0.0023	0.0025
21	Food serving services	0.0556	0.0075	0.0226	0.0226	0.0031	0.0358	0.0398
22	Health and medical-related services	0.0077	0.0066	0.0068	0.0068	0.0021	0.0031	0.0028
23	Transport equipment rental services	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Cultural and religious services	0.0002	0.0002	0.0002	0.0002	0.0003	0.0001	0.0001
25	Sporting and recreational services	0.0011	0.0024	0.0019	0.0019	0.0053	0.0005	0.0004
26	Tourism	0.0579	0.0334	0.0403	0.0403	0.0139	0.0277	0.0259
Input multiplier		1.9413	2.0541	1.9892	1.9892	1.4082	1.4826	1.2797

(continued)

Table 7 (continued)

S. No.	Industries	8	9	10	11	12	13	14
1	Agriculture	0.0003	0.0037	0.0130	0.0011	0.0095	0.0022	0.0010
2	Mining and other n-tourism-sp. manu	0.0028	0.1312	0.1011	0.0295	0.3463	0.0879	0.0192
3	Trade	0.0008	0.0047	0.0682	0.0010	0.0155	0.0036	0.0048
4	Transport freight services	0.0003	0.0073	0.0247	0.0075	0.0181	0.0035	0.0014
5	Other n-tourism-sp. serv	0.0004	0.0109	0.0346	0.0008	0.0162	0.0028	0.0014
6	Processed food	0.0032	0.0010	0.0034	0.0004	0.0027	0.0008	0.0003
7	Beverages	0.0001	0.0003	0.0005	0.0001	0.0009	0.0005	0.0001
8	Tobacco products	1.1381	0.0001	0.0004	0.0000	0.0004	0.0053	0.0001
9	Readymade garments	0.0000	1.0191	0.0015	0.0003	0.0104	0.0058	0.0002
10	Books, journals, magazines, stationery, etc.	0.0000	0.0009	1.0229	0.0001	0.0022	0.0009	0.0001
11	Leather footwear	0.0000	0.0007	0.0002	1.0016	0.0232	0.0001	0.0000
12	Travel-related consumer goods	0.0000	0.0001	0.0001	0.0001	1.0040	0.0001	0.0000
13	Soaps and cosmetics	0.0005	0.0006	0.0011	0.0002	0.0019	1.0795	0.0001
14	Gems and jewellery	0.0002	0.0024	0.0032	0.0005	0.0191	0.0015	1.3019
15	Railway passenger transport services	0.0000	0.0002	0.0003	0.0000	0.0004	0.0001	0.0000
16	Land passenger transport services	0.0001	0.0020	0.0038	0.0004	0.0033	0.0012	0.0003
17	Water passenger transport services	0.0000	0.0006	0.0002	0.0000	0.0002	0.0001	0.0000
18	Air passenger transport services	0.0000	0.0002	0.0001	0.0000	0.0002	0.0002	0.0000
19	Travel agencies and other reservation services	0.0000	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000
20	Accommodation services	0.0000	0.0005	0.0004	0.0000	0.0003	0.0003	0.0000
21	Food serving services	0.0002	0.0041	0.0031	0.0003	0.0023	0.0013	0.0003
22	Health and medical-related services	0.0000	0.0040	0.0029	0.0002	0.0018	0.0006	0.0002
23	Transport equipment rental services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Cultural and religious services	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000
25	Sporting and recreational services	0.0000	0.0004	0.0010	0.0000	0.0011	0.0006	0.0001

(continued)

Table 7 (continued)

S. No.	Industries	8	9	10	11	12	13	14
26	Tourism	0.0058	0.0142	0.0127	0.0015	0.0267	0.0065	0.0209
Input multiplier		1.1529	1.2092	1.2997	1.0457	1.5072	1.2054	1.3523

S. No.	Industries	15	16	17	18	19	20
1	Agriculture	0.0135	0.0258	0.0001	0.0116	0.0009	0.0351
2	Mining and other n-tourism-sp. manu	0.2243	0.1945	0.0009	0.4028	0.0251	0.2234
3	Trade	0.0109	0.0920	0.0001	0.0135	0.0007	0.0877
4	Transport freight services	0.0167	0.0208	0.0001	0.0171	0.0050	0.1869
5	Other n-tourism-sp. serv	0.0601	0.0372	0.0000	0.0580	0.0008	0.1490
6	Processed food	0.0038	0.0057	0.0000	0.0032	0.0003	0.0097
7	Beverages	0.0007	0.0009	0.0000	0.0010	0.0001	0.0015
8	Tobacco products	0.0046	0.0015	0.0000	0.0022	0.0000	0.0012
9	Readymade garments	0.0068	0.0034	0.0000	0.0048	0.0003	0.0038
10	Books, journals, magazines, stationery, etc.	0.0018	0.0016	0.0000	0.0027	0.0001	0.0015
11	Leather footwear	0.0015	0.0005	0.0000	0.0006	0.0000	0.0005
12	Travel-related consumer goods	0.0002	0.0001	0.0000	0.0002	0.0000	0.0001
13	Soaps and cosmetics	0.0027	0.0023	0.0000	0.0063	0.0001	0.0021
14	Gems and jewellery	0.0348	0.0337	0.0076	0.0526	0.0004	0.0110
15	Railway passenger transport services	1.0003	0.0003	0.0000	0.0003	0.0000	0.0018
16	Land passenger transport services	0.0027	1.0038	0.0000	0.0032	0.0005	0.0364
17	Water passenger transport services	0.0002	0.0009	1.0000	0.0003	0.0000	0.0011
18	Air passenger transport services	0.0001	0.0003	0.0000	1.0001	0.0000	0.0010
19	Travel agencies and other reservation services	0.0002	0.0003	0.0000	0.0001	1.0001	0.0009
20	Accommodation services	0.0003	0.0005	0.0000	0.0004	0.0001	1.0029
21	Food serving services	0.0022	0.0041	0.0000	0.0025	0.0003	0.0184
22	Health and medical-related services	0.0025	0.0032	0.0000	0.0019	0.0002	0.0283
23	Transport equipment rental services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
24	Cultural and religious services	0.0001	0.0001	0.0000	0.0001	0.0000	0.0005
25	Sporting and recreational services	0.0012	0.0006	0.0000	0.0010	0.0000	0.0019
26	Tourism	0.0140	0.0155	0.0005	0.0149	0.0015	0.0850
Input multiplier		1.4061	1.4499	1.0095	1.6015	1.0365	1.8919

S. No.	Industries	21	22	23	24	25	26
1	Agriculture	0.0351	0.0011	0.0294	0.0110	0.0165	0.0193
2	Mining and other n-tourism-sp. manu	0.2234	0.0114	0.5178	0.3567	0.1907	0.1885

(continued)

Table 7 (continued)

S. No.	Industries	21	22	23	24	25	26
3	Trade	0.0877	0.0017	0.0206	0.0126	0.0054	0.0539
4	Transport freight services	0.1869	0.0059	0.1218	0.0215	0.0097	0.0397
5	Other n-tourism-sp. serv	0.1490	0.0383	0.0730	0.0723	0.0137	0.0520
6	Processed food	0.0097	0.0003	0.0074	0.0033	0.0024	0.0051
7	Beverages	0.0015	0.0001	0.0015	0.0007	0.0005	0.0015
8	Tobacco products	0.0012	0.0001	0.0021	0.0007	0.0045	0.0020
9	Readymade garments	0.0038	0.0002	0.0064	0.0180	0.0048	0.0046
10	Books, journals, magazines, stationery, etc.	0.0015	0.0001	0.0025	0.0038	0.0010	0.0015
11	Leather footwear	0.0005	0.0000	0.0009	0.0005	0.0008	0.0010
12	Travel-related consumer goods	0.0001	0.0000	0.0003	0.0002	0.0001	0.0002
13	Soaps and cosmetics	0.0021	0.0001	0.0033	0.0040	0.0025	0.0023
14	Gems and jewellery	0.0110	0.0009	0.0253	0.0475	0.0066	0.0303
15	Railway passenger transport services	0.0018	0.0006	0.0086	0.0004	0.0002	0.0005
16	Land passenger transport services	0.0364	0.0008	0.0238	0.0044	0.0025	0.0076
17	Water passenger transport services	0.0011	0.0000	0.0028	0.0002	0.0002	0.0006
18	Air passenger transport services	0.0010	0.0000	0.0012	0.0002	0.0001	0.0003
19	Travel agencies and other reservation services	0.0009	0.0000	0.0004	0.0002	0.0001	0.0003
20	Accommodation services	0.0029	0.0001	0.0022	0.0005	0.0003	0.0008
21	Food serving services	1.0184	0.0004	0.0099	0.0032	0.0021	0.0058
22	Health and medical-related services	0.0283	1.0003	0.0074	0.0031	0.0015	0.0060
23	Transport equipment rental services	0.0001	0.0000	1.0002	0.0001	0.0000	0.0000
24	Cultural and religious services	0.0005	0.0000	0.0004	1.0014	0.0001	0.0002
25	Sporting and recreational services	0.0019	0.0002	0.1487	0.0337	1.0582	0.0019
26	Tourism	0.0850	0.0035	0.0713	0.0237	0.0112	1.0239
Input multiplier		1.8919	1.0662	2.0891	1.6237	1.3356	1.4498

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Growth of Service Sector in India (1983–84 to 2011–12): An Input–Output Analysis

Probir Karar and Smriti Karar Mukhopadhyay

Abstract It is now a well-documented fact that the Indian economy has undergone a significant structural change in the last couple of decades. If one looks at the share of GDP contributed by agriculture, industry, and services sectors, it can be argued that in the early 1950–51, the Indian economy was basically an agro-based economy which has now emerged as predominant in the services sector activities. This change is likely to cause significant changes not only in the sphere of production and demand but also in the linkages among various sectors. This development has various ramifications for the overall growth and the process of development in the Indian economy. This paper seeks to analyze the reasons for this growth of services sector of India and consequent structural change in the economy for the period 1983–84 to 2011–12 and try to highlight its implication for the future economic development of India using input–output structural decomposition analysis (I-O SDA). It has been found that the major reasons for the growth of services sector are due to change in demand rather than change in technology and again it is the domestic demand which dominates over the foreign demand.

Keywords Services · Growth · India

JEL Classification O10 · O11

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1 Introduction

It is now a well-documented fact that the Indian economy has undergone a significant structural change in the last couple of decades. If one looks at the share of GDP contributed by agriculture, industry, and services sectors, it can be argued that in the early 1950–51, the Indian economy was basically an agro-based economy which has now emerged as predominant in the services activities. This change is likely to cause significant changes not only in the sphere of production and demand but also in the linkages among various sectors. This development has various ramifications for the overall growth and the process of development in the Indian economy.

The theoretical standpoint of development of services sector in an economy has two dimensions: one for advanced economies and other for developing economies. The stylized facts are: First, it has been argued that so-called Clark-Fisher theory of structural change has occurred mainly for developed countries but same is not true in case of developing economies. Second, the growth of services sector has characterized by commensurate growth in output and employment in advanced countries, but developing countries have experienced a non-proportional growth of employment vis-à-vis output in services sector.

Ten Raa and Schettkat (2001) have addressed the question of why advanced economies are still experiencing sustained growth rates of real output and employment of service industries, despite trends of increasing input costs and prices. On the other hand, Griliches (1992) has seriously questioned the potential mis-measurement of real output and productivity of services more than two decades ago, leading the ‘service paradox’ unresolved. After the debate around tertiarization started with Clark (1940), the growth of services output share has mainly been attributed to shift in private domestic consumption which was sustained by a positive income effect, more than compensating a negative price effect. However, according to Ten Raa and Schettkat (2001), the overall demand for services has been steadily growing in spite of the fact that real income has declined from the mid-1970s onward. So, it seems that at the back of the whole ‘service paradox’ a change in demand conditions dominates over other effects.

It is unfortunate that the ‘black box’ of the change in demand condition has been vaguely put forward but not properly unfolded since then. It can be argued that ‘service paradox’ is likely to have been affected by major technological changes in services like ICT, IT. They have a two-fold impact on services; First, the productivity estimates directly and second indirectly on output growth via the changing composition of final and intermediate demand for services. This change in intermediate demand can be argued to complement and in the same cause dominate the role of income and price led change of final demand in accounting for the structural change leading to growth of services.

Keeping this fact in mind, this paper seeks to analyze the reasons for the growth of services sector of India and consequent structural change in the economy for the period 1983–84 to 2011–12 and try to highlight its implications for future economic development of India using input–output structural decomposition analysis (I-O SDA). Section 2 presents a brief review of the literature on structural decomposition analysis followed by the brief description of Indian service economy in Sect. 3. The methodology and database of this study have been presented in Sect. 4, while Sect. 5 reports the empirical results. Finally, some concluding observations have been made in Sect. 6.

2 Brief Review of the Literature on SDA

SDA becomes a very important technique for macroeconomists particularly for those researchers who are working on the line of input–output model. This typical method tries to distinguish major sources of change in the structure of an economy by means of a set of comparative static changes in key parameters between two points of time. It is an important technique by which one can disentangle the effect of growth of some variables in a general equilibrium framework to analyze the growth of major macroeconomic variable like GDP, employment. When there are two or more sets of input–output data of an economy, it is possible to disaggregate the total change in some variable of that economy into contribution made by its various components. For example, the change in gross output (GDP) between two points of time can be broken down into several parts associated with changes in technology and changes in the composition of final demand such as consumption, investment, net export. Let us touch upon very briefly the major works on SDA across advanced economies followed by the Indian economy.

There is no doubt that Leontief is the father of modern input–output analysis. This analysis has grown and matured in the hands of Leontief (1953a, b) and later by Chenery (1960), Carter (1970) with works of SDA. In these works, SDA has been used widely to identify the sources of growth of different variables of macroeconomics, like output, energy, service industries in different points of time mostly for a number of developed economies of the world. For example, Feldman et al. (1987) have used this concept to decompose the growth of fifteen fastest growing sectors in the US economy during the period 1963–1978. We can mention similar studies of Skolka (1989) for Austria, Fujimagari (1989) for Canada et al. (2001) for the Netherlands. Pamuku and Boer (1999) have applied the technique of SDA for analyzing the growth of Turkish economy. In a very interesting paper, Barker (1990) has analyzed the growth of British service industries during 1979–84. Akita and Hermawan (2000) have analyzed the structural change and sources of industrial growth in Indonesia between 1985 and 1995. The growth and structural changes of food and fiber industries of USA for the period 1972–82 have been analyzed with the technique of SDA by Lee and Schluter (1993). Mohammadi and Bazzazan (2007) have studied the sources of economic growth of Iran using I-O SDA. In a relatively recent study, regarding economic growth, Savona and Lorentz (2006) have analyzed the contribution of demand and technology to structural change and growth of the tertiary sector for four countries, namely Germany

(1978–1995), the Netherlands (1972–1998), UK (1968–1990), USA (1972–1990), using the methodology of SDA. The sources of growth of Malaysian manufacturing industry have been analyzed nicely by Kamaruddin and Masron (2010). It can be mentioned that one can find a critical survey of the technique of SDA in Rose and Casler (1996). Messa (2013) has investigated the sources of structural change in the Brazilian economy in the 2000s. He has used a modified I-O SDA to incorporate the effect of prices on technological coefficients over time, thus making them to represent changes in production structure The analysis has shown that '*growth differential between services and industry in that period was induced by the production structure: more precisely, by a lower intermediate consumption of domestic industrial inputs by the production chain of all economic sectors, concomitant with a higher intermediate consumption of services*.' Kabeta and Sidhu (2016) have used a decomposition method to identify the service sector contributions to per capita GDP and employment growth during two periods of 1999–2005 and 2005–2013 for Ethiopian economy. Per capita GDP was decomposed into employment rate, productivity, and demographic changes. The result shows that during 1999-2005, '*… Ethiopian per capita GDP growth was mainly contributed by employment rate changes originated from the agriculture sector*,' whereas '*… the service sector has the highest contribution in productivity but a negative contribution in employment change*.' However, during the period of 2005–2013, '*the growth in per capita GDP is due to productivity growth which emanates from the service sectors specifically from the distributive service sector*.' de Souzaa et al. (2015) have shown that the service sector expansion is a multiple trend process, producing distinct sectorial compositions. They have made '*a comparison between two large economies in different stages of development with an extensive service sector of Brazil and USA by focusing on final and intermediary demand changes and sectorial productivity as well*.' With the help of I-O matrices of two countries, applying the tools of SDA and total factor productivity analysis, they have shown that among several reasons, household consumption turns out to be an important reason in explaining the growth of services sector in both the countries. They have also shown that inter-industrial linkages play a major role in USA but that is not the case for Brazil. Evidence of cost disease has not been found for Brazil. Although labor productivity is lower in Brazil, yet it has increased above the average in some service sectors.

The literature on services sector in the Indian economy has assumed a serious position in growth analysis of the Indian economy. Several studies have been done to find the reasons of service-led growth of the economy and its sustainability in the long run. The whole literature on services can be grouped into two categories; one, from the point of view regression analysis in a macroeconomic framework using simultaneous equation model and second using the input–output analysis. In the first category, we can mention some of the important studies done by Papola (2005), Gordon and Gupta (2003), Banga (2005), Rath and Rajesh (2006), Joshi (2010), Ghani (2010), Sirari and Bohra (2011), Sen (2011), Agarwwal (2012). In the second category, the literature in analyzing the growth and structural change in certain macroeconomic variables in the Indian economy becomes worthy to be mentioned. Earlier, the methodology of demand-side decomposition of output growth has been done by Bhardwaj and Chadda (1991). Dholakia et al. (2009) have studied the trends in technical progress in the Indian economy during the period 1968–2003. In analyzing the changing pattern of sources of growth of Indian manufacturing industry, Kumari (2005) has used SDA to compare the period before liberalization (1983–84 to 1989–90) and after liberalization (1989–90 to 1997–98). Roy et al. (2004) have used the SDA method to study the sources of growth of the information services of the Indian economy for the period 1983–84 to 1993–94. Hansda (2002b) has addressed the issue of service-led growth and its sustainability in terms of the inter-sectoral linkages as emanating from I-O table for 1993–94 both at disaggregated level of 115 activities and the aggregated level of 10 constructed national income categories. He has concluded that at the disaggregated level, the Indian economy is found to be predominantly service-driven with 55% activities, direct service-intensive sector, and industry, the most service-intensive sector. However, since the multiplier value remains less than one for all the activities including services, the expansionary potential of a service-led growth may not be possible unless accompanied by growth impulses from other sectors. Sastry et al. (2003) have examined the linkage of growth among the agriculture, industry, and services sectors of the Indian economy, using both an I-O analysis and a simultaneous equation framework. It has been concluded that despite the substantial increase in the share of services sector in GDP over the years, the I-O tables suggest that the agricultural sector still plays an important role in determining the overall growth rate of the economy through demand linkages with other sectors of the economy. Eichengreen and Gupta (2010) have analyzed the growth of services sector of India through a structural decomposition analysis assuming that for a given input–output coefficient, the growth of services equals the weighted average of the growth in various sectors (agricultural and industrial, etc.), the weights being the relative size of each sector relative to the size of the service sector as a whole. Using I-O tables for India (1993, 1998, and 2003), they assess the potential employment growth in the Indian services sector. They have concluded that "....... *India should continue exploiting its comparative advantage in services instead of following the usual route to economic growth in the process of economic development consists in building-up labour intensive manufacturing, in raising living standards in the country*".

From the above literature survey, particularly for the Indian service economy, we can say that there is a serious gap exists mainly in the study of growth of services sector in line with I-O structural decomposition analysis where tertiarization of the Indian economy has been judged empirically through technological change and final demand change that is to say both from supply side and from demand side. This study, we hope, will try to bridge this gap and will focus on reasons for this growth for a long period of 1983–84 to 2011–12 using I-O tables of 1983–84, 1993–94, 2003–04, and 2011–12. Before going into the methodology of the study, let us have a look on the Indian service sector.

3 Services Sector of India: Prospects and Challenges

The services sector covers a various types of activities ranging from services provided by '… *the most sophisticated sectors like telecommunications, satellite mapping, and computer software to simple services like those performed by the barber, the carpenter, and the plumber; highly capital-intensive activities like civil aviation and shipping to employment-oriented activities like tourism, real estate, and housing; infrastructure-related activities like railways, roadways, and ports to social sector related activities like health and education*' (Economic Survey 2013–14). Thus, there is no 'one-size-fits-all' definition of services resulting in some overlapping and some borderline inclusions. In the Indian context, we can mention that according to National Accounts Classification, services sector incorporates trade, hotels and restaurants, transport, storage, and communication, financing, insurance, real estate, and business services, and community, social, and personal services.

The services sector of India has shown a consistent rise in GDP share and growth rate since the early 1950s. For example, the share of services in GDP has risen from 28% in the 1950s to 34% in the 1970s, 44% in the 1990s, 54% in the 2000s, and further to 61% in the 2010s. The growth rate of this sector has also increased continuously, and it has shown a growth rate of 4.1% in the 1950s to 4.6% in the 1970s, 7.7% in the 1990s, and 9.2% in the 2000s (Table 1). Though the contribution of the secondary sector to GDP share has shown a consistent rise since the 1950s, the growth rate has registered a fluctuating trend. For example, there was a deceleration of industry growth in the decade of the 1960s, 1970s, and 1990s and further in the 2000s. The relative share of primary sector has been declining consistently since the 1950s, and growth rate has shown a fluctuating trend throughout the periods between the 1950s and 2010s.

If we look at the contribution to GDP and growth pattern at disaggregated services, a fluctuating trend may be observed. For example, there was a decline in the growth rate of banking and insurance, public administration and defense, and

Table 1 Average GDP share (%) and trend Growth Rate (%)

Year	Primary		Secondary		Tertiary	
	GDP share	Growth share	GDP share	Growth share	GDP share	Growth share
1950s	56	2.7	16	5.8	28	4.1
1960s	48	1.5	21	5.5	31	4.5
1970s	43	1.8	23	4.5	34	4.6
1980s	36	2.9	25	6.5	39	6.6
1990s	29	3.2	27	6.2	44	7.7
2000s	22	3.9	24	7.2	54	9.2
2010s[a]	18	3.0	21	7.0	61	9.0

Source Singh (2012) and National Accounts Statistics, Central Statistical Office
[a]Till March 2015

storage from the 1980s to the 1990s. But, there was a continuous increase in the growth rate of different services like trade, hotel and restaurants, and communications during the period from the 1990s to the 2000s (Table 2).

The slowdown in services, in particular the transport, and storage sectors, could be attributed to the loss of momentum in commodity-producing sectors. The moderate revival in the global economy in the late 2000s may have helped the growth in business services. In the absence of sufficiently high growth in agriculture and industry, it seems that services would be seriously constrained to sustain growth acceleration on auto-pilot mode since many of the services are dependent on buoyancy in the commodity-producing sectors, especially industrial sector. It can be mentioned that using the input–output table of 2006–07, it has been found, through linkage analysis, that out of the total input requirement of the agriculture and allied sectors, 55.3% was contributed by the sector itself, while industry and services accounted for 21.4% and 23.3%, respectively. More than two-thirds of the total inputs required by industry came from industry itself, while nearly one-fourth were from the services sector. Over half of the inputs for the services sector came from the industrial and agricultural sectors. The analysis highlights the importance of the industrial sector in sustaining economic activity in the services sector. As is evident from the data of input–output tables, the agricultural sector accounted for 11.8% of the total inputs employed in the economy, while the industrial and services sectors accounted for 59.6% and 28.6%, respectively. Hence, a sustained

Table 2 Average annual Growth Rate and GDP shares of Services sub-sectors (%)

Services sub-sectors	The 1980s growth share	GDP share in the 1980s	The 1990s growth share	GDP share in the 1990s	The 2000s growth share	GDP[b] share in the 2000s
Trade	5.9	11.9	7.3	13.7	8.6	10.4
Hotels and restaurants	6.5	0.7	9.3	1.0	10.3	1.08
Railway transport	4.5	1.4	3.6	1.1	7.3	0.79
Transport by other means	6.3	3.8	6.9	4.3	8.9	4.19
Storage	2.7	0.1	2.0	0.1	2.7	0.06
Communication	6.1	1.0	13.6	2.0	25.7	1.68
Banking and insurance	11.9	4.2	9.7	7.0	9.9	6.07
Dwelling, real estate, and business ser.	10.6	5.1	12.4	5.6	8.0	13.9
Public admn. and defense	7.0	6.0	6.0	6.1	3.6	5.58
Other services	5.7	6.4	6.6	8.3	7.1	6.68

Source Singh (2012) and National Account Statistics, Central Statistical Office
[b]Share of GVA (till March 2015)

recovery in the industrial sector is at the heart of a sustained growth recovery (Economic Survey 2013–14).

The immediate challenge for the services sector covering various activities and areas lies in its growth revival. According to some researchers, India's growth has been basically a service-led growth pulling up overall growth of the economy; this could be through a 'business-as-usual approach,' but they have argued that a more targeted approach with focus on 'big-ticket' services could lead to exponential gains for the economy. While software and telecom services have led by example, there are some other important services like tourism including medical tourism and shipping and logistics which can not only lead to higher growth but also more inclusive growth. Another important challenge facing by the services sector lies in its growth, both internally and externally. One of the major challenges is to retain and expand our competitive advantage in those services where we have already made a mark. The present advantage in services may not continue forever, with new competitors from other developing countries making rapid strides even in areas where we had the initial advantage as in the case of software services. Further expansion of established services like software and telecom into new markets and greater usage of these services domestically can not only increase services growth but also propel growth in other sectors with greater efficiency in these sectors using knowledge-based and technology-based services. Removing or easing domestic regulations is another important challenge facing the Indian economy right now. While removal of market barriers in the form of domestic regulations in other countries depends on multilateral and bilateral negotiations, the myriad restrictions and regulations in the different services domestically need immediate attention. Removing or easing them can lead to dynamic gains for the Indian economy (Economic Survey 2013–14).

We have already mentioned that growth of the services sector in the Indian economy does not follow some 'stylized facts' as it has been noticed for the advanced countries of the world. However, this 'service-led' growth has become the center of attraction for many researchers. According to some of them, this growth has two distinct features. From the demand side, it is due to high income elasticity of demand for services, increase in use of service inputs in other sectors and rise in services exports. From the supply side, there were two factors responsible; first, trade liberalization and second advanced technology. Let us discuss the methodology adopted in the study as well as the database.

4 Methodology

There are different methods of examining the structural relationship in an economy and its change over time. Among them, two methods, namely regression analysis and input–output analysis, are perhaps worth to be mentioned. Perhaps, the most widely used method of analysis of structural relationship and its change is through I-O structural decomposition analysis (Mukhopadhyay et al. 2014).

We know that I-O tables provide valuable insights into the interdependence of various sectors in an economy. For example, the so-called forward linkages and backward linkages can well explain the interdependence. But a change in sector composition over time can be explained with the help of structural decomposition analysis. The technique of SDA, utilized in the paper, is based on an accounting identity as proposed by Savona and Lorentz (2006). Let S be the services output at time 't'; L the Leontief inverse matrix of the coefficient of direct and indirect input requirements to produce 'S' at time 't' composed of private and public consumption C; investment and change in stock, I; and net exports, NX, respectively, all at time 't'. The basic material balance equation in period 't' and '$t - g$' can be expressed through Eqs. (1) and (2) as follows:

$$\begin{aligned} S_t &= L_t.\mathrm{FD}_t \\ \text{Or}, S_t &= L_t(C_t + I_t + \mathrm{NX}_t) \\ \text{Or}, S_t &= L_t.C_t + L_t.I_t + L_t.\mathrm{NX}_t \end{aligned} \tag{1}$$

Similarly for time 't − g', we get

$$S_{t-g} = L_{t-g}.C_{t-g} + L_{t-g}.I_{t-g} + L_{t-g}.\mathrm{NX}_{t-g} \tag{2}$$

Subtracting Eq. (1) from Eq. (2), we get

$$\begin{aligned} S_t - S_{t-g} &= L_tC_t - L_{t-g}.C_{t-g} + L_t.I_t - L_{t-g}.I_{t-g} + L_t.\mathrm{NX}_t - L_{t-g}.\mathrm{NX}_{t-g} \\ &= \left(L_tC_t + L_tC_{t-g} - L_tC_{t-g} - L_{t-g}C_{t-g}\right) \\ &\quad + \left(L_tI_t + L_tI_{t-g} - L_tI_{t-g} - L_{t-g}I_{t-g}\right) \\ &\quad + \left(L_t\mathrm{NX}_t + L_t\mathrm{NX}_{t-g} - L_t\mathrm{NX}_{t-g} - L_{t-g}\mathrm{NX}_{t-g}\right) \\ &= \left\{\left(L_tC_t - L_tC_{t-g}\right) + \left(L_tC_{t-g} - L_{t-g}C_{t-g}\right)\right\} \\ &\quad + \left\{\left(L_tI_t - L_tI_{t-g}\right) + \left(L_tI_{t-g} - L_{t-g}I_{t-g}\right)\right\} \\ &\quad + \left\{\left(L_t\mathrm{NX}_t - L_t\mathrm{NX}_{t-g}\right) + \left(L_t\mathrm{NX}_{t-g} - L_{t-g}\mathrm{NX}_{t-g}\right)\right\} \\ &= L_t\left(C_t - C_{t-g}\right) + \left(L_t - L_{t-g}\right)C_{t-g} + L_t\left(I_t - I_{t-g}\right) \\ &\quad + \left(L_t - L_{t-g}\right)I_{t-g} + L_t\left(\mathrm{NX}_t - \mathrm{NX}_{t-g}\right) + \left(L_t - L_{t-g}\right)\mathrm{NX}_{t-g} \\ &= L_t\left(C_t - C_{t-g}\right) + L_t\left(I_t - I_{t-g}\right) + L_t\left(\mathrm{NX}_t - \mathrm{NX}_{t-g}\right) \\ &\quad + \left(L_t - L_{t-g}\right)\left(C_{t-g} + I_{t-g} + \mathrm{NX}_{t-g}\right) \\ &= L_t\left(C_t - C_{t-g}\right) + L_t\left(I_t - I_{t-g}\right) + L_t\left(\mathrm{NX}_t - \mathrm{NX}_{t-g}\right) + \left(L_t - L_{t-g}\right)\mathrm{FD}_{t-g} \end{aligned} \tag{3}$$

Dividing both sides of Eq. (3) by $g.S_{t-g}$, and rearranging, we get

$$\frac{S_t - S_{t-g}}{g.S_{t-g}} = \frac{\left(L_t - L_{t-g}\right)\mathrm{FD}_{t-g}}{g.S_{t-g}} + \frac{L_t\left(C_t - C_{t-g}\right)}{g.S_{t-g}} + \frac{L_t\left(I_t - I_{t-g}\right)}{g.S_{t-g}} + \frac{L_t\left(\mathrm{NX}_t - \mathrm{NX}_{t-g}\right)}{g.S_{t-g}}$$

Thus the above equation represents the growth equation of services sector with the decomposition of its into different constitutive components.

The first component of the equation of the right-hand side denotes the change in intermediate demand, i.e., to say change in input combination to produce a certain level of output at two different points of time. This component basically signifies the change in input coefficient keeping the final demand constant at its original level. This is the impact of technological change on the overall change in the services output.

The second part of the equation denotes the impact of change in the final demand on the overall change in the output in services, assuming that there is no change in the technology. To put it in a nutshell, we can say that this component shows the change in consumption at two different points of time, because of changes in the structure of taste and preferences or for change in the income elasticity of demand and so on.

The third component is final demand change in capital stock. This is the impact of change of investment at two different points of time assuming no change in technology. This is very natural in the sense that as economy progresses, there is an increase in demand for more material output and hence capital goods.

The fourth part is final demand change through net export. This component shows the impact of change in international demand for services assuming no change in technology. This can be explained with the help of comparative advantage theory, as well as with the help of changes in composition and direction of international trade. Basically, it shows the net trade effect on the change in output growth.

4.1 Database and Aggregation Problems

We have taken the data on input–output transactions tables of 1983–84, 1993–94, 2003–04, and 2011–12 from different publications of Central Statistical Office, Ministry of Statistics and Programme Implementation, Government of India. From the I-O table of different periods, the services activities have been selected and reaggregated, to some extent, on the basis of homogeneity in the product characteristics and the technological content. To allow time comparability, we have deflated all the current price tables on the basis of appropriate market price index and common base year.

We all know that the number of input–output table often, referred to as ‘sectoral’ aggregation, is usually decided in the context of the problem being considered. In case of Indian input–output transactions table, special care is needed because many new sectors are being added in the new tables as compared to the old ones. In this study, aggregation has been done keeping in mind its problems and biases. In fact, aggregation has great impact on output vectors, coefficient matrix, and final demand vectors. The changes in final demand may be a result of a change in the overall ‘level’ of final demand (level effect) or of a change in the relative proportions of expenditure on the various goods and services in the final demand vectors (mix effect). Final demand data may be collected and presented in several vectors, one for each final demand 'category,' such as household consumption, exports, government spending (central, state, and local), and the relative importance of these categories may change. Again, changes in the Leontief inverse may result from changes in the coefficient matrix—which in turn may reflect various technology changes, such as changes in production recipes, substitution caused by relative price change of factors of production (Miller and Blair 2009). We have reported only the different categories of change in final demand in the study.

5 Empirical Findings

We have grouped the different services activities into five categories, namely public utility services (PUS) which include electricity, gas, water supply and construction; transport services (TTS) which include railway transport, other transport, storage and warehousing and communication; trade services (TRS) which include trade, hotel and restaurant; financial services (FIS) which comprise of banking and insurance and ownership of dwelling; social services (SOS) sector which includes education and research, medical and health, and other services.

Table 3 has two segments. The first one shows the change in output due to change in technology and change in demand. It can be seen that in case of public utility services and transport services, the intermediate demand or the technological change has a negative impact whereas the change in demand factor has a positive effect and mainly responsible for the output growth for all services. The highest change has occurred in case of transport services followed by financial intermediaries, public utility services during the period 1983–84 to 1993–94. If we look at the second part of the table, it is clear that the change in demand has occurred mainly due to change in consumption and investment rather than exports. To explain this type of demand-driven growth pattern in the pre-reform era, we can mention Sen (2011). His estimates show that a unit increase in trade, hotel and

Table 3 I-O Structural Decomposition of average annual Growth rate of Output (in percentage and in constant prices) 1983–84 to 1993–94

Services	Gross output	Output change due to		Demand change due to		
		Technology	Demand	Consumption	Investment	Net export
PUS	0.2350	−0.0043	0.2393	0.1690	0.0569	0.0134
TTS	−0.7319	−1.2268	0.4949	0.3524	0.1137	0.0288
TRS	0.0645	0.0140	0.0505	0.0329	0.0136	0.0040
FIS	0.5512	0.0572	0.4940	0.3491	0.1163	0.0286
SOS	0.2083	0.1145	0.0975	0.0716	0.0208	0.0051

Source Authors own calculation

restaurants, transport, storage, and communications leads to 0.484 units increase in services output, while a unit increase in community, social, and personal services leads to 0.272 units increase in service output and a unit increase in finance, insurance, real estate, and business services leads to 0.237 units increase in service output. In this pre-reform period, trade, software services, and banking services should have been given an impetus by the then government as they had a higher contribution to GDP, rising domestic demand, higher growth rates and boost productivity of manufacturing sector, leading to a sectorally linked productivity spiral. Education and health care should have been deregulated to meet domestic demand (Singh 2012).

Table 4 shows that transport services have grown at a faster rate followed by public utility services and financial services in the period 1993–94 to 2003–04. If we look at the reasons for this growth, we can see that it is the change in demand which is mainly responsible as compared to the change in technology for this growth. The same is true in the case of trade services. Again, if we look at the change in the demand, we can say that this change has occurred mainly due to the growth of consumption and investment for all categories of services. This acceleration of service sector growth, in the post-reform period, can be attributed by an increase in demand, including final consumption demand by household. While there are many categories of services that are not consumed by most households, many key services, such as education, health care, and transportation, are in the consumption basket of all household. Between 1993–94 and early years of the 2000s, the average inflation-adjusted total monthly per capita expenditure (MPCE) has increased by 38% in rural and 51% in urban India. In the same period, the inflation-adjusted average MPCE on services has increased by 167% in rural and 137% in urban India. Household expenditure on services has increased more than three times as fast as total expenditure in both rural and urban India. Among the different categories of services, the per capita monthly expenditure on entertainment has grown by 472%, education by 298%, and personal services by 197% in rural India and in urban India, the percentage growth rates have increased to 382%, 170%, and 209%, respectively. Again, while consumption inequality has been steadily increasing in rural and urban India since 1993–94, there is a narrowing of

Table 4 I-O Structural Decomposition of average annual Growth rate of Output (in percentage and in constant prices) 1993–94 to 2003–2004

Services	Gross output	Output change due to		Demand change due to		
		Technology	Demand	Consumption	Investment	Net export
PUS	12.0808	0.6378	11.443	7.1445	3.2590	1.0395
TTS	16.1387	0.2545	15.8842	9.9241	4.5056	1.4545
TRS	2.2915	0.1259	2.1657	1.3560	0.6109	0.1988
FIS	10.8428	0.5675	10.2753	6.4183	2.9184	0.9386
SOS	0.9420	0.0943	0.8477	0.5328	0.2331	0.0818

Source Authors own calculation

Table 5 I-O Structural Decomposition of average annual Growth rate of Output (in percentage and in constant prices) 2003–04 to 2011–12

Services	Gross output	Output change due to		Demand change due to		
		Technology	Demand	Consumption	Investment	Net export
PUS	18.5154	1.4473	17.0680	0.4313	16.5264	0.1103
TTS	1.9503	0.2371	1.7132	1.7461	0.0303	−0.0631
TRS	11.6514	0.6591	10.9923	11.1388	0.1506	−0.2971
FIS	5.6128	0.2769	5.3359	5.7051	0.0132	−0.3823
SOS	2.1659	0.3110	1.8549	1.8303	0.0083	0.0164

Source Authors own calculation

the difference between rich and poor households in terms of the share of monthly spending on services. Rich households spend a larger share of their monthly budget on services between 1993–94 and 2004–05 (Basu and Das 2017).

Table 5 shows the growth of different categories of services for the period 2003–04 to 2011–12. During this period, the public utility services have recorded the highest growth rate followed by transport and financial services. If one looks at the reasons for this growth, one can say that the change in demand factor is mainly responsible; the intermediate demand plays a minor role in shaping the growth of services in this period. The second part of the table shows that the change in demand has occurred mainly due to the change in consumption and investment; net exports have negative effect in three categories of services. This growth pattern in the 2000s can be explained from a different angle. In the organized services sector, during 1981–2000, social services, in large part, government services, were the most important contributor to the growth of services. But this trend has changed in the period 2000–2010, where modern services were the most important contributor. The growth acceleration of modern services is explained by the growth acceleration in real estate, renting, and business services. Organized wholesale and retail trade and organized hotels and restaurants, in particular, recorded rapid growth in the decades of the 2000s. In the unorganized segment, traditional services (PUS and SOS) were by far the most important contributor of services growth. But modern services (TTS, TRS, and FIS) too grew rapidly in 2000–2010. This essentially reflected quite spectacular growth of communication, which in turn reflected growth of mobile phone services. Social services in unorganized sector (basically cover personal services like services of security guards, gardeners, cooks, cleaners etc.) also increased quite rapidly in this period (Ghose 2014). It is quite clear that rapid growth of services was driven very largely by the growth of non-traded services and thus by the growth of domestic demand during 2003–04 to 2011–12.

Table 6 shows that the highest growth has occurred in transport and communication sector followed by financial intermediaries and trade, hotel and restaurant during the entire period of 1983–84 to 2011–12. If we look at the reasons for the growth of all these services categories, it is clear from the table that the change in demand factor is mainly responsible for the growth of output in different services

Table 6 I-O Structural Decomposition of average annual Growth rate of Output (in percentage and in constant prices) 1983–84 to 2011–12

Services	Gross output	Output change due to		Demand change due to		
		Technology	Demand	Consumption	Investment	Net export
PUS	4.7776	0.1908	4.5868	4.1732	0.3349	0.0787
TTS	50.2031	0.5162	49.6869	50.7359	5.2964	−6.3454
TRS	17.9471	0.9236	17.0235	16.4708	1.7848	−1.2321
FIS	21.0723	0.3745	20.6978	31.4788	0.3764	−11.1574
SOS	10.236	0.7193	9.5167	8.7983	0.2376	0.4808

Source Authors own calculation

during this period. The intermediate demand change or technological change is not so important for the above growth during the entire period of analysis, but the change in demand has occurred mainly due to consumption demand and investment demands rather than exports. From the table, it is clear that domestic final demand (mainly consumption and investment demand) for services has recorded a rapid growth in a low-income economy like India. The available evidence suggests some proximate explanatory factors; first, rapid growth of public consumption expenditure reflected in the rapid expansion of public services and second high (significantly greater than unity) household income elasticity of demand for services as reflected in the rapidly rising share of services in private final consumption expenditure (Rakshit 2007; Nayyar 2012). In real terms, public final consumption expenditure has grown by 5.8% per annum during 1981–2000 and at 5.2% per annum during 2000–2010. In the same period, private final consumption expenditure, in real terms, also has grown rapidly, particularly in the 2000s; the rate of growth was 4.35% per annum during 1981–2000 and 6.45% per annum during 2000–2010. At the same time, the share of services in private final consumption expenditure was steadily growing (Nayyar 2012).

6 Concluding Observations

From the above empirical results of structural decomposition, we have seen that in the different time periods, as well as in the entire period of analysis, the growth of services sector in the Indian economy during the period 1983–84 to 2011–12 has occurred mainly due to the growth of final demand as compared to that of change in technology. Again, this demand change has been attributable mainly due to the growth of consumption demand and investment demand rather than exports demand. Ghose (2014) has opined that '… *rapid growth of services clearly sustained very largely by the growth of domestic final demand which account for 84 percent in the period 1981-2000 and 78 percent in between 2000-2010.*' Basu and Das (2017) have examined India's recent service sector-led growth from the perspective of household expenditure. Using household-level expenditure data from the 'thick' rounds of Household Consumer Expenditure Survey (1993–94, 2004–05, and 2011–12), they present evidence of two important trends. '… *First, a significant portion of demand for services comes from poor households; and second, a puzzling trend has emerged since 2004-05-the shrinking of the difference in the share of monthly expenditure spent on services between rich and poor household*.' One plausible explanation of this can be made in this line. The essential services provided by the government are cheap and of low quality. Due to resource or political constraint, there is a rationing of publicly provided services, so much so that a poor family cannot meet all its requirements from government sources alone. As an alternative to this, higher quality of services can be purchased in the open market at a much higher price. While the rich can afford to purchase higher quality services from open market, the poor afford government services because that is the only way to meet their needs. Thus, when publicly provided services are curtailed—for instance, because of neoliberal turn in government policy—the poor are forced to purchase services from the open market. Hence, for households with a given level of income, expenditure on services increases (Basu and Das 2017).

Therefore, the challenges, before the Indian service sector, lie in its revival of growth through technology upgradation in all spheres of activities, removing or easing of domestic regulations for internal trade and financial intermediaries and an all-out effort to retain and expand our competitive edge in exports of services where we have already made a mark, such as software and telecom services, and tourism including medical tourism and shipping and logistics. So, to sustain this service-led growth of the Indian economy in the future and to continue this demand-driven growth, technological change and the growth of exports coupled with the growth of goods sector have become the major challenges facing our economy right now.

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Part IV
Energy Modelling

Energy Input–Output Analysis for Household Sector of India

Chetana Chaudhuri

Abstract With expanding population, increase in standard of living and associated growth in demand for goods and services lead to higher demand for energy resources. Excessive use of energy causes environmental degradation and pollution. People from lower income group are more vulnerable to the effects of environmental degradation, because of limited access to resources to abate the adverse effects of environmental hazards. But residential sector is responsible for consumption of bulk of energy in different forms and plays a crucial role in determining the pattern of energy consumption of the economy. It consumes energy directly in form of primary fuels like coal or in form of secondary fuels like electricity or petroleum products. Additionally, all the goods and services consumed by this sector require different forms of energy in production, distribution, and transport process, which are carried out in different sectors. This paper identifies energy-intensive sectors in Indian economy and explores the role of residential sector in energy consumption, in direct and aggregate terms, through energy input–output analysis. Results show evidence of high-energy intensity in electricity and petroleum products. Among non-energy sectors, direct energy intensity is high for chemical and cement industries. Apart from these industries, total energy intensity is high for textile, leather and rubber, metal products among manufacturing industries, and for transport, storage and communication among services sector. The analysis shows that average per capita total (direct and indirect) energy consumption by residential sector in urban area is quite high as compared to rural sector. Direct and total energy distribution pattern is significantly different among rich and poor, owing to the difference in their lifestyles. Policy measures to promote energy efficiency through economic and technological interventions are discussed in this context.

This study is a part of Ph.D. thesis of the author.

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Energy input–output analysis · Energy inequality

1 Introduction

Energy is the driving force of any activity or process in nature (Stern 2011) and is one of the important inputs in the production process. According to Peet (2004), energy does not have substitute and it has direct impact on economic development. According to IEA (2017), between 1971 and 2014, global Total Primary Energy Supply (TPES) has increased by 2.5 times and total final consumption of energy expanded by 2.2 times. In India also, total primary energy supply has increased from 305.7 Mtoe (Million tonnes of oil equivalent) to 824.7 Mtoe from 1990 to 2014. Energy input–output analysis is an important tool for analyzing the sources of energy demand in the production process for different sectors and industries and the impact of final consumption on energy consumption.

Input–output model captures the flow of different goods and services across different sectors and hence provides the theoretical framework for the linkage between energy use and economic activities. Input–output technique displays the complex interaction among different sectors of the economy. Energy-oriented input–output model developed in this study focuses on the energy sector through capturing intersectoral transaction between those sectors. The present paper analyses direct and indirect energy consumption of different sectors, with a special attention to household sector. Household consumption is responsible for a major part of energy consumption. Major part of it comprises of energy used in the production process of different goods and services. National- or regional-level total energy consumption can be calculated using "top-down approach" for both consumption and production. Top-down models bring macroconsistency; for example, computable general equilibrium (CGE) approach in static setup. Total energy requirement and associated CO_2 emission can also be estimated using "bottom-up approach" (e.g., input–output analysis), where consumption of any good or service is converted to primary energy requirement, both direct and indirect. Bottom-up approach or consumer lifestyle approach (CLA)-based research studies are attracting interest because huge disparity in the consumption pattern of rich and poor people in a developing country like India also gets reflected in pattern of access to resources. While rich are making wasteful consumption, poorer section of the society is unable to afford the essential goods and services required for survival. With the burden of huge population, total consumption of different goods and services also results in enormous amount of direct and embedded energy consumption.

This study intends to make energy input–output table for India and to quantify the direct and indirect energy consumption by the household sector in India. Energy-extended input–output table shows the physical energy flows across different sectors. Energy content of final demand by household/residential sector reflects the actual energy requirement of the supplying sectors. The study is structured as follows: Sect. 2 reviews the literature on energy input–output model. Section 3 describes the conventional input–output analysis and extension for generation of hybrid energy input–output analysis. Section 4 describes proposed methodology and data requirement for generation of energy input–output table in the context of India. Section 5 presents results and analysis. Section 6 discusses conclusion and policy implications.

2 Input–Output Energy Analysis: Review of Existing Literature

Input–output analysis is an economic-statistical approach, where transactions between various sectors of an economy are presented in input–output matrix. The technique of input–output analysis was originally developed by Nobel laureate Prof. Wassily Leontief. His model captures interdependence of different industries and sectors of the economy, showing how output from one industrial sector is used as input to another sector or to that sector itself. Input–output matrix is generally described in monetary units which can be converted to the physical units to obtain the energy requirement associated with the delivery of the final goods and services to the consumer through a series of mathematical operations. Thus, energy requirement of a complete life cycle of a consumer good can easily be quantified with the help of input–output model.[1]

Energy input–output analysis is an application of input–output analysis. Input–output matrix describes the transactions between different sectors of the economy in financial terms. It is the matrix representation of the system of linear equations describing the interdependence of different sectors of the economy on each other. It illustrates commodity flow from producers to intermediate and final consumers. Due to comprehensive and detailed data coverage of the matrix, it has been widely used by economists over the years. This tool has been extended to several applications in the discipline of economics. This framework was applied to quantify the embodied energy consumption of the economy and this application started during first oil crisis in the 1970s (Bullard and Herendeen 1975; Herendeen and Tanaka 1976). These studies have derived physical units of energy consumption from flow of energy products in monetary terms and calculated energy intensity of the sector. The technique is lot less tedious compared to the process analysis and can provide the accurate results for average national intensities of homogenous sectors (Pachauri 2007).

[1]There is some simplification in terms of the assumption to make the calculation feasible. Input–output analysis does not make any distinction between different products produced in the same sector, e.g., flowers and vegetables are both produced in the same sector, i.e., horticulture. Input–output analysis implicitly assumes a sector in the input–output table is homogenous. In reality, a range of products is produced in one sector, and their energy intensities can be different.

Energy input–output analysis has been utilized to analyze direct and indirect household energy requirement in the context of different countries (Vringer and Blok 1995 for Netherlands; Lenzen 1998 for Australia; Vringer and Blok 2000 for Netherlands; Weber and Perrels 2000 for West Germany, France and the Netherlands; Reinders et al. 2003 for EU member states; Cohen et al. 2005 for 11 capital cities of Brazil, Bin et al. 2010 for USA, Park and Heo 2007 for Korea, Liang 2007 for China). Munksgaard et al. (2000) discussed wide range of literature survey for different countries showing the applicability of input–output analysis in different spheres of economics while combined with different data sources and tools. Kok et al. (2006) discussed three different methods of estimation of environmental burden of consumption using input–output energy analysis. Roca and Serrano (2007) conducted a structural decomposition analysis for the period 1995–2000 and analyzed the emissions of greenhouse gases associated with the consumption patterns of different household groups based on their levels of expenditure for the year 2000 using input–output analysis for Spain. Girod and Haan (2009) used life cycle analysis (LCA) to evaluate the greenhouse gas reduction potential from sustainable consumption for Sweden. Kherkhof et al. (2009) estimated the CO_2 emissions of households in the Netherlands, UK, Sweden, and Norway, around the year 2000 by combining a hybrid approach of process analysis and input–output analysis with data on household expenditures. Baiocchi et al. (2010) applied geo-demographic consumer segmentation data in an input–output framework to understand the direct and indirect carbon dioxide (CO_2) emissions associated with consumer behavior of different lifestyles in the United Kingdom. Duarte et al. (2012) examined the social factors that underlie the composition of final demand and determine the final volume of emissions for Spain. Golley and Mend (2012), in a study on China, analyzed variations in direct and indirect carbon dioxide emissions using input–output analysis, across households with different income levels, using China's Urban Household Income and Expenditure Survey (UHIES) 2005.

Input–output analysis has been used in the context of India in several studies (Mukhopadhyay 2002a, b, c; Mukhopadhyay and Chakraborty 2000); Hikita et al. (2007) constructed hybrid energy input–output table mapping input–output matrix and energy balance table. Mukhopadhyay and Chakraborty (2005) have calculated direct and total energy intensities for the year 1983–1984, 1989–1990, 1993–94, and 1998–99 using Input–output transaction tables. Using the hybrid input–output analysis to get the energy intensity of different sectors, the study shows that highest coal intensity is in coal tar industry followed by cement and iron and steel. The total oil intensity is highest for other transport services. They have analyzed the change in energy intensities of different sectors and highlighted the reasons behind it. Pachauri and Spreng (2002) quantified total energy intensities for energy carriers using the input–output table. The present study intends to make hybrid input–output table for India using input–output table and energy balance table, using the composite price for energy sectors. Total energy requirement generated from varied use of goods and services by the household sector is also derived.

3 Input–Output Framework

Input–output model exhibits all the economic operations in the economy and accounts for the complex interactions which occur within different sectors of the economy. The model contains an input flow/absorption matrix and an output/make matrix, from which several matrices like a base year transaction matrix, technical coefficient matrix, product mix matrix, market share matrix, and Leontief inverse matrix can be generated. These matrices are utilized to analyze the economic issues and problems, and would be helpful in projection of future trend, using the pool of economic information assembled and integrated within the input–output framework.

The transaction matrix displays the flow of commodities among the sectors of the economy, exhibiting the array of transactions in monetary value (Rupee for India) amounts moving from origin sector to destination sectors. Entries in a given row show the distribution of sales (in Rupees) for the sector represented in that row. Entries in a given column exhibit the purchases (in Rupees) by the sector corresponding to the column. There are two kinds of sectors: "intermediate sectors" and "final use sectors." The intermediate sector represents the flow of intermediate inputs from one sector to another to facilitate the process of production of final goods. The matrix of intermediate sector has one row and one column for each sector of the economy and shows, for each pair of sectors, the value of goods and services that flowed directly between them during a stated period. Typically, the matrix is arranged in a way so that the entry in the 'r'th row and 'c'th column gives the flow from the 'r'th sector to the 'c'th sector. The production of intermediate sectors is determined in response to the requirement of the "final demand" sectors, which is the origin of all consumptions. The final demand sector corresponds to the components of gross national product (GNP) and includes private final consumption expenditure, Government final consumption expenditure, gross fixed capital formation, changes in stock, exports and imports. In other words, "final use" sector is the aggregate of the individual exogenous final demand sectors, which appear as column entries in the transaction table. Final demand, which is the exogenous sector in the system, determines the level of total output in the intermediate sectors. Total output consists of final demand and output of intermediate sectors that is required to produce final demand. The intermediate sectors are thus endogenous sectors and are determined within the system through the relationship specified by the model.

A technical coefficient matrix is derived from the transactions matrix by expressing sector inputs as fractions of aggregate input, or output, as total sales equal total purchases. Each column's entries in the transaction matrix are divided by the column total to obtain the technical coefficient matrix. The inverse matrix of the net output matrix (Leontief Inverse matrix) is derived from technical coefficient matrix. The inverse matrix is used to derive industry gross output through the process of solving a set of equations in which inverse is multiplied by final demand.

Any entry in a given column of the inverse matrix shows the direct and indirect requirements in all sectors induced by a one rupee increase in final demand of the sector corresponding to that column. The mathematical model is presented below:

Let us assume that the economy is categorized into n sectors. If we denote the total output (production) of sector i by x_i and the total final demand for sector i's product by f_i, we can write a simple equation representing the way in which output of sector i is distributed through sales to other sectors and to final demand sector as:

$$x_i = z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^{n} z_{ij} + f_i$$

The term z_{ij} represents inter-industry sales by sector to all sectors j including itself, when $i = j$. In matrix notation, this equation can be written as:

$$x = Z_i + f$$

where

$$x = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \text{ and } z = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix} \text{ and } f = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix}.$$

If we define technical coefficient matrix A of dimension $n \times n$, each element of which is technical coefficient a_{ij} which is defined as:

$$a_{ij} = \frac{\text{value of product of } i\text{th sector used as input by } j\text{th sector}}{\text{value of production of sector } j}$$

Therefore,

$$A = Z \cdot \hat{x}^{-1}$$

where

$$\hat{x} = \begin{bmatrix} x_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & x_n \end{bmatrix}.$$

Therefore, the complete $n \times n$ system can be written in matrix notation:

$$(I - A)x = f$$

For a given set of f's, this is a set of n linear equations with n unknowns, x_1, x_2, …, x_n, and hence, it may or may not be possible to find a unique solution. In fact, whether or not there is a unique solution depends on whether or not $(I - A)$ is singular, that is, whether or not $(I - A)^{-1}$ exists or not. From the basic definition of an inverse for a square matrix,

$$(I - A)^{-1} = \left(\frac{1}{|I - A|}\right)[\mathrm{adj}(I - A)]$$

If $|I - A| \neq 0$, then $(I - A)^{-1}$ can be found, and then using standard matrix algebra, results for the linear equations gives the unique solution as:

$$x = (I - A)^{-1} f = Lf$$

This is evident from the above equation that gross output depends on the values of final demand.

There are two major assumptions behind the input–output framework. One is the assumption of constant returns to scale. The other assumption is that there is no possibility of substitution among inputs in the production of any good or service. In other words, the second assumption states that there is only one process used for the production of each output. Alternatively, the level of output of a product determines uniquely the level of each input required. This assumption, thus, excludes the all other/alternative choices about the proportions in which inputs are to be combined in the production of a given output and negates the possibility of optimization. With this type of production function, all inputs are assumed to be perfect complement to each other. Marginal product of every alternative combination of them is zero, except the particular combination with all other inputs defined in the model.

The assumption of constant return to scale is also very much restrictive. It is often argued that the functions are more complex than simple proportions if we want to describe production function realistically. In the industries like railways or communication, installation of large infrastructure is needed which requires large investment, even before any output appears. Simple proportions production function is defined on the basis of the parameters of the production process at a certain point of time. This makes the computation process simplified though it loses certain important information. It would also be a very much complicated process to identify the type of function which can be used for each and every production process in the economy.

One of the extensions of the Leontief framework is to account for inter-industry energy flow by converting the general input–output matrix to a “hybrid” energy input–output matrix. In general, energy input–output analysis typically determines the total amount of energy required to deliver a unit of product to meet the final demand, both directly as the energy consumed by an industry’s production process and indirectly as the energy embodied in that industry’s inputs.

In the energy input–output model, total energy requirement per unit of output of any industry is called energy intensity of the industries. This is similar to Leontief inverse of the traditional input–output model, which is in monetary unit. Difference is that in energy input–output analysis, we are concerned about the total requirement of physical energy rather than monetary value. One way of calculating this physical energy requirement is that we can first compute the total monetary value of the requirement of primary energy through conventional input–output analysis and then convert these values to suitable physical unit of energy by means of prices relating monetary value and physical unit of energy outputs. But such procedure creates inconsistencies in the accounting of energy consumption due to certain over-simplifications in the process. To solve the problem, in computing energy intensity of a product, primary (coal and lignite, crude oil, natural gas) and secondary energy (petroleum products, electricity) are separately treated. Secondary energy sectors receive primary energy as an input and convert it to the secondary energy form. Both the primary energy input and secondary energy inputs in physical unit are calculated and are further used to estimate the total primary energy requirement. Hybrid energy input–output model represents a transaction table in hybrid unit, where the non-energy items are in monetary unit and the energy items are in physical unit.

4 Methodology and Data Requirement

Hybrid energy input–output analysis describes energy consumption by different sectors in the economy. It is based on the theory of conservation of energy embodied in products and services, which says that energy embodied in the output of an industry is equal to the energy embodied in the input commodities and external energy inputs to the industry (Bullard and Herendeen 1975; Bullard et al. 1978; Casler and Wilbur 1984; Hawdon and Pearson 1995; Miller and Blair 2009). As mentioned earlier, hybrid input–output model is an extension of input–output model, where energy and non-energy sectors are in different units; non-energy sectors are in monetary unit and energy sectors are in physical unit. Physical unit of energy consumption through different energy carriers is converted to one particular unit of energy, for example, in this study the unit used is kgoe or kilogram of oil equivalent unit (Fig. 1).

In a hybrid input–output model, the values of certain rows, which show the use of energy, are replaced by relevant details of physical quantity. The final demand columns are also made up partly by values in monetary unit and partly by energy uses in physical unit. The output of the selected energy branches is also given in physical unit.

Theoretically, the model starts with basic input–output identity:

$$x = z_i + f$$

The total number of sectors, n, is divided into energy and non-energy sectors, where number of energy sectors is r. So number of non-energy sectors is $(n–r)$. Rows in the energy sectors are replaced by the values in physical unit.

	Intermediate use		Final Use					Total Output
Commodities\Commodities	Non-energy goods	Energy goods	Private final Consumption	Gross Fixed Capital Formation	Government Expenditure	Export	Import	
Non-energy goods	Intermediate use (Rs.)		(Rs.)	(Rs.)	(Rs.)	(Rs.)	(Rs.)	(Rs.)
Energy goods	Intermediate use (Kgoe)		(Kgoe)	(Kgoe)	(Kgoe)	(Kgoe)	(Kgoe)	(Kgoe)
Gross value added (Rs.)								
Total Output								

⇦ Energy Balance

Fig. 1 Structure of hybrid input–output table (units are in parenthesis)

Transactions in hybrid units are made from the original inter-industry transaction matrix Z, by replacing the energy rows with the corresponding rows in the energy flows matrix, E. Thus, we define a new hybrid transaction matrix, Z^*. We define the vectors:

$$z^* = [z_i^*] = \begin{cases} z_{ij} \text{ where } i \text{ is a nonenergy sector} \\ e_{kj} \text{ where } k \text{ is an energy sector} \end{cases}$$

$$z^* = [f_i^*] = \begin{cases} f_i \text{ where } i \text{ is a nonenergy sector} \\ q_k \text{ where } k \text{ is an energy sector} \end{cases}$$

$$x^* = [x_i^*] = \begin{cases} x_i \text{ where } i \text{ is a nonenergy sector} \\ g_k \text{ where } k \text{ is an energy sector} \end{cases}$$

$$g^* = [g_i^*] = \begin{cases} \text{ where } i \text{ is a nonenergy sector} \\ g_k \text{ where } k \text{ is an energy sector} \end{cases}$$

where Z^* is of dimension $n \times n$, f^* is of dimension $n \times 1$, x^* is of dimension $n \times 1$ and g^* is of dimension $n \times 1$.

The corresponding hybrid matrices are:

$$A^* = Z^* \cdot (\hat{x}^*)^{-1}$$

and

$$L^* = (I - A^*)^{-1}$$

where A^* is direct requirement matrix of coefficient in hybrid unit and L^* is total requirement matrix of coefficient hybrid unit. In a two-sector model, where there is one energy and one non-energy sector and they are defined as sector 1 and 2, respectively, then the units of the matrices are:

$$Z^* = \begin{bmatrix} \text{Rs} & \text{Rs} \\ \text{kgoe} & \text{kgoe} \end{bmatrix}$$

$$f^* = \begin{bmatrix} \text{Rs} \\ \text{kgoe} \end{bmatrix}$$

$$x^* = \begin{bmatrix} \text{Rs} \\ \text{kgoe} \end{bmatrix}$$

$$g^* = \begin{bmatrix} 0 \\ \text{kgoe} \end{bmatrix}$$

Hence, $A^* = \begin{bmatrix} \text{Rs/Rs} & \text{Rs/kgoe} \\ \text{kgoe/Rs} & \text{kgoe/kgoe} \end{bmatrix}$

The matrix L^* will have same units as A^* except that they are in terms of the input requirement (kgoe or Rs) per unit (kgoe or Rs) of final demand (i.e., total requirement) instead of per unit of output (direct requirement).

To separate out the energy rows to construct, a matrix of energy rows (with m × n dimension) can be defined, as G, with element g_k is corresponding to the energy sector k and industry sector j when they are the same industrial sector. Other element of the matrix is zero. This means that nonzero entries will appear along the principal diagonal of G, or, the locations of nonzero elements in G are located where $k = j$.

Hence, we define

direct energy coefficients matrices as δ, where $\delta = G(\hat{x}^*)^{-1}A^*$

and total energy coefficients matrices as $\alpha = G(\hat{x}^*)^{-1}L^*$

The direct energy coefficient matrix, 'δ', provides the direct energy intensity of other sectors as well as own energy sector. Direct demand for energy items for the production of that array of products in the final demand vector can be determined through multiplication of the matrix 'δ' with final demand vector. The total energy coefficient matrix "α" represents total energy intensity of different goods and services, which consists of both the direct and indirect energy demand. If we multiply this with final demand vector, we get the total energy consumption by the product in its production and consumption process.

Input–output transaction table, for India, compiled by Central Statistical Organization (CSO) for the year 2007–2008 is used for the purpose of the study. The 2007–2008 matrices are at 130 × 130 sector classification, of which first 37 sectors belong to primary sector (agriculture, forestry, fisheries and mining), the next 68 sectors cover manufacturing related industries, and the remaining 25 sectors represent tertiary sector, i.e., service activities. The classification of manufacturing industries generally corresponds to four digit level National Industrial Classification

2004 (NIC 2004) which is employed in the Annual Survey of Industries. Input–output transaction table is provided in monetary unit. The original input–output matrix provides information on energy consumption in different forms of fossil fuel by different sectors in terms of rupee value (at current prices) of coal and lignite (sector 27), coal tar products (sector 64), crude petroleum (sector 29), natural gas (sector 28), petroleum products (sector 63), and electricity (sector 107). Additionally, Energy Balance Table of the year 2007 for the data on energy supply and demand is obtained from International Energy Agency (IEA) for the data on energy production and consumption for different sectors of the economy. Data on final demand of the households are available in the Consumer Expenditure Data published by NSSO (National Sample Survey Organization) (NSSO 2014). We have used the Consumption Expenditure Survey Data for the year 2011–2012 (68th Round) for the data on household consumption on different goods and services.

Central Statistical Organization (CSO) provides input–output data for Indian economy in two matrices: Absorption matrix and Make matrix. The former is a (commodity × industry) matrix and provides information on the value of intermediate inputs going into the production of each and all the commodities produced in the economy. Another matrix is make matrix, which is an (industry × commodity) matrix, provides information on the value of goods and services produced from each of all the industries in the economy for the corresponding year. The absorption matrix can be used to define the input coefficients of an industrial activity when operated at a unit level. The make matrix, on the other hand, would define the relative weights or proportion (or linear combination) in which different activities are to be operated to obtain one unit of a given good or service. The multiplication of the former coefficient matrix by the latter one of activity weights would yield the final commodity by commodity input–output coefficient matrix. Each term in the transaction matrix gives information on how much commodity is used to produce how much of the various goods and services in the economy.

In this study, for the purpose of analysis, 73 categories of consumption are defined, of which 67 categories are for non-energy sector and 6 categories are for energy sectors. Here, underlying assumption is that technological coefficients are unchanged in 2007–2008 and 2011–2012. So, technical input–output coefficients of goods and services for 2011–2012 are assumed to be similar to the technical input–output coefficient values in the input–output table for 2007–2008. Input–output table for India provided by CSO contains 130 sectors for 2007–2008, which are aggregated into 73 sectors in this study. This aggregation is important in carrying out the analysis because the energy data is available at a very aggregate level and concordance of the sectors across every industry between input–output table and other datasets on physical consumption or price poses many problems. But mere comparison of the aggregate sectors in the energy balance table and the input–output table is quite simplistic and requires making a lot of assumptions regarding the distribution of inputs in the production process, which may affect the accuracy of the results. Additionally, the emphasis of the study is household sector; and many of the products produced in the industries are not used by the household sector. As a result, energy intensity of these products would not have direct impact on the energy requirement of the household sector. Hybrid energy input–output table is prepared after matching the energy flow data across sectors in energy balance table in physical terms and input–output table in monetary terms.

In this study, implicit composite price of the energy products is used for different sectors by comparing input–output absorption matrix and the energy balance table instead of taking the explicit price of different energy items from different government documents as done by other researchers (Pachauri and Spreng 2002). Use of different individual price of energy items to derive quantity of consumption often leads to over or under estimation of energy price, because price level of same energy items differs accross sectors of utilization or regions. By deriving implicit price of energy items, the vector of final demand for the 73 consumption categories for each household in the NSSO consumption expenditure survey data is generated in concordance with the newly defined 73 sectors of input–output table. Total per capita energy requirement of households of different expenditure categories are derived from the hybrid energy input–output coefficients for those sectors. It is assumed that the technology of production of goods and services imported are similar to the domestically produced goods and services.

5 Results and Analysis

Following the methodology discussed above, hybrid input–output table is prepared for India from the monetary input–output table and the energy balance table. Physical value of total requirement of different energy items for different sectors is estimated and used to analyze the total energy distribution accross sectors and regions. The role of residential sector in energy consumption pattern of Indian economy is further discussed and the inequality of energy consumption in residential sector is explained in the context of aggregate energy consumption.

Table 1 shows the intermediate use of different commodities in hybrid transaction table for the Indian Economy, that is, subdivided into 12 sectors: (1) Agriculture, forestry, and fishing; (2) Mining and quarrying, (3) Manufacturing, (4) Construction, (5) Transport, storage, and communication, (6) Community, social and personal services, (7) Coal tar products, (8) Petroleum products, (9) Coal and lignite, (10) Natural gas, (11) Crude oil and (12) electricity. The hybrid transaction table is generated for the year 2007–2008 where the non-energy items are in Rs. Million Unit and Energy items are in Million Tonnes of oil equivalent unit (Mtoe). The table summarizes the annual flow of goods and services across different intermediate input sectors. The input–output matrix is generated by applying the industry technology assumption where input structure of a secondary product is considered to be similar to that of the industry where it has been produced. The item in the rows in this table shows the volume of inputs (non-energy items in Rs. Million terms and energy items in Mtoe terms) absorbed by the industries to produce the commodities presented in the columns. The table shows that the major primary energy item used as intermediate input is crude oil and coal

Table 1 Flow of goods and services accross intermediate input sectors (Non-energy items in Rs. Million and energy items in Mtoe)

	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture, forestry, and fishing (1)	2,490,769	4	2,305,470	284,499	118,817	679,403	108	775	0	1	0	2,208
Mining and quarrying (2)	3	98	402,009	154,583	0	2,787	306	96	0	0	0	643
Manufacturing (3)	622,345	28,982	114,56,008	2,987,060	1,009,404	1,408,478	15883	88768	45,360	11,543	49,700	135,574
Construction (4)	88,522	3,267	287,583	1,315,193	113,120	329,418	354	2,585	1,577	2,370	24,212	28,264
Transport, storage, and communication (5)	287,229	9,195	1,881,009	547,433	388,299	932,114	8,146	74,582	23,904	4,145	15,390	70,525
Community, social, and personal services (6)	825,020	24,742	3,920,025	1,250,907	1,295,741	2,605,632	14,636	111,209	32,784	4,778	23,134	188,718
Coal tar products (7)	0	0	6	53	0	1	1	0	0	0	0	5
Petroleum products (8)	7	0	45	4	39	6	0	11	0	0	0	9
Coal and lignite (9)	0	0	58	0	0	13	4	0	3	0	0	174
Natural gas (10)	0	0	12	0	1	0	0	2	0	0	0	15
Crude oil (11)	0	0	36	0	0	1	13	1,008	0	0	0	1
Electricity (12)	12	0	23	4	3	6	0	1	1	0	0	5

Source Author’s calculation

Table 2 Direct energy intensity coefficients for Indian economy by commodities in 2007–2008 (energy commodities in Mtoe/Mtoe and non-energy commodities in Mtoe/Million Rs.)

	Coal and lignite	Natural gas	Crude petroleum	Total
Coal and lignite	0.0140817	0.0000000	0.0000000	0.0140817
Natural gas	0.0000010	0.0000755	0.0000000	0.0000764
Crude petroleum	0.0000000	0.0000000	0.0000000	0.0000000
Electricity	2.3710774	0.2044375	0.0078975	2.5834125
Coal tar products	0.0829070	0.0012294	0.2594082	0.3435446
Petroleum products	0.0004443	0.0109916	5.8917725	5.9032085
Agriculture, forestry and fishing	0.0000000	0.0000000	0.0000000	0.0000000
Mining and quarrying	0.0000001	0.0000000	0.0000000	0.0000001
Manufacturing of food and beverages	0.0000002	0.0000000	0.0000000	0.0000002
Textile	0.0000002	0.0000000	0.0000000	0.0000002
Furniture and wood	0.0000027	0.0000001	0.0000003	0.0000031
Leather and rubber	0.0000001	0.0000000	0.0000000	0.0000001
Chemical	0.0000008	0.0000041	0.0000155	0.0000204
Cement	0.0000142	0.0000003	0.0000000	0.0000144
Metal Products	0.0000037	0.0000003	0.0000000	0.0000039
Machinery	0.0000013	0.0000000	0.0000000	0.0000013
Other manufacturing	0.0000007	0.0000002	0.0000004	0.0000013
Construction	0.0000000	0.0000000	0.0000000	0.0000000
Water supply	0.0000000	0.0000086	0.0000000	0.0000086
Transport, storage, and communication	0.0000000	0.0000000	0.0000000	0.0000000
Trade, hotels, and restaurants	0.0000010	0.0000000	0.0000001	0.0000011
Financing, insurance, real estate, and business services	0.0000000	0.0000000	0.0000000	0.0000000
Health	0.0000011	0.0000001	0.0000000	0.0000012
Education	0.0000000	0.0000000	0.0000000	0.0000000
Community, social, and personal services	0.0000001	0.0000000	0.0000000	0.0000001

Source Author's calculation

and lignite. Apart from secondary energy producing sectors like petroleum products or electricity, most important energy-consuming sector is manufacturing.

The matrix of direct energy coefficient for commodities is shown in Table 2. In Table 1 (with 12 sector classification) manufacturing sectors are clubbed together in one sector to facilitate presentation. To capture the coefficient in a more detailed manner, technical coefficients of hybrid input–output matrix are estimated for 25 sectors. Each item in the matrix is obtained by dividing each entry in the transaction table by its column total, i.e., output of the respective industry. The non-energy sectors are in Mtoe/Rs. Million unit and energy sectors are in Mtoe/Mtoe unit. This

Table 3 Total energy intensity coefficients for Indian economy by commodities in 2007–2008 (energy commodities in Mtoe/Mtoe and non-energy commodities in Mtoe/Million Rs.)

	Coal and lignite	Natural gas	Crude petroleum	Total
Coal and lignite	1.02673	0.00166	0.03932	1.0677160
Natural gas	0.01503	1.00215	0.04495	1.0621264
Crude petroleum	0.00825	0.00117	1.03537	1.0447945
Electricity	2.64403	0.23028	1.10090	3.9752155
Coal tar products	0.09742	0.00435	0.35975	0.4615251
Petroleum products	0.07981	0.02481	6.64159	6.7462093
Agriculture, forestry and fishing	0.00000	0.00000	0.00001	0.0000186
Mining and quarrying	0.00000	0.00000	0.00001	0.0000119
Manufacturing of food and beverages	0.00001	0.00000	0.00002	0.0000228
Textile	0.00001	0.00000	0.00002	0.0000298
Furniture and wood	0.00001	0.00000	0.00002	0.0000257
Leather and rubber	0.00000	0.00000	0.00002	0.0000281
Chemical	0.00001	0.00001	0.00017	0.0001825
Cement	0.00002	0.00000	0.00003	0.0000582
Metal products	0.00001	0.00000	0.00002	0.0000291
Machinery	0.00001	0.00000	0.00002	0.0000261
Other manufacturing	0.00001	0.00000	0.00004	0.0000496
Construction	0.00001	0.00000	0.00002	0.0000244
Water supply	0.00000	0.00001	0.00001	0.0000254
Transport, storage, and communication	0.00000	0.00000	0.00004	0.0000404
Trade, hotels, and restaurants	0.00000	0.00000	0.00001	0.0000109
Financing, insurance, real estate, and business services	0.00000	0.00000	0.00000	0.0000041
Health	0.00000	0.00000	0.00002	0.0000269
Education	0.00000	0.00000	0.00000	0.0000031
Community, social, and personal services	0.00000	0.00000	0.00000	0.0000042

Source Author's calculation

study considers three energy sectors, i.e. coal and lignite, natural gas, and crude oil. Direct energy intensity coefficient is very high for petroleum products and electricity followed by chemical and cement industry among non-energy sectors (Table 2). Crude oil intensity is very high for petroleum products and coal intensity is very high for electricity.

Total energy intensity covers the energy demand from direct utilization of a fuel by a sector and the energy demand generated from the inter-industry linkage of different sectors in the economy. Total energy intensity coefficient is provided for all 25 sectors, including energy and non-energy sectors for Indian economy for 2007–2008 in Table 3. Like direct energy intensity coefficient, non-energy sectors

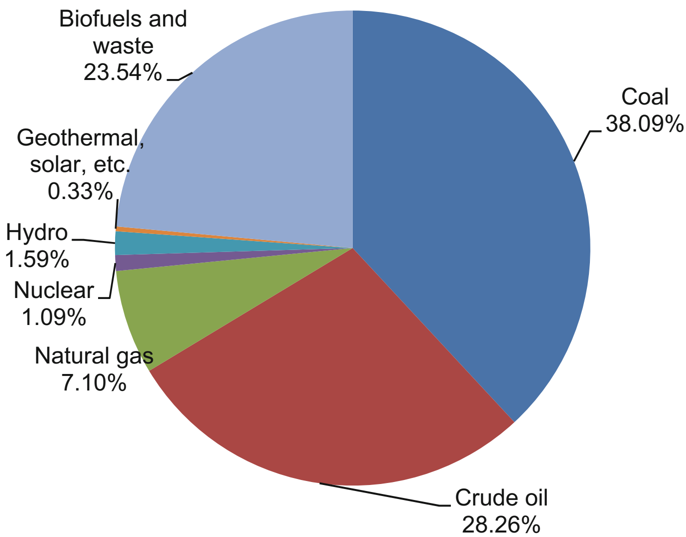

Fig. 2 Share of different fuels in total supply of energy in India (2011). *Source* IEA energy balance Table 2011–2012

are in Mtoe/Rs. Million unit and energy sectors are in Mtoe/Mtoe unit. It is observed that total energy intensity is quite high for all the energy goods as compared to the similar for the direct energy intensity. Total energy intensity is highest for crude petroleum, followed by electricity. Unlike direct energy intensity coefficient, electricity is both coal-intensive and oil-intensive, in terms of total energy intensity coefficient.

Energy is not only a critical input to the production of goods and services of the economy; efficient energy supply enables growth and development of the economy by stimulating economic activity and facilitating essential services. Being a large sector itself, energy can play an important role directly in overall growth of the economy. For example, petroleum products have been an important direct contributor to India's growth in recent years by attracting large investments in refining or distribution (GoI 2017a). India is heavily dependent on import for its energy needs. Despite having huge demand for energy by its increasing volume of population (17% of world population), India shares only 0.6% of gas, 0.4% of oil and 7% of the coal reserve in world. Due to this supply-side constraint, demand-size intervention to optimize energy use is becoming growingly important in policy arena. Figure 2 shows the share of different fuels in total energy supply in India, which is very much dominated by coal, followed by crude oil.

Total demand for energy is quite high in India, but per capita energy consumption is very low in India. As per world development indicator, per capita electricity consumption in India is 806 kwh in 2014, which is lower than many

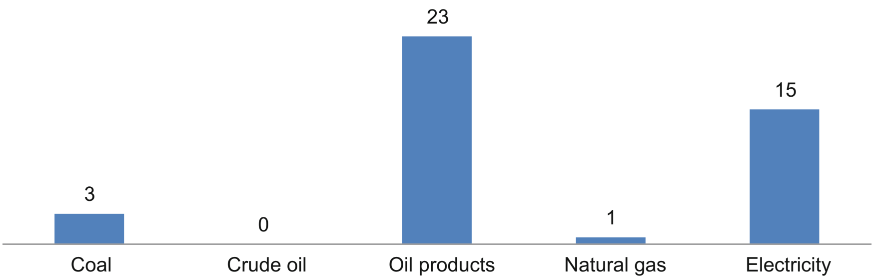

Fig. 3 Residential direct energy consumption in million tonnes of oil equivalent (2011). *Source* IEA energy balance for India

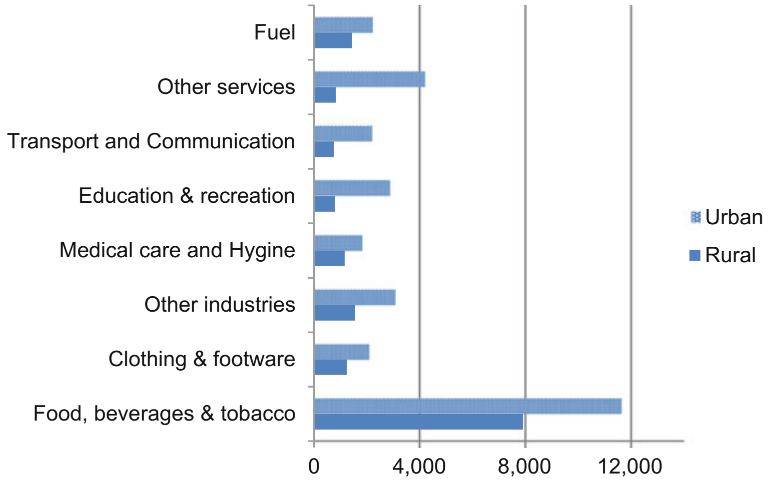

Fig. 4 Average annual consumption expenditure at current prices in rural and urban India in 2011–12 (Rs.). *Source* Author's calculation based on NSSO data 2011–2012

countries, and lowest among BRICS nations.[2] Per capita electricity consumption in Brazil is three times than India. For China, Russia, and USA, it is 5, 8, and 16% higher than India, respectively. With a huge burden of population still living below poverty line, 25% of the population do not have access to electricity. Figure 4 shows the distribution of aggregate residential direct energy consumption (in Mtoe) across different fuels. It can be seen that highest demand for direct energy is for oil products followed by electricity (Fig. 3).

With huge burden of population, residential sector is one of the largest energy-using sectors in India. Direct energy consumption by households accounts

[2]BRICS is acronym for an association of five major countries: Brazil, Russia, India, China, and South Africa

for almost 14% of total commercial energy demand in 2012–2013 (TERI 2014). Direct energy is consumed in the form of electricity, kerosene, LPG, non-commercial energy sources like firewood, dung cake. Pattern of direct energy consumption by residential sector is often discussed in the literature (Reddy 2004, 1999; Pachauri 2004), the emphasis being on direct requirement of energy for cooking or lighting. But residential sector plays an important role in policy perspective for energy conservation, energy security, and emission because this sector itself is responsible for the huge energy demand caused by the energy use in the consumption and production process of the goods and services of their daily use. Households are end-user of goods produced and services delivered by economic production sectors, which require energy for the manufacturing and delivery of these goods. Energy use of manufacturing and service industries can be considered as indirect energy use of households. The total energy use of households, direct and indirect, constitutes the total household energy requirement. Thus, apart from direct energy consumption for cooking and lighting purposes, household sector influences the total energy demand through its consumption pattern and lifestyle trend, which is attributed to the household expenditure. Private final consumption expenditure accounted for 63.6% of GDP (Gross Domestic Product) at factor cost in 2011–2012 (GoI 2015). The embodied energy requirement depends on energy intensities of the products consumed and on the product mix of consumption. The household consumption behavior thus plays a key role in the distribution pattern of embodied energy consumption, and hence total energy consumption.

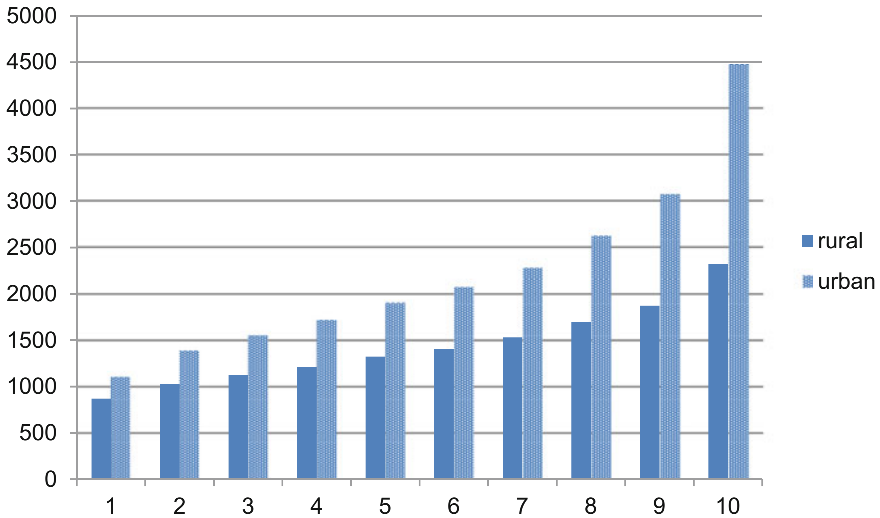

Fig. 5 Annual average expenditure on direct consumption of fuel by rural and urban households across different income decile groups (2011–2012). *Source* NSSO consumption expenditure survey 2011–2012

The average annual consumption expenditure in different consumption category for different income classes for 2011–2012 is shown in Fig. 4. While in rural sector, 51% of per capita expenditure is spent on food items (food, beverage, and tobacco), it is only 39% on an average in urban sector. Fuel accounts for 9% of average consumption expenditure in rural India, while it is 7% for urban India.

Energy is an essential commodity for household sector, for the puposes like cooking and lighting. However, there is significant variation in expenditure in direct consumption of fuels across different categories of households. Average expenditure on fuel rises with an increase in income (Fig. 5). There is significant variation for rural and urban consumption.

Based on the energy intensity and the final consumption expenditure data, the total energy requirement of the household sector is derived through the analysis of hybrid input–output table. Total primary energy consumption is defined as the aggregate consumption of primary sources of energy like coal and lignite, crude oil and natural gas. Tables 4 and 5 show the income class-wise distribution of total

Table 4 Average annual total (direct and indirect) energy consumption of households for different income classes (rural sector) (in kg of oil equivalent) (2011–2012)

	1	2	3	4	5	6	7	8	9	10
Coal and lignite	60	80	93	110	123	144	169	200	245	392
Natural gas	11	14	16	18	20	23	27	33	40	63
Crude petroleum	779	923	1,096	1,217	1,397	1,717	2,101	2,613	3,608	5,750
Total primary energy	850	1,017	1,205	1,345	1,540	1,884	2,297	2,846	3,893	6,205

Source Author's calculation

Table 5 Average annual total (direct and indirect) energy consumption of households for different income classes (urban sector) (in kg of oil equivalent) (2011–2012)

	1	2	3	4	5	6	7	8	9	10
Coal and lignite	141	203	248	292	344	396	447	536	662	1,125
Natural gas	22	33	42	49	57	65	72	84	100	152
Crude petroleum	2,104	3,658	4,854	5,638	6,530	7,202	7,889	8,685	9,611	10,822
Total primary energy	2,267	3,894	5,144	5,979	6,931	7,663	8,408	9,305	10,373	12,099

Source Author's calculation

energy consumption in kg of oil equivalent unit for rural and urban sector. It is evident that with rise in income, there is huge increase in consumption and the associated direct and indirect energy demand. Inequality is also widening with income, which is more for urban areas. It is evident that with rise in income, there is huge increase in consumption and the associated direct and indirect energy demand.

6 Conclusion and Policy Implications

Energy is an essential input in the production process and without it we cannot survive. Economy needs sustainable supply of energy to maintain certain level of growth. At the same time, excessive use of energy leads to environmental degradation and air pollution (Mukhopadhyay 2011). People from lower income group are more vulnerable to the effects of environmental degradation.

Energy use pattern of the economy and choice of fuel determines the extent of fuel use and the pollution generated from it. Residential sector plays a crucial role in the pattern of energy consumption. It consumes energy directly in the form of primary fuels like coal or in the form of secondary fuels like electricity or petroleum products. Additionally, all the goods and services consumed by residential sector require energy in their production, distribution and transport process. The paper highlights the energy-intensive sectors in Indian economy and explores the role of residential sector in energy consumption, in direct or aggregate terms. It also emphasizes on the underlying inequality in energy consumption across different income classes across rural and urban sector.

Results of this paper show the evidence of high-energy intensity in electricity and petroleum products. Both the commodities are integral part of household consumption expenditure. This is also reflected in total primary energy consumption pattern of the typical household. Among the non-energy sectors, direct energy intensity is high for chemical and cement industries. Apart from these industries, total energy intensity is high for textile, leather and rubber, metal products manufacturing industries. Even among services sector, total energy intensity is high for transport, storage, and communication sector. It is important to note that demand for textile, leather, rubber, and metal products are linked with basic necessities. And demand for these products will increase along with the change in lifestyle or process of economic development. Energy analysis for residential sector suggests that India is facing the challenge of growing inequality in the economy, both in terms of monetary expenditure and exploitation of energy resources. There is huge difference in the consumption pattern and lifestyle across different socio-economic groups in the country, which leads to the difference in distribution pattern of consumption of energy resources. The analysis shows that average per capita total (direct and indirect) energy consumption in urban area is quite high as compared to rural sector. Low-income population lives in a very miserable condition consuming only essential, sometimes inferior goods, resulting in very low per capita energy consumption. On the other hand, upper-income classes, due to significant difference in lifestyle, which sometimes leads to conspicuous consumption pattern, is responsible for a very high per capita energy consumption. Rich-poor gap is very prominent in energy use pattern in the household sector, both in direct as well as in aggregate terms.

With expanding population, increase in standard of living along with growing demand for goods and services leads to high demand for energy resources. India is world's sixth largest energy consumer, responsible for 3.4% of global energy consumption. Energy needs for industries in India are met through conventional sources like coal, oil, or electricity. Renewable sources are still not able to provide reliable and sufficient sources of energy due to lack of infrastructure and investment. Targeting better industrial energy efficiency is the most effective tool for lowering energy demand in manufacturing sector. Energy efficiency can be increased through use of energy efficient equipments and through other technological interventions. Some low-cost modifications are very effective and encouraging, which the industries need to identify. For example, Madukkarai Cement Works plant in Tamil Nadu producing cement installed variable frequency drive (VFDs) in the clinkering sections for seven cooler fans in the Kiln and for vacuum pumps to reduce specific energy consumption by fans. As a result, 96.7 kWh of energy was saved per fan and 30 kWh for the two vacuum pumps (TERI 2013). Energy consumption should be optimized to ensure energy security and to reduce pollution. Companies need to identify and implement the best practices by making similar changes in equipment or processes. Waste heat recovery and utilization of that heat is also effective tool for saving energy by industrial plants. Energy audit and estimation of cost and saving in terms of energy can help in defining the baseline standard. Financial incentives like provision of funds through public or private sources (like corporate social responsibility) or provision of credit guarantee to the early investors for energy efficient projects can also be useful in this regard. For example, in Brazil, National Electricity Regulator asked energy distribution companies to invest 0.5% of their revenue in energy-efficiency projects in 1998, which has been successful in providing finance to such projects, even for now (IISD 2014). Monitoring, verification, and increase in awareness of efficient technologies can also play an important role in determining the applicability and certainty of the technologies. Legal and regulatory framework including the possibility of tax exemption needs to be developed to facilitate investment in such projects. There is a dire need to adopt policy measures like clean technology, increasing energy efficiency, and fuel switching in energy-intensive services sectors like transport and communication, for which experiences from different countries can help to design feasible policy options (Mukhopadhyay 2008).

Power sector is one of the most energy-intensive sectors, with 65% of electricity produced by thermal power plants. Industry sector is largest consumer of electricity (43%), followed by residential sector (24%) in 2015–2016 (GoI 2017b), and their demand is growing at a faster rate than other sectors. Average CO_2 emission from coal-fired thermal plants is 1.08 kg per KWh, which is 14% higher than that of China's. Transmission and distribution loss causes loss of around 22% of electricity generated in India in 2015–2016. Thermal efficiency of coal-fired power plants is

35–38% (Bhattacharya and Cropper 2010), due to high ash content and low heat content of Indian coal. According to Khanna and Zilberman (2001), thermal power plants would increase energy efficiency by improving coal quality. High tariff on imported coal and lack of coal-washing facilities pose as impediments to implement it. Growing demand for fuel is a major concern for thermal power plants, where unavailability of gas or lack of infrastructure to adopt renewable technology pose major problem in addition of capacity. High dependence on imported coal also contributes to the high generation cost. Coal production needs to be increased by encouraging private participation, which requires redesigning of regulatory framework. Populist tariff schemes and operational inefficiencies are two major impediments of financing, which need interventions to make the projects win-win situation for all the stakeholders and to make energy-efficiency investments easier and profitable. Apart from these, India needs to develop both conventional and non-conventional forms of energy keeping in view of the pattern of energy demand, fuel cost and availability of fuels.

Residential energy consumption in India is sourced from both commercial and non-commercial energy sources. Firewood, crop-residue, and dung cake are major sources of energy for domestic use. Commercial sources are electricity, kerosene, and liquefied petroleum gas (LPG). Commercial fuels are energy efficient with better heat exchange at the time of combustion and less polluting as compared to non-commercial sources. Households generally switch to costly and cleaner commercial fuels with increase in income, which is evident from the increase in average expenditure on energy with increase in income. Switching to commercial energy would increase energy efficiency and reduce pollution but annualized cost is much higher for them. Providing subsidy to poor households for cleaner fuels like LPG would help them to switch to cleaner fuels. Research and development need to be encouraged to promote improved biomass stoves to ensure energy security. Energy efficient electrical appliances would promote energy saving in household sector. Electrical energy consumption can be significantly reduced through use of energy efficient equipments for cooking, lighting, and other appliances like air-conditioner or refrigerators. Energy efficient buildings can also reduce energy demand in residential sector. Energy consumption tax on higher income groups can also discourage excess energy consumption.

Residential sector is the ultimate consumer of goods and services. Total consumption pattern of energy through goods and services suggests that inequality is quite high for urban sector as compared to rural sector. Total energy consumption is quite low in lower decile groups as compared to high-income groups, both in rural and urban sector. Electrical appliances are a major source of energy consumption, especially in higher income classes. These are energy intensive in direct terms, as well as in terms of energy used for their production. Standard and labeling program for energy appliances used in residential as well as agriculture sector like agricultural pump sets, distribution transformers, motors, and other electrical machineries has been beneficial in the context of energy saving. Petrochemical sector is one of the major growing industries in India, covering the variety of products in every sector, ranging from clothing, food packaging, furniture, toys, computers and household items to automobiles, construction and medical appliances. With changing standard of living, the demand for these commodities is growing at a very fast rate. Industries are required to adopt energy-efficient technologies in production process and to promote energy efficient products to cut down energy consumption. Research is needed to examine factors behind the slow diffusion of energy efficient technologies in Indian context. Energy prices and tariffs should be revisited to encourage the adoption of energy efficient technologies, especially in rural and low-income households.

Change in consumption pattern due to change in lifestyle with the process of economic development and access to basic services in remote rural areas may increase energy demand, thereby promotion of alternative energy sources would be helpful in overcoming the inequality. The changing global economy is creating opportunities for continued progress in human development, which has negative environmental effects like worsening climate change and growing social unrest. Local and global initiatives should be taken to ensure adequate provision of global public goods to meet global and regional challenges and respond to the growing need with greater equity and sustainability.

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Mapping Meso-Economic Impacts of Grid-Connected Solar PV Deployments in India: A Social Accounting Matrix Approach

Surabhi Joshi and Pritee Sharma

Abstract This chapter provides critical insights on developmental impacts of renewable energy scale-up for Indian economy by constructing a social accounting matrix (SAM). Taking a techno-economic perspective, impacts of grid-connected solar deployment as new production activity are estimated for two-established categories (DCR and Open) of solar deployment. This involved construction of independent solar IO blocks integration as a new sector in 35 $\times$ 35 national input–output table (2011) obtained from world input–output databases (WIOD). Wage incomes associated with installation of a unit of grid-connected ground-mounted photovoltaic solar power capacity in India is estimated in terms of skill-based labor compensation generation. The study compiles data from NSSO 68th round data (2011) on household consumption expenditure, employment and unemployment indicators and status of education and vocational training to create consumption and income distribution profile of the nine household categories. The analysis reveals greater wage generation for urban households associated with solar deployment and also highlights the fact that projects using domestically manufactured solar panels provide comparatively wider distribution of wages across the household categories and with better penetration in lower deciles of per capita expenditure indicative of superior developmental impacts.

Keywords Social accounting matrix · Renewable energy · Regional green growth Income impacts · Technology localization · Domestic content requirement

JEL Code E1 · O11 · O25 · P5 · Q4 · R11

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1 Introduction

Dynamics of renewable technology promotion has unprecedently transformed globally in less than a decade, following a sharp decline in production costs of various renewable energy technologies. This has led to over sixfold growth in renewable energy capacity installations (from 85 to 657 GW between 2005 and 2015), with over 164 countries working toward policy driven renewable energy capacity targets (REN21 2016) in the coming decade. Indian energy mix is also systematically transitioning toward a greater renewable energy base scaling up from roughly 4000 MW installed capacities in 2002 to over 57,000 MW by 2017; accounting for almost 16% of the country's total generation capacities (CEA 2017).

The policy decisions aiming at energy transition of such magnitude implies concomitant lock-in of substantial capital and material resources across the deployment process. Further, as this process of change inextricably interacts with economy, environment, and energy simultaneously a sufficiently sophisticated analytical framework is needed to understand emerging techno-economic trends and formulate effective policies around these energy transitions for developing country like India.

Being a tropical country, potential of solar-based energy generation was recognized quiet early in the country with multiple initiatives promoting solar thermal and photovoltaic installations more from the stand-alone end-user perspective. A systematic supply-side intervention for solar scale-up came up under flagship of National Solar Mission in 2010. The mission set a highly ambitious target of 20 GW in the program with an umbrella of incentives for scaling up grid-connected utility scale solar power plants.

In February 2015, the Government of India released the report on "Renewable Electricity Roadmap 2030 for India" (Niti Ayog 2015) in the first RE-INVEST summit. Sharp decline in global solar photovoltaic (PV) costs and wind costs led to revamping the already existing solar and wind target to 175 GW on renewables by 2022 (MNRE 2015). The policy decision to logarithmically scale-up RE capacities of this magnitude bring with it strong expectations of not only transforming the energy mix (54.4% renewable by 2027, NEP 2016) but also playing a critical role in articulating the targets for Intended Nationally Determined Contribution (INDC) set under UNFCCC Paris agreement for India. As of April 2017, the country's solar grid had a cumulative capacity of 12.28 GW. India quadrupled its solar-generation capacity from 2,650 MW on May 2014 to 12,289 MW on March 31, 2017. The country added 3.01 GW of solar capacity in 2015–2016 and 5.525 GW in 2016–2017, the highest of any year (MNRE 2017).

Public policies for renewable promotion thus are endorsed with multiple performance expectations. Policymakers usually delineate a list of benefits which range from climate change mitigation to security of energy supply, creation of domestic industry and local employment, expansion of domestic export, and also as climate change adaptation strategy. (Joshi and Sharma 2014; Allan et al. 2011; Hallegatte et al. 2011; Del Rio and Burguillo 2009; Reddy et al. 2006).

India has voluntarily committed to divert substantial resources toward RET scale-up under its national action plan on climate change. National Solar Mission (NSM) has been the most ambitious of the proposed renewable energy promotion program for the country. This makes it essential to critically assess implicit socioeconomic benefits associated with Indian solar scale-up keeping a developmental perspective in mind. This chapter estimates macro-economic impacts of grid-connected solar PV deployment[1] on Indian economy in terms of GDP and employment generation potential along with distributive efficiency of wage income generated among various skill categories and sectors across economy. The work also compares impacts associated with the two distinct categories of solar deployment under NSM, i.e., projects with domestic content requirement (DCR) and open category projects to understand the localizations impacts.[2]

To address the above research agenda, the study has used input–output (IO) analysis. Direct and indirect impacts of solar deployment are estimated by tracing interindustry transactions involved in installing a unit of grid-connected ground-mounted photovoltaic (GGPV) solar capacity. An independent solar IO block is constructed for both DCR and open category deployment in order to compare the economic impacts of technology localization. The study compiles a representative model for existing grid-connected solar PV deployment policy strategy in India using the SAM framework.

SAM extends the existing IO framework and depicts solar deployment leading to income generation which in turn is allocated to institutional sectors. The impacts in the study are distributed between two economic agents, i.e., the households, getting labor incomes, and private corporations getting capital gains. The households are categorized into nine categories on the basis of occupation. The relationship between production structure, income distribution, and consumption profile of nine household groups is harmonized for the analysis.

The prominent inquiry implicit in this work thus relates to developing an understanding from techno-economic perspective of the qualitative differences in the economy-wide impacts of the two modes of solar deployment in India. As the green growth potential of a technology relates to its localization effects which is markedly different for different renewable energy technologies (Carvalho 2015), critical analysis of the deployment preferences for Indian solar transitions become crucially important. A SAM for India with Keynesian-type multiplier model was constructed and the following research questions are being addressed in the study:

- How do solar scale-up under DCR and open category deployment affect household income generation via their effects on sector, production factors, and consumption pattern?

[1]Grid-connected ground-mounted solar PV presently constitutes 98% of total solar deployment capacity in India.

[2]National Solar Mission (2010) phase I provided differentiated incentives for solar deployment projects using domestically manufactured (DCR projects) solar panels from those using imported (open projects) C–Si solar panels.

- How do solar sector induced economic growth trickle downs to poor for the two categories?

The organization of contents for the chapter is as follows. Section 2 provides a brief overview of existing Indian solar policy frameworks and elements. This is followed by a discussion on the use and relevance of domestic content requirement as a policy instrument for renewable promotion globally. Section 4 details methodology, data sources, and data compilation for solar block integration and the social accounting matric construction. The analysis and estimation of distributive impacts of DCR and open solar deployment categories are detailed in section five followed by concluding remarks in the last section, i.e., Section 6.

2 Indian Solar Policy: An Overview

India being a tropical country has immense potential for solar power generation. Country enjoys over 300 sunny days annually with theoretical solar power reception on land area of about 5 PW-hours per year. The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 with about 1500–2000 sunshine hours per year (Indian Energy portal (2010).

There have been a number of long-running programs promoting demand-side use of solar energy for cooking, lighting, water heating, small solar home systems, and water pumping for agricultural use. This includes a long-term solar cooker promotion program between 1980 and 1994 wherein 30% subsidy was provided on the solar cooker purchase which was reduced to 15% subsequently subsidy is being made available to manufacturer on 50% cost-sharing basis (Since 1994). Ministry of New and Renewable Energy (MNRE) initiated a solar lantern program in early 2000, providing 30% capital subsidy on solar lantern purchase till 2009. Further, there have been many incentives at state level for renewable promotion, for example, Punjab Electricity Development Authority undertook a program for financing large-scale PV pumps between (2000–2004) providing more than (70%) subsidy on solar agricultural water pumping. These were mainly demand-side interventions but major sectoral reforms were put in place to integrate establish major renewable component to supply side in India.

There have been series of sectoral reforms augmenting renewable promotion in India. The liberalization regime leads to two major reforms in the early 1990s for the energy sector. The initial reform in the year 1990 opened utility companies to private competition in India followed by a second reform in 1993 imposing demand-side subsidy reduction. Since then there have been series of sectoral reforms augmenting renewable promotion in India. The liberalization regime leads to two major reforms in the early 1990s for the energy sector. This has been followed by few major institutional changes for integration of renewable energy in the power mix as summarized below:

- **Electricity Act 2003**: The aim of this act was the modernization and liberalization of the energy sector through the implementation of a market model with different buyers and sellers. The main points included making it easier to construct decentralized power plants, especially in rural areas and for captive use by communities, and giving power producer's free access to the distribution grid to enable wheeling.
- **National Electricity Policy 2005**: Allows state electricity regulatory commission (SERC) to establish preferential tariffs for electricity generated from renewable sources. National Tariff Policy 2006: Mandates that each SERC specifies a renewable purchase obligation (RPO) with distribution companies in a time-bound manner with purchases to be made through a competitive bidding process.
- **Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) 2005**: Supports extension of electricity to all rural and below poverty line households through a 90% subsidy of capital equipment costs for renewable and non-renewable energy systems.
- **Eleventh Plan 2007–2012**: Establishes a target that 10% of power generating capacity shall be from renewable sources by 2012 (a goal that has already been reached); supports phasing out of investment-related subsidies in favor of performance-measured incentive. The latest national electricity plan (NEP-2016) puts the target of 40% renewables in the energy mix by 2027. The major composition change is expected to come from the existing target of 100 GW grid-connected solar by 2022 with over.

As the major capacity addition in renewable energy sector is post-reforms. The Indian renewable energy sector is predominantly driven by the private sector. The next section delineates the details of the current solar policy and program initiated under flagship of National Solar Mission (NSM) in 2010.

2.1 National Solar Mission (NSM)

For realizing immense solar potential in India an ambitious program, Jawaharlal National Solar Mission (JNNSM) was launched on January 11, 2010. The objective of the program has been to establish India as a global leader in solar energy by creating the policy conditions for rapid technology diffusion and investment across the country. The key initial mission targets are enumerated below

- To create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022. As the global dynamics of solar-based generation transformed this target has been revamped to installation of 100 GW of grid-connected solar by 2022

- To ramp up capacity of grid-connected solar power generation to 1000 MW within three years by 2013; an additional 3000 MW by 2017 through the mandatory use of the renewable purchase obligation. As the capital cost of solar utility installation drastically dropped, the earlier targets have been already surpassed and Indian solar capacity stands at over 6 GW.
- To create favorable conditions for solar manufacturing capability, in particular, solar thermal for indigenous production and market leadership.
- To promote program for off-grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022
- To achieve 15 million m^2 solar thermal collector area by 2017 and 20 million by 2022.
- To deploy 20 million solar lighting systems for rural areas by 2022.

The mission adopted a three-phase approach, phase I from 2012–13, phase II from 2013 to 17, and phase III from 2017 to 2022. A wide umbrella of dynamic policy instruments aimed at efficient rent management under the conditions of emerging cost and technology trends both under domestic and global spaces were executed. The aim was to protect government from subsidy exposure in case expected cost reduction does not materialize or is more rapid than expected (MNRE 2011). The next section details various policy instruments, structure, and elements put in place for solar scale-up and their performance.

2.2 Policy Instruments for Solar Promotion in India

The Indian Government subsidizes solar power through a variety of policy mechanisms like financial incentives, public financing and regulatory policies and their associated instruments as illustrated in Table 1 Renewable energy source (RES) subsidies constitute market intervention on the part of the regulator are designed to increase RES production by either lowering production cost or consumer costs to under market rates or requiring demand to purchase certain volume of RES such subsidies can be direct or indirect (Kammen and Pacca 2004). Tables 2 and 3 delineate various direct and indirect subsidies for solar promotion

Indirect subsidies are not explicit payments or discounts but rather institutional support tools. They include research and development funding, below cost provision of infrastructure or services or positive discriminatory rules such as regulations facilitating grid access for RES power. Direct subsidies are explicit and quantifiable payments, grants, rebates or favorable tax or premium (Batlle 2011). High inherent substitutability of energy as commodity makes it difficult for a clean technology to replace the established energy technologies in the existing centralized energy regime. Promotion of clean technologies therefore invariably depends on subsidies and incentives made available by policymakers.

Table 1 Policy mechanisms and instruments for solar promotion

Policy mechanisms	Policy instruments
Financial incentives	Capital subsidy, grants, rebates Tax incentives Energy production payment
Public financing	Public investments, loans, or financing Public competitive bidding
Regulatory policies	Feed-in-tariff Utility quota obligation Net metering Obligation and mandate Tradable renewable energy certificate

Table 2 Direct subsidies for solar deployment: NSM phase I

Subsidy type	Details
Power purchase agreements	State government undergo long-term power independent power producers
High feed—in tariffs	CERC fixes a premium solar tariffs (INR 11 to INR 14 per unit of power produced)
Distinct REC solar credits	INR 9.30 to INR 13.4 per Kwh

Source MNRE reports 2011–12

Table 3 Indirect subsidies for solar deployment: NSM phase I

Subsidy type	Act
Providing renewable power producers (IPP) free access to the distribution grid to enable wheeling[a]	Electricity Act 2003
Setting up preferential tariffs for RE generation from and differentiated renewable purchase obligations for Discoms (state-wise targets for solar generation)	National Electricity Policy 2005
Policy targets for renewable energy generation (10% by 2012)[a]	Eleventh plan 2007–2012
Power unbundling and development of renewable energy credit trading markets	CERC 2010
Single window clearance for renewable projects	NSM 2010
Allows 100% FDI in the sector through JV	MNRE 2003
Research and development funding	NSM 2010
Relaxation on environmental clearance, i.e., no EIA for PV-based solar power projects	NSM 2010
States facilitate utility-scale solar power projects transmission substation (land, water, and clearances	NSM 2010
Proposed solar parks in states for facilitating targeted solar capacity addition	NSM

[a]Some states like Karnataka have indicated to charge evacuation and wheeling charges in case power is wheeled out of the state

The policy targets have been revamped as the solar-generation costs have been falling primarily due to the more than 80% reduction in production costs of C–Si solar PV panels. The cost of solar generation which was 15–16 INR/kwh in the year 2010–2011 have already reached grid parity with some new megaprojects like Bhadla in Punjab quoting as low as 2.44 INR/kwh in May 2017. The next section details the solar policy structure under National Solar Mission.

2.3 Solar Policy Structure

The solar policy structure is two-tiered wherein state government has the autonomy to formulate and operate through a separate state-level solar policy. Each state already has a state energy development authority (SEDA) which had been traditionally routing the renewable energy projects facilitated through IREDA. The policy framework and implementation get highly heterogeneous at state level.

The NSM mandates differentiated solar capacity targets for various states with renewable purchase obligations (RPOs) and renewable energy credits (RECs) under state jurisdiction. For specific technologies, central government policies and guidelines have been implemented to different degrees by individual states, which have resulted in inconsistencies between states. For example, states have different policies regarding which entity (developer, power purchaser or transmission and distribution company) is required to finance the extension of transmission and distribution lines when generation facilities are developed beyond the reach of the current grid. States also have different regulations regarding technical standards such as mandating the location of the meter, which affects the measurement of the amount of energy that is sold to the grid (NREL 2011).

Most of the initial solar scale-up in the country has been through the state routes. Many states did not conform to the initial domestic content requirement (DCR) put in place for the JNNSM projects and thus have been major drivers of the solar capacity scale-up, by providing much needed arbitrage opportunity for international solar manufacturers to route their solar panel into Indian market. Further, states were provided autonomy for instrumenting many direct and indirect subsidies to solar power plants like State of Gujarat added more than 800 MW solar capacity by providing a secured power purchase agreement to the solar plant installers with no DCR requirement. The entry of international solar panels drastically reduced the cost of solar power generation from Rs. 16/KWh in 2011 to Rs. 3.40/KWh as quoted by Rewa project of Madhya Pradesh in December 2016 (in a short span of 6 years) falling still further. The next section details the important policy elements and sketches the details of growing solar innovation system in India.

2.4 Solar Policy Elements

The initial NSM draft included strategies for solar promotion and technology diffusion through three different routes. The policy document thus provides separate incentives and performance standards for the three routes on the basis of technology characteristics, existing market conditions, energy security coverage, and the scale of deployment. The three elements of solar scale-up include

(1) Grid-connected ground-mounted PV-based solar power plants catering to supply side of power generation.
(2) Off-grid or stand-alone PV installations with battery storage, along with various end-user devices for lighting and ventilation catering demand-side market.
(3) Solar thermal-based power generation along with solar water heaters for domestic and industrial use.

The performance of the three policy elements has been heterogeneous with grid-connected solar PV generation outperforming not only the other two but also the laid policy targets due to unprecedented advances in global solar PV manufacturing. The drastic fall in solar panel prices (almost 80% between 2009 and 2013) led to steep fall in levelized cost of energy production (INR 11/kwh to INR 3.40 in 2017) for grid-connected solar thus reaching grid parity for industrial and household users in India. The last few years have seen the solar promotion in India largely skewed toward scaling up of grid-connected solar PV installations with off-grid solar and solar thermal targets not coping with the solar PV growth. Figure 1 illustrates elements of solar innovation systems, transitions, and transformation of policy targets along with key players in the domain.

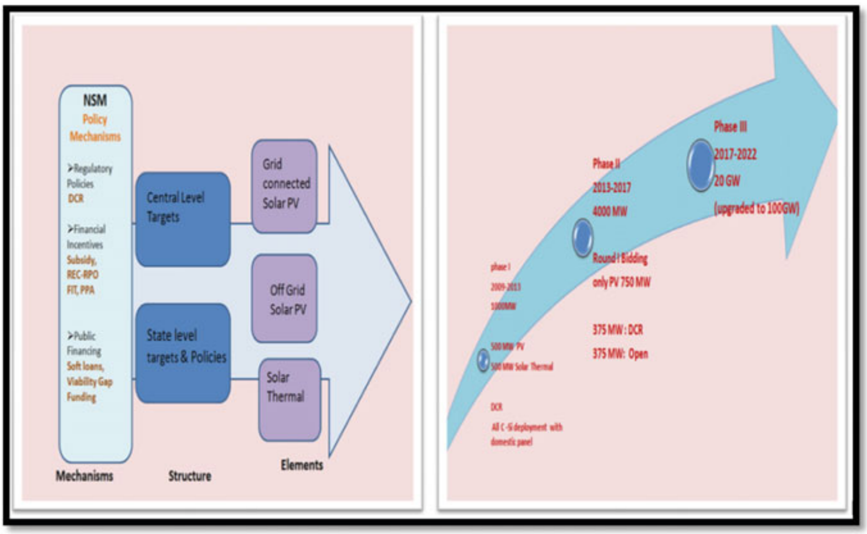

Fig. 1 Elements of solar innovation system in India and transition process. *Source* Author's compilation

3 Renewable Energy Technology Promotion and Domestic Content Requirements

The national-level policies for promotion of RETs focus more on socioeconomic benefits taking the endogenous development route. For example, renewable energy policies of many developed countries complying with Kyoto protocol targets, like Spain, Germany, and Italy, focus on employment generation potential from the sector (Del Rio and Burguillo 2009). Further, emerging economies like India and China focus on export possibilities through promotion of in-house solar manufacturing.

According to Kuntze and Moerenhout (2013) renewable energy policy of many countries, at different levels of economic development attach local/domestic content requirements to their support schemes and procurement tenders. Local content requirements are policy measures that mandate foreign or domestic investors to source a certain percentage of intermediate goods that are being used in their production processes from local manufacturers or producers. These local producers can be either domestic firms or localized foreign-owned enterprises. Often, the legislation foresees a gradual increase in the percentage of inputs that needs to be sourced locally. The overall objectives of local content requirements are seldom spelled out explicitly, but usually developing local competitive industries or increasing employment are addressed (Tomsik and Kubicek 2006).

Instruments like local content requirements/domestic content requirement (LCR/DCR) have been imposed in countries like Brazil, Spain, China, and Canada for wind-based generation while other countries like Denmark and Germany have resorted to soft loans for projects having high local content-based elements. Recently, even the developed technology market resorted to trade restrictions with European markets imposing anti-dumping regulation on Chinese solar panels. In India, policymakers initially focused on distinct local content requirements for grid-connected solar PV and solar thermal projects. Further, as the DCR content in Indian solar policy was questioned in WTO, Directorate General of Anti-Dumping (DGAD) in India had proposed to impose anti-dumping duties of up to \$0.48 per watt on solar cells coming from the US and \$0.81 per watt from China. For countries like Malaysia and Taiwan, it is \$0.62 per watt and \$0.59 per watt, respectively (Economic Times 2014). The strategy took a U-turn post-India's ratification to Paris convention of UNFCCC, where a target of 175 GW grid-connected renewables was proposed with 100 GW capacity additions only with solar.

Although WTO in the year 2016 has ruled against the DCR content in Indian solar policy, mandating that it violates the free trade agreements and has to be removed, studying the impacts of DCR on Indian solar sector is critically important to understand the economy-wide impacts of promoting local manufacturing of solar panels considering the fact that solar scale-up is one of the major elements in green growth strategy for India.

The solar technologies are characterized by comparatively high spatial mobility (Carvalho 2015), the supply chain tends to integrate more globally than locally.

According to Farrel (2001), capability of LCR to create green jobs serves as the first economic objective that helps in gaining political support. According to Del Rio and Burguillo (2008), ability to create a high-quality permanent job in case of PV sector occurs only during panel manufacturing. The process of power plant installation is short for about initial 3–4 months usually creating temporary local labor jobs followed by a handful of jobs for plant operation and maintenance over the entire life cycle of about 25 years. Thus, the possibility of permanent green job creation through solar promotion lies predominantly in the manufacturing sector.

Secondly, as LCR/DCR is aimed at fostering infant industries by protecting them from foreign competition but may subsequently aimed at growth of an export-oriented new sector. India traditionally has been an exporter of solar panels and advent of JNNSM opened a path for indigenous demand creation. The timing of the policy also coincides with unprecedented growth of Chinese solar manufacturing sector adversely impacts the industry niche creation in India. The LCR criteria provided a security net for domestic manufacturing against Chinese dominance in the sector.

According to Lewis and Wiser (2005), the LCRs also provide an increased tax base for the government due to increased growth in manufacturing. Although GDP and tax-base consolidation due to house manufacturing is economically favorable there have been concerns regarding inflation in panel price in interstate transaction reducing their viability w.r.t imported panels not needing to pay state taxes. The government in the new GST regime has decided on 5% tax on the use of solar panels thereby attempting to make up for the revenue loss due to use of imported solar panels.

The LCR as a policy instrument can be effective when the proportion of required domestic content is not too high and are gradually phased in (Lewis and Wiser (2005). The first phase of NSM (2010–2011) has set the requirements that the projects to be selected in the first round (2010–11) that are based on crystalline–silicon technology had to use modules manufactured in India. This requirement was strengthened in the second round (2011–12) in which all eligible PV projects must use cells and modules manufactured in India (Government of India 2010). The NSM further required that 30% of a project's value in solar thermal projects must be sourced locally. The scheme was administered by the NTPC Vidyut Vyapar Nigam Ltd (NVVN 2010), which is a subsidiary of the public power producer National Thermal Power Corporation.

Lewis and Wiser (2005) and Veloso (2001) find that LCR is only effective if applied to a large stable market for a longer period. The NSM sets a long-term policy target for scaling up solar installed capacity to 20 GW by 2020 revamped in 2015 to 100 GW of grid-connected solar by 2022. Thus, the policy holds potential for a large solar market but the markets have been volatile with an unprecedented fall in the cost of solar panel manufacturing globally. The second round of NSM encompassing a capacity of 700 MW was later modified to effectively factor in discrepancies in the cost of power generation for PV projects by equally dividing the II phase quota to be auctioned under two heads through viability gap funding mechanism with 350 MW of installed capacity routed through DCR route and

350 MW through non-DCR-based route. According to Bridge to India (2014), the differential in bidding between DCR and non-DCR projects translates to an additional expense of 65% incurred by the government.

The DCR content in Indian solar policy has to be phased out in accordance with the WTO rulings but this also makes it crucially important that impacts of not including a DCR content are evaluated from a developmental perspective. A cognizance of the fact that the Indian solar policy articulated under National Solar Mission is a major initiative within national action plan for climate change (NAPCC 2008), catering also to the climate change vulnerability and climate change induced adaptations for India. The next section provides details of DCRs in renewable energy policies globally.

The socioeconomic expectations implicit in renewable scale-up often warrant use of unique, normatively tailored policy design that fits well with economy-specific developmental agenda. A highly criticized but popular strategy among policymakers has been to instrument channelization of intermediate goods for renewable energy deployment through local producer or manufacturer by including domestic or local content requirements (DCR/LCRs).

Paradoxically even after being readily endorsed globally, status of DCR as a policy instrument has been controversial and often criticized for its performance ambiguities. For instance, Shrimali and Sahoo (2014) point at performance inconsistencies even within the limited context of renewable energy industry while Pack and Saggi (2006) find use of DCRs in industrial policies limiting for the purpose of building competitive domestic market.

Contrastingly, Veloso (2001) evaluates DCR impacts positively pointing to the fact that negative welfare assessments ignore gap between social and private evaluations. According to him, DCRs encourage growth of networks between domestic firms and protected industry, trigger learning effects, and attract greater foreign direct investments. Lewis and Wiser (2001) find that DCRs increasing growth in manufacturing and also bringing concomitant environmental benefits mainly in the form of spillover effects with more competition lowering the cost of green energy technology.

According to Farrel (2011), capability of LCR/DCR to create green jobs serves as an economic objective strongly backed by political support. Augmented by the fact that possibility of creating high-quality permanent job in solar PV sector occurs predominantly during panel manufacturing phase (Del Rio and Burguillo 2009), Kuntze and Moerenhout (2013) recommended case by case basis analysis of DCR impacts that internalize complex country- and technology-specific conditions.

Taking the clue, this study takes the case of DCRs associated with targeted solar PV deployments under Indian National Solar Mission (NSM). Existing literature on the issue (Shrimali and Sahoo 2014 and Sahoo and Shrimali 2013) point at deficiencies in Indian solar innovation system prescribing removal of DCR requirements in order to make Indian solar sector globally competitive and also to leverage trade benefits associated with open markets in sector. However, regional socioeconomic benefits rendered by Indian solar DCRs have not been assessed.

National Solar Mission (NSM) introduced a dynamic domestic content requirement (DCR) for solar capacities deployed under National Solar Mission covering all the three phases of policy roadmap. Phase I (2010–2013) stipulated stringent domestic content requirement (DCR) criteria prohibiting installers from using imported crystalline–silicon (C–Si) solar panels for NSM projects. However, policy allowed use of imported thin-film panels leading to an evident arbitrage toward thin-film installations.

For enhancing overall economic efficiencies of the program, NSM phase II (commenced January 2014) applies a strategy of partial DCR-based capacity addition. Thus, NSM phase II, batch I bidding involves bids for 750 MW of capacity deployment comprising equally divided capacity for 375 MW DCR and 375 MW open categories (SERC 2013). The mandatory DCR criteria although applies only to NSM projects funded by central (federal) government (MNRE 2009) making the policy sufficiently open to leverage trade induced benefits from imported panels in state-level deployment, as discussed WTO has recently passed a ruling against the DCR criteria classifying it as violation of free trade agreement in year 2016 (WTO 2016).

The inquiry implicit in this work thus relates to developing an understanding from techno-economic perspective of the qualitative differences in the economy-wide impacts of the two modes of solar deployment in India. As the green growth potential of a technology relates to its localizations effects which is markedly different for different renewable energy technologies, critical analysis of the deployment preferences for Indian solar transitions become crucially important.

The next section compiles an input–output-based simulation to assess economic impacts associated with deployment of a unit MW of grid-connected ground-mounted solar PV capacity in India. The impact estimation compares projects using DCRs and those constructed under open category where primarily imported solar panels have been used.

4 Model Compilation and Data

The section details methodology and data sources used for estimating direct and indirect impacts of grid-connected solar PV deployment under DCR and Open categories. Impacts of adding grid-connected utility-scale solar PV plants under DCR and open category are traced by determining intersectoral productive relations of Indian economy using input–output analysis. The section initially details methodology and data sources for constructing solar blocks for DCR and open category projects followed by construction of the social accounting matrix from IO tables.

4.1 Constructing the Solar Block

Miller and Blair (1985) propose two approaches to capture new economic activity within an economy: i.e., through construction of a new final demand vector or through addition of new elements in technical coefficient table of an economy. In this work, we introduce solar generation as a new production activity for Indian economy through construction of a separate solar deployment sector. Solar deployment uses characteristically different inputs as compared to prevalent coal-based power generation, independent solar IO blocks for both DCR and open category deployment are constructed and integrated as a new sector in 35 × 35 national input–output table (2011) compiled from world input–output databases (WIOD).

As there do not exist substantial contribution of grid-connected PV solar-based power generation in Indian energy mix till 2011, a solar production block is designed using expert data integrating engineering principle as elaborated later in the text. Direct coefficients for employment and household income obtained from WIOD socioeconomic accounts were used to estimate output multipliers. Figure 2 illustrates solar block formulation for both DCR and open category projects. The constructed solar blocks are presented in Appendix 1 and 2.

Both solar blocks compile data at purchaser's price obtained from 2013, MNRE benchmark pricing which includes prices for C–Si PV panels, mounting structure, power conditioning unit, construction, preoperative costs, operation, and maintenance along with various financial intermediation activities undertaken in India during deployment of ground-mounted solar power plant. The component inputs for a unit MW installation were further detailed using various technical inputs (detailed in Appendix 2). This is followed by adjustments for existing fiscal elements like applicable subsidies, VAT, excise duty, and incurred transportation costs. The input data is prepared at producer price for IO analysis.

The DCR block is differentiated by dissociation of solar panel manufacturing industry into inputs for manufacturing module, wafer, and cells within the economy while in case of non-DCR solar blocks, solar panels feature in the imports column. The silicon ingots and investors are modeled imported for both the categories. The constructed solar blocks are added as a new sector (36th) in already existing 35 × 35 IO table for India obtained from WIOD database. The following subsection details the IO analysis was undertaken.

WIOD national IO tables combine National Account System data which is generated on the annual basis with national supply-use table (SUTs) to derive time series of SUTs (Termurshoev and Timmer 2011). National supply and use tables are available at current and previous year prices (35 industries by 59 products) and National Input–Output tables in current prices (35 industries by 35 industries) data. The database also provides a socioeconomic account sector-wise for the 15-year time series. The data includes sector-wise employment coefficients and labor distribution data essential for employment impact assessment.

Inputs Solar Sector	Solar Panels	Balance of Operation	Charge Controller and Switches	Inverter	Construction and Civil Work	Land Transport	Water Transport	Insurance Pre-operative Cost	Financing Cost	Project Management Cost	Land acquirement
Sector Concordance for WIOD IOT	Solar Sector (36)	Basic & Fab Metal (12)	Electrical & Optical equipment (14)		Construction (18)	Surface travel (23)	Water Travel (24)	Financial Intermediation (28)			Capital formation

Input Solar Sector	Module						Cell					Silicon Wafer
Sector concordance	Packaging	JB, Ribbon, Back sheet	Frame	Electricity	Maintenance	glass	Screen	Energy	Chemicals	Maintenance	Metal Paste	IMPORT
Sector Concordance for WIOD IOT	Paper & pulp (7)	Basic & Fab Metal (12)	Basic & Fab Metal (12)	Electricity supply (17)	Machinery (13)	Other non-metal (11)	Basic & Fab Metal (12)	Electricity supply (17)	Chemical (9)	Machinery (13)	Basic & Fab (12)	Solar Sector (36)

Fig. 2 DCR solar block

Deployment of new solar capacities would not only create direct and indirect sectoral demand but also concomitantly generate local employment and wage incomes. As Indian solar policy distinguishes between projects using imported and domestically manufactured solar panels, independent solar IO blocks and integrated as a new sector in 35 $\times$ 35 national input–output table (2011) for India from world input–output databases (WIOD). Wage incomes associated with installation of a unit of grid-connected ground-mounted photovoltaic solar power capacity in India is estimated in terms of skill-based labor compensation generation using WIOD socioeconomic account database (Fig. 3).

A social accounting matrix (SAM)-based analysis is performed to analyze channels through which demand-driven interventions associated with grid-connected solar PV deployments (DCR and Open) may affect income of various occupational classes in India. This is done in two steps. First structure of Indian economy (inclusive of the newly introduced solar sector) is sketched with social accounting matrix (SAM) framework. This involved juxtaposition of macro-data (national accounts and input–output table) and micro-data (national surveys) under a unified data matrix to portray meso-level interactions of various economic agents. The agents include production sectors, factor of production, household groups and other institutions. Subsequently, SAM is used to develop a multiplier simulation model aimed at tracking and quantifying the nature and extent of linkages among demand created due to solar deployment, economic growth, and income generation reflecting on concomitantly poverty reduction and distribution impacts of solar deployment under DCR and open category.

4.2 SAM Construction

The SAM approach is a flexible tool which can be deployed with varying degree of sophistication. The structure of SAM varies across countries. The differences are with respect to kinds of classification applied, the kinds of sectors and groups transactions distinguished and the degree of detail with which SAM is designed. In general, the formats of SAMs are guided by socioeconomic structure of the countries to which SAMs apply to, varying situations as regards to availability, scope, and nature of basic data needed for SAM and are often tailored to the pertinent research questions (Round 1981).

A SAM was compiled for India with specific integration of new solar sector representative for DCR and open category deployments in India. The production sector involved 36 sector economy modelled using 35 sector Indian IO table (World Input–Output Database 2011) and one solar sector compiled by creation of solar blocks. Further, the National Sample Survey, India (68th round; 2010–2011) was used to compile distribution of per capita consumption expenditure for nine household occupational classes. NSSO data also provides distribution of the rural and urban population among five rural and four urban households. This data was used to estimate household class consumption expenditure for year 2010–2011.

Figure 4.1 (b) Solar Block for Open Category Solar Deployment

Inputs Solar Sector	Solar Panels	Balance of Operation	Charge Controller and Switches	Inverter	Construction and Civil Work	Land Transport	Water Transport	Insurance Pre-operative Cost	Financing Cost	Project Management Cost	Land acquirement
Sector Concordance for WIOD IOT	IMPORT Solar Sector **(36)**	Basic & Fab Metal **(13)**	Electrical & Optical equipment **(15)**		Construction **(23)**	Surface travel **(23)**	Water Travel **(25)**	Financial Intermediation **(28)**			Capital formation

Fig. 3 Open category solar block

NSSO sector-wise consumption data was concorded to WIOD 35 sectoral classification adopted for SAM construction. The consumption expenditure thus obtained was used to estimate household class share of consumption expenditure.

Trade, banking, insurance, business services, and real estate sector do not appear in NSSO's consumption list. The household consumption pattern given in recent SAM for India (2007–2008; Pal et al. 2012) was used to obtain household consumption expenditure for trade, insurance and banking sector, business service, and real estate sectors. Thus, the household final consumption expenditure was distributed among the nine household's classes in 2010–2011.

The total income of each of the nine households was estimated. The households receive income through various sources like labor income, income from capital owned by households, land income, and transfer income from government, and rest of the world. The compiled data included only payments of wages for each of the domestic sectors thus wage income estimated and considered endogenously rest other components were exogenous to the model developed. The estimation of income distribution involved use of WIOD socioeconomic accounts (SEA) data. The sector-wise gross value added (GVA) was first segregated into labor and capital component (Table 4).

The labor component which was available in three categories, i.e., high-skilled, medium-skilled, and low-skilled labor was then estimated. The matching of skill-based income was performed with nine occupational categories. The procedure involved two sets of data sources. The data on percentage distribution of population in various occupational classes according to educational qualification was used from NSSO 68th round key indicators of employment and unemployment in Indian database. The dataset also provided distribution of working population sector-wise (NIC 2008 classification) and also demographically (Rural and Urban). This data was concorded to 35 sector WIOD classification for the study.

To estimate household income from capital ownership data on payments of the domestic production sector for the capital for year 2010–2011 was used. The payment of capital along with net capital income of from ROW is treated as gross capital income of the economy. The capital income was distributed into household classes by obtaining households capital income shares available in SAM of 2007–2008.

This is followed by estimating land income received by agricultural households. The incomes would apply only to the income from land is received only by rural agricultural self-employed household. The total payment for land factor is taken as total land income of the class. The household personal income from different sources does not match the column total of each HH classes of our SAM. A pro-rata adjustment is done to obtain the control total, i.e., the row total of the each household class in the SAM. Figure 4 illustrates the SAM constructed for DCR and open category projects.

The SAM was constructed by extending 36 × 36 solar integrated IO table both DCR and open category. The SAM matrix thus contained total 46 sectors, with 36 production sectors, nine households, and one for capital generation in the economy.

Table 4 Distribution of household income with respect to sources of income and by wages and other components

Rural households	Category	Urban households	Category
H1	Self-employed in agriculture	H6	Self-employed
H2	Self-employed in non-agriculture	H7	Regular wages/ salaries
H3	Agricultural labor	H8	Casual labor
H4	Casual labor	H9	Other HH
H5	Regular wages + others		

Multiplier Analysis

The impact of any demand addition on the exogenous accounts of SAM is transmitted through the interdependent SAM system among endogenous account. The interdependent nature of system implies that incomes of factor, households, and production sectors are all derived from exogenous injection in the economy via multiplier

$$Y = A * Y + X = (I - A)^{-1} * X = M_a * X$$

Y = Vector of endogenous variable, X = Vector of exogenous variables (accounts)

A is the matrix of average propensities of expenditure for endogenous accounts, I is the Identity matrix and M_a or $(I - A)^{-1}$ is the matrix of aggregate accounting multipliers (Table 5).

$$\text{Total} = \text{aggregate multiplier} = \text{Gross output multiplier}$$

When demand-driven interventions occur through sectors, relevant block for impact analysis refer to M11 (Gross output impact of 36 sectors) or output multiplier, M21 (GDP impacts of two factor of production) value added or GDP multiplier, M31 (consumption impact in terms of nine consumption items) consumption multiplier M41, household impacts of nine household groups or income multiplier.

One important feature of the SAM-based multiplier analysis is that it lends itself easily to decomposition, thereby adding an extra degree of transparency in understanding the nature of linkage in an economy and the effects of exogenous shocks on distribution and poverty (Round 2003). The richness of the SAM multipliers comes from their tracing out chains of linkages from changes in demand to changes in production, factor incomes, household incomes, and final demands (Thorbecke 2000). Therefore, the SAM framework permits tracing and quantifying all the propagation channels in the economy, and in doing so, provides a very useful policy instrument for meso-level economy-wide impact analysis of demand-driven interventions.

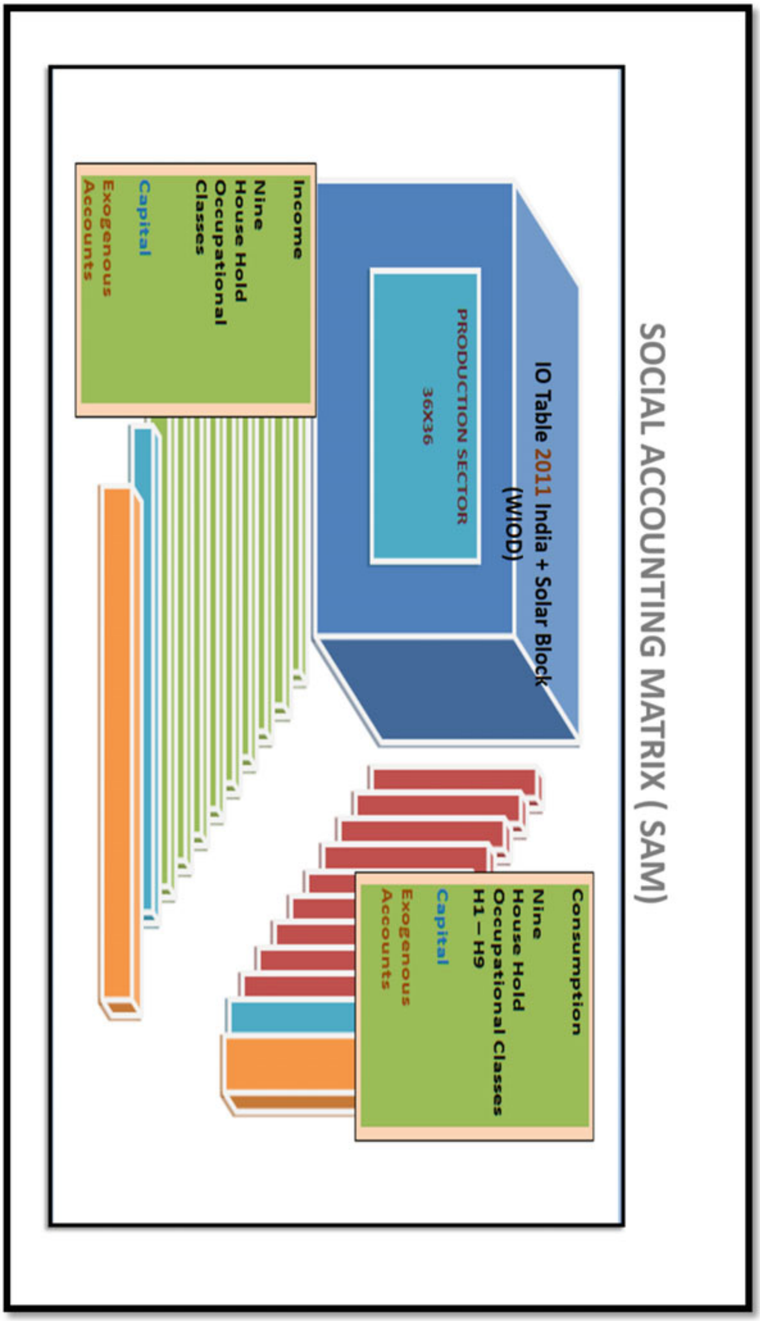

Fig. 4 Schematic of constructed SAM

Table 5 Impact submatrices of multiplier (M_a)

	Sectors	Factor	Consumption	Household
Sectors	M11 (36 × 36)	M12 (36 × 2)	M13 (36 × 9)	M14 (36 × 9)
Factors	M21 (2 × 36)	M22 (2 × 2)	M23 (2 × 9)	M24 (2 × 9)
Consumption	M31 (9 × 36)	M32 (9 × 2)	M33 (9 × 9)	M34 (9 × 9)
Household	M41 (9 × 36)	M42 (9 × 2)	M43 (9 × 9)	M44 (9 × 9)
Total	Backward linkages	Backward linkages	Backward linkages	Backward linkages

Multiplier matrix can be decomposed either as multiplicative decomposition or additive decomposition. This analysis uses a multiplicative decomposition of matrix. A fully articulated SAM would include essentially all economic transactions and transfers between all economic agents. The matrix Z thus is a square matrix where row and column sums are equal. There are certain parts exogenously specified making openings for the model. For instance,

$$G = \begin{bmatrix} Z & F \\ W & B \end{bmatrix}$$

where F is the matrix of exogenous expenditure and B is matrix of exogenous income allocation to final expenditures and F includes categories of final demand which is specified exogenously.

For construction of SAM, the endogenous accounts Z are also distinguished between interindustry transactions, final demand, and value-added categories. Let S be the matrix of SAM coefficients which can also be partitioned into corresponding coefficients for interindustry transactions (A), final demand (C), and value-added category (V/H). This work uses a reduced version of SAM where all value added is distributed into household incomes (wages and capital).

$$S = \begin{bmatrix} A & \cdots & C \\ \vdots & \ddots & \vdots \\ H & \cdots & 0 \end{bmatrix}$$

where

A is the matrix of interindustry coefficients
C is the matrix of endogenous final consumption
H is the matrix of coefficients allocating household income to value added
S can be defined as sum of two matrices

$$S = Q + R \tag{1}$$

where

$$Q = \begin{pmatrix} A & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{pmatrix} \ \& \ R = \begin{pmatrix} 0 & \cdots & C \\ \vdots & \ddots & \vdots \\ H & \cdots & 0 \end{pmatrix}$$

so that

$$\mathbf{X} = S\mathbf{X} + \mathbf{F} \tag{2}$$

where X = (XY) and F = (Fg). The vector X is, once again, the vector of total outputs, Y is vector of total household income, F is the vector of exogenous final demand, and g is the vector of exogenous household income.

Using these definitions in (Eq. 2), we can rewrite (Eq. 3) as:

$$X = QX + RX + F \tag{3}$$

It follows that X − QX = RX + F or

$$X = (I - Q)^{-1}RX + (I - Q)^{-1}F \tag{4}$$

We define $T = (I - Q)^{-1}R$ so that (Eq. 4) becomes

$$X = TX + (I - Q) - 1F \tag{5}$$

If we multiply through (Eq. 5) by T

$$\text{we find } TX = T^2X + T(I - Q)^{-1}F = T(T^{-}X) + T(I - Q)^{-1}F \tag{6}$$

but it also follows directly from Eq. 5 that

$$\begin{aligned} TX &= X - (I - Q)^{-1}F \text{ so that} \\ X &= T\left[TX + (I - Q)^{-1}F\right] + (I - Q)^{-1}F \\ X &= (I - T2)^{-1}(I + T)(I - Q)^{-1}F \end{aligned} \tag{7}$$

or

The matrix dissociation is performed as follows

$$\mathbf{X} = \mathbf{M3M2M1F}$$

$M1$ is intra-group or transfer effect (within accounts effects) due external income injection, where $\mathbf{M1} = (\mathbf{I} - \mathbf{Q})^{-1}$.

This matrix defined as what is often called “direct (effect” multipliers since they include what are easily recognized as Leontief output multipliers, but do not include the multiplier effects associated with other sectors such as value added or households, usually treated as exogenous in input–output models. These multipliers are also sometimes referred to as “intra-group” or own multipliers.

*M*2 is the extragroup or cross-effects. For the case of M2, we again use the special case of partitioned inverse to obtain

where

$$\mathbf{M2} = (\mathbf{I} - \mathbf{T}) = \left(\mathbf{I} + (\mathbf{I} - \mathbf{Q})^{-\mathbf{1}}\mathbf{R}\right)$$

The matrix *M*2 is often referred to as the matrix of indirect multipliers, since it records how the effects of exogenous inputs of each type get transmitted of each type get transmitted to the households’ sector but not the feedback of those increases (or decreases) in household income subsequently on commodity consumption. These multipliers are sometimes referred to as “extragroup” or open group multipliers, since the feedback loop of the impact on household consumption and value added is not included.

*M*3 is circular or inter-group effects measuring full circular effects

where

$$\mathbf{M3} = \left(\mathbf{I} - \mathbf{T^2}\right)^{-\mathbf{1}} = \left(\left[\mathbf{I} - (\mathbf{I} - \mathbf{Q})^{-\mathbf{1}}\mathbf{R}\right]^2\right)^{-\mathbf{1}}$$

The matrix of multipliers *M*3 is also referred to as the matrix of the cross or “closed loop” multipliers, since they capture the feedback effects. For example, for an increase in commodity exports, an exogenous demand, there is an accompanying increase in the interindustry production to satisfy that demand as well as an increase in household income, which in turn feeds back to further increase demand for commodities and so on.

where

$$\mathbf{Ma} = \mathbf{M3} * \mathbf{M2} * \mathbf{M1}$$

The next section addresses the question as to how changes in sectoral demand due to solar deployment under DCR and open category impact different sectors, factors, and consumption patterns. The total multiplier impacts are delineated in Appendix 4 and 5.

5 Results and Discussion

Development of an energy project generates impacts on local economy by creating direct and indirect sectoral demand along with employment generation. The estimations reveal favorable impacts on output multipliers under both DCR and open category deployments in India. The multipliers of the two deployment categories differ both within and across sectors indicative of the fact that the two deployment categories will have different socioeconomic impacts on Indian economy.

The gross output multipliers (Appendix 4 and 5) for the solar sector (sector 36) is highest in both DCR and open category projects although GDP, income and consumption multipliers do not indicate the same trend pointing to the fact that net economic and social impacts of solar deployments can significantly vary. The DCR category shows high GDP multipliers for sectors like agriculture, retail, and wholesale trade. The open category GDP multiplier was highest for wholesale trade, followed by telecommunication and other supporting and auxiliary transport activities.

The income multipliers in case of DCR are highest for retail trade followed by agriculture and public administration. The income multipliers for open category are higher for wholesale trade followed by telecommunication and electricity supply. The consumption multipliers for DCR are highest for agriculture followed by construction and inland transport. In case of open category, deployment agriculture has also had highest consumption, multiplier followed by inland transport and construction.

The multiplier model thus obtained was used to estimate income distribution across the nine occupational household classes segregated in SAM. The analysis indicated that total income generated/MW of solar deployment in 23.35% higher in case of DCR deployments. Further, the composition of rural employment compensation in total income is 46.7% in case of DCR and 35.84% in case of open employment.

The DCR deployment triggers greater income generation in self-employed in non-agriculture (37.27%) and casual labor (29.80%) categories for rural households while the income generated are higher for self-employed in agriculture (26.4%) and regular wages categories (22.01%), in case of open category. For urban households, the highest income generation is in regular wages (68.56%) followed by self-employed (19.1%) for DCR. The household income is more uniformly distributed for urban households in open category with low of 23.85% for others to high of 26.51% for casual labor. The income composition profile is illustrated in Fig. 5.

Further, multiplier decomposition was performed to segregate direct, indirect and circular impacts of solar deployment under DCR and open categories of deployment. The matrix $M1$ is defined as intra-group or transfer effect, which

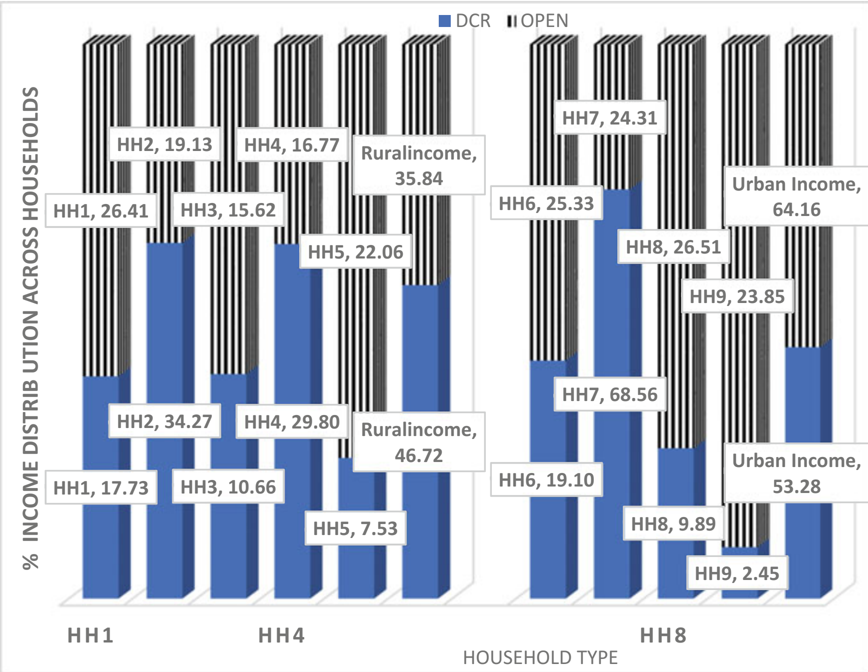

Fig. 5 Income distribution across households for DCR and open category solar deployment

measures the within account effects resulting out of an external income injection into the system. *M*2 is denominated as cross-effects or extragroup effects, which measures the effects on the accounts other than the one where the injection took place. *M*3 is the circular or inter-group effects, which measures the full circular effects resulting out of an exogenous income injection into the system, after returning to the account where the injection originated (Alarcon 2000).

Table 6 delineates results in terms of net difference in multipliers (% change) under the DCR and open categories. Direct impacts of open category deployments (*M*1) is marginally higher than the DCR category but it do not show any cross-sector impacts highlighting the fact that open category deployments are not integrated deeply within the economy. The indirect impacts or the cross-sector impacts (*M*2) is predominantly under the DCR category with highest impacts mapped in textile, paper and pulp, leather and footwear, water transport and private household category. The *M*3 circular effects are for both DCR and open categories but the sector impacted by circular effects widely vary between DCR and open category. In case of DCR, the highest impacts are mapped for other community and

Table 6 Summary of direct ($M1$), cross ($M2$), and circular impacts of solar deployment in India

Sector	DCR	Open	No. of sectors	High impact sectors
M1	present	present	36, 36	
M2	present	Not detected	36, 0	Textile, paper and pulp, leather, transport,
M3	present	present	18, 18	
Income			High impact households	
M1	present	present	9, 9	
M2	present	Not detected	RH4, UH6, RH5, UH9	
M3	present	present	UH9, RH5, UH8	RH4, UH7

social services, agriculture and community services while sectors like electricity, wholesale trade, and post- and telecommunication are higher in case of open category deployment. These results further highlight the qualitative difference and the potential of extremely distinct socioeconomic impacts induced by DCR and open category deployments.

In case of household income multiplier, $M1$ multipliers for direct effects are equal in case of both DCR and open deployments, $M2$ cross-effect multipliers are higher for DCR category rural casual labor, rural wage, and others, urban self-employed, urban others, $M3$ circular effects are higher for urban other, rural wage and others and urban casual labor for DCR and rural casual labor, urban regular wages, and rural self-employed in agriculture in case of open category. The results thus indicate a good backward integration of DCR deployment in the Indian economy. The $M3$ or the circular impacts are mixed for DCR and open categories.

Thus, DCR deployments would lead to greater economic engagement and benefit in terms of GDP and jobs generation. Recent literature dealing with employment impacts of renewable energy policies indicate that local socioeconomic benefits from renewable energy policies are only possible when elasticity of substitution between labor and capital is low and when capital is not internationally mobile. Further, the benefits would accrue when labor intensity of renewable generation is high as compared to conventional generation (Rivers 2013).

According to the latest Indian census 2011 over 69% of population stays in rural India, the distributive efficiency of income effects for solar deployment is better under DCR category having greater income generation for rural households. Further as highest income generation is in self-employed in non-agriculture and casual labor, studying the within-group quintile data (NSHIE 2004–2005) indicates that over 68.8% of the casual labor fall in the lower two income deciles.

In case of solar PV sector, possibility of high-skilled permanent employment generation predominantly occurs during manufacturing stage, followed by a small number associated with operation and maintenance of the plant. Furthering, this is the fact that at present there exists a strong trend toward vertical integration of solar PV manufacturing sector instrumented by use of fully automated assembly lines leading to greater probabilities of labor capital substitution in the sector. This trend reduces future probabilities of international fragmentation of factors or splicing of supply chain thus concentrating manufacturing of solar panels in a region or territory which already has monopoly in the market.

According to Veloso (2001), welfare effects of DCR are well established primarily in the cases where there exists a generic gap between social and private opportunity costs of resource use by an industry or when there is a strong possibility of learning and knowledge spillover associated with foreign manufacturer investing in developing economies. The authors argue that for efficiently leveraging economic growth opportunities rendered by National Solar Mission, strategies to home the capital associated with solar manufacturing becomes critically important. Policy instruments like DCR have potential to play a pivotal role in homing the characteristically mobile capital of solar PV manufacturing by providing an opportunity for long-term stable solar market demand and also ensuring domestic employment creation.

Further, authors argue that NSM is one of the key initiatives undertaken under the umbrella of National Action Plan on Climate change (NAPCC) launched by Indian government in the year 2008. Therefore, impacts of various policy instruments like domestic content requirement (DCR) under NSM have to be analyzed through a more holistic perspective bringing in the concerns of distributive efficiency under climate constrained conditions and economy-wide welfare impacts of the policy into focus. The agenda for Indian National Solar Mission transcends the existing narrative of conventional industrial policy strategy for promoting RET deployment in India to a developmental strategy fine-tuned for alleviating impacts of intrinsic climate change vulnerabilities of Indian economy along with fulfilling the aspired developmental goals.

6 Conclusions

The justification of scaling up renewables in developing and emerging economies is not only framed under an opportunity to leapfrog and move toward low emission developmental pathways but also an expectation of inclusive and equitable economic growth. However, there exits significant ambiguities in forecasted values of green job creation associated with renewable energy deployment in both meta- and country-specific studies. For instance, Cameron and Van Der Zwaan (2015) find significant uncertainties in quoted figures of job creation potential for RETs, both across and within the existing studies. Jain and Patwardhan (2013) analyze impacts of renewable energy policies in India and conclude mixed impacts of scaling RETs for Indian economy, depending mostly on character and configuration of specific RETs.

Further, Cai et al. (2011) estimate that a percentage increase in solar PV generation in China will lead to 0.68% percent increase in total employment. A later study by the authors (Cai et al. 2011) also points toward aggravated gender inequality in the new, fast-growing renewable energy sector for China. Cox et al. (2014) find a negative unconditional cross-price elasticity of labor demand and rising electricity prices due to renewable installation.

This chapter focuses on estimating economy-wide impacts of solar PV deployment under two well-defined categories of DCR and open category projects in India by understanding the pathway for the economy-wide impacts triggered due to deployment of solar power plants in India. The analysis reveals greater wage generation for urban household in medium and high skill category associated with current solar deployment strategy. Further, DCR deployments have higher backward integration in Indian economy with strong cross-sectoral linkages. The study also highlights the fact that projects using domestically manufactured solar panels provide comparatively wider distribution of wages across the household categories and with better penetration in lower deciles of per capita expenditure. Thus, DCR deployments provide better opportunities for inclusive economic growth and development for India as compared to open category solar deployments.

Green growth regime has ushered an era of phenomenal transformation in composition and structure of energy sectors globally and more so for countries like India which are expected to leapfrog into cleaner energy alternatives. Trajectory of these transitions are critical and defining the development pathways for emerging economies of India, requiring a clear understanding of socioeconomic impacts.

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Appendix 1: Solar Block for DCR Projects

Products at purchasers' price	Intermediate Industries														
	Solar sector (36)	Basic and fab metal (12)	Paper (7)	Other non-metals (C11)	Chemicals (C9)	Maintenance (19)	Electricity (17)	Construction (18)	Electrical and optical equipment's (14)	Financial intermediation (28)	Water travel (24)	Surface travel (23)	Total economy	Gross capital formation	Total industry output at base price
Solar silicon wafers (imported)	193.43	0	0	0	0	0	0	0	0	0	0	0	193.43	0	193.43
Back sheet, ribbon, frame, screen metal paste	0	103.79	0	0	0	0	0	0	0	0	0	0	103.79	0	103.79
Hot galvanized steel frames	0	21.9	0	0	0	0	0	0	0	0	0	0	21.9	0	21.9
Packaging	0	0	4.84	0	0	0	0	0	0	0	0	0	4.84	0	4.84
Glass	0	0	0	24.18	0	0	0	0	0	0	0	0	24.18	0	24.18
Chemicals	0	0	0	0	14.5	0	0	0	0	0	0	0	14.5	0	14.5
Maintenance	0	0	0	0	0	29.01	0	0	0	0	0	0	29.01	0	29.01
Electricity	0	0	0	0	0	0	14.5	0	0	0	0	0	14.5	0	14.5
Ground leveling and civil work	0	0	0	0	0	0	0	27.56	0	0	0	1.1	28.66	0	28.66
Wires and transmission, switches charge controller infrastructure	0	0	0	0	0	0	0	0	33.64	0	0	0	33.64	0	33.64

(continued)

(continued)

Products at purchasers' price	Intermediate Industries														
	Solar sector (36)	Basic and fab metal (12)	Paper (7)	Other non-metals (C11)	Chemicals (C9)	Maintenance (19)	Electricity (17)	Construction (18)	Electrical and optical equipment's (14)	Financial intermediation (28)	Water travel (24)	Surface travel (23)	Total economy	Gross capital formation	Total industry output at base price
Invertors	0	0	0	0	0	0	0	0	26.5	0	0.55	0.34	26.84	0	26.84
Insurance	0	0	0	0	0	0	0	0	0	1.72	0	0	1.72	0	1.72
Contingency	0	0	0	0	0	0	0	0	0	5.16	0	0	5.16	0	5.16
Interest during construction	0	0	0	0	0	0	0	0	0	17.2	0	0	17.2	0	17.2
Project management	0	0	0	0	0	0	0	0	0	3.44	0	0	3.44	0	3.44
Financial cost	0	0	0	0	0	0	0	0	0	3.44	0	0	3.44	0	3.44
Pre-operative cost	0	0	0	0	0	0	0	0	0	3.44	0	0	3.44	0	3.44
Water transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land cost	0	0	0	0	0	0	0	0	0	0	0	0	0	10.32	10.32
VAT	0	2.28	0.106	0.531	0.319	0	0	0	0	0	0	0	3.232	0	3.236
Net custom duty	0*	0	0	0	0	0	0	0	0.76	0	0	0	0.76	0	0.76
Subsidy	0	0	0	0	0	0	0	0	(−1.20)	0	0	0	−1.2	0	−1.2
Total output at base price	193.43	127.97	4.95	24.71	14.82	29.01	14.5	27.56	59.7	34.4	0.55	1.44	533.04	0	542.81

Net custom duty 5.5% and subsidy on panel import 4.2%, VAT@ 2.2% All values adjusted to Million USD (2011) exchange rate 46.42 (WIOD database), custom duty is wavered for solar grade semiconductors

Appendix 2: Solar Block for Open Category Projects

Products at purchaser's price	Solar sector (36)	Basic and Fab Metal (12)	Construction (18)	Electrical and optical equipment's (14)	Financial intermediation (28)	Water travel (24)	Surface travel (23)	Total economy	Gross capital formation	Total industry output at base price
Solar panel (imported)	189.27	0	0	0	0	18.91	1.79	0	0	209.97
Hot galvanized steel frames	0	21.94	0	0	0	0	0	0	0	21.94
Ground levelling and civil work	0	0	27.56	0	0	0	1.10	0	0	28.66
Wires and transmission, switches charge controller infrastructure	0	0	0	33.64	0	0	0	0	0	33.64
Inverters	0	0	0	26.50	0	0.55	0.34	0	0	27.39
Insurance	0	0	0	0	1.72	0	0	0	0	1.72
Contingency	0	0	0	0	5.16	0	0	0	0	5.16
Interest during construction	0	0	0	0	17.20	0	0	0	0	17.20
Project management	0	0	0	0	3.44	0	0	0	0	3.44
Financing cost	0	0	0	0	3.44	0	0	0	0	3.44
Preoperative cost	0	0	0	0	3.44	0	0	0	0	3.44
Water transport	0	0	0	0	0	0	0	0	0	0
Land transport	0		0	0	0	0	0	0	0	0
Land cost	0	0	0	0	0	0	0	0	10.32	10.32
VAT	0	0.504	0	0.76	0	–	–	–	–	1.264
Nat custom duty	11.37	0	0	1.58	0	–	–	–	–	12.95
Net subsidy (−)	(−) 9.27	0	0	−1.20	0	–	–	–	–	−10.47
Total output at base price	191.37	22.444	27.56	61.28	34.4	19.46	3.23	359.744	10.32	370.064

Appendix 3

Impacts of DCR and open category deployments are estimated in terms of total GDP output, household income, employment, and distributive efficiencies of income generation. Research models introduction of a new sector (solar PV) in Indian economy. The IO analysis maps relationship between expenditure generated during project deployment and its impacts on 35 + 1 sector Indian economy. The results are estimated in terms of either increased demand in the economy or total change in output of regional economy due to a final demand of the new sector j estimated using the equation:

$$\Delta X = \mathrm{OM}_j \times \Delta \mathrm{FD}_j$$

X total output of the regional economy,
OM output multiplier
FD final demand

The relationship between expenditure generated by a certain project ΔFD and its impacts in the economy in terms of increased demand of good and services (ΔX) is depicted in following relation

$$\Delta X = (I - A)^{-1} \Delta D$$

where I is the identity matrix, A is the matrix of technical coefficients (which reflects the percentage of production from each sector consumed by each of all productive sectors) and $(I{-}A)$ is Leontief inverse that represents the total (direct and indirect) requirements per unit of final demand.

Therefore change in output of total economy (35 sectors, WIOD National Input–Output table for India) where demand of n sectors change can be estimated as

$$\Delta X_{(1\times1)} = n_{(1\times35)} \times \left(\mathrm{OM}_{(35\times1)} \times \mathrm{FD}_{(35\times1)}\right)$$

The employment change in the economy due to given change in final demand of sector j is estimated as

$$\Delta E = \mathrm{TDIE} \times \Delta \mathrm{FD}_j$$

where E is the sectoral employment and TDIE is employment total direct and indirect employment coefficient or simple employment multiplier of sector j. The total change in the employment of the economy in case where final demand of n sectors changes is estimated by

$$\Delta E_{(1\times 1)} = n_{(1\times 35)} \times \left(\mathrm{TDIE}_{(35\times 1)} \times \mathrm{FD}_{(35\times 1)}\right)$$

The total household income change in the regional economy due to given change in final demand of sector j is estimated as

$$\Delta I = \mathrm{TDII} \times \Delta \mathrm{FD}_j$$

where I is household income and TDII is household direct and indirect income coefficient or income multiplier of sector. The total change in household income in the case where final demand of n sector changes is estimated by:

$$\Delta I_{(1\times 1)} = n_{(1\times 35)} \times \left(\mathrm{TDII}_{(35\times 1)} \times \mathrm{FD}_{(35\times 1)}\right)$$

The distributive efficiencies of employment generation between high, medium and low-income jobs were estimated using year-wise socioeconomic accounts data made available by WIOD satellite accounts. The database provides sector-wise low-, high-, and medium-skilled labor share in the total income generated. The estimations involve

$$\Delta I = \Delta \mathrm{HSL} + \Delta \mathrm{IMSL} + \Delta \mathrm{ILSL}$$

Total income generated can be classified into high-skilled income, medium-skilled income, and low-skilled income generation. The distributive efficiency of income generation when final demand change of all the n sectors in the economy are considered

$$\Delta \mathrm{IHSL}_{(1\times 1)} = n_{(1\times 35)} \times \left(\mathrm{TDIHSL}_{(35\times 1)} \times \mathrm{FD}_{(35\times 1)}\right)$$

$$\Delta \mathrm{IMSL}_{(1\times 1)} = n_{(1\times 35)} \times \left(\mathrm{TDIMSL}_{(35\times 1)} \times \mathrm{FD}_{(35\times 1)}\right)$$

$$\Delta \mathrm{ILSL}_{(1\times 1)} = n_{(1\times 35)} \times \left(\mathrm{TDILSL}_{(35\times 1)} \times \mathrm{FD}_{(35\times 1)}\right)$$

.

Appendix 4: Estimated Multipliers for DCR Projects

	Sector	Rank	Gross output	Rank	GDP multiplier	Rank	Income multiplier	Rank	Consumption multiplier
1	Agriculture, hunting, forestry, and fishing	2	3.416	1	1.271	2	0.655	1	4.215
2	Mining and quarrying	32	1.236	29	0.116	30	0.050	13	1.339
3	Food, beverages, and tobacco	14	2.205	24	0.187	22	0.076	9	1.676
4	Textiles and textile products	24	1.807	20	0.219	20	0.114	11	1.475
5	Leather, leather, and footwear	33	1.137	35	0.034	34	0.020	31	0.112
6	Wood and products of wood and cork	15	2.069	15	0.384	12	0.238	30	0.132
7	Pulp, paper, paper, printing, and publishing	16	2.067	22	0.194	19	0.126	27	0.369
8	Coke, refined petroleum, and nuclear fuel	18	2.016	32	0.075	35	0.018	7	1.904
9	Chemicals and chemical products	27	1.729	23	0.189	28	0.053	15	1.070
10	Rubber and plastics	30	1.436	31	0.081	32	0.036	26	0.384
11	Other non-metallic mineral	20	1.921	18	0.248	18	0.126	23	0.529
12	Basic metals and fabricated metal	12	2.384	21	0.204	23	0.076	4	2.533
13	Machinery, nec	29	1.503	27	0.125	27	0.054	20	0.747
14	Electrical and optical equipment	25	1.806	26	0.156	24	0.067	22	0.653
15	Transport equipment	19	1.957	25	0.185	26	0.059	18	0.898
16	Manufacturing, nec, recycling	28	1.697	28	0.119	29	0.052	12	1.469
17	Electricity, gas, and water supply	23	1.843	19	0.229	21	0.114	19	0.856
18	Construction	4	2.820	10	0.602	8	0.327	2	3.048
19	Sale, maintenance and repair of motor vehicles and motorcycles, retail sale of fuel	35	1.072	34	0.040	33	0.025	29	0.157
20	Wholesale trade and commission trade, except of motor vehicles and motorcycles	5	2.698	3	0.940	5	0.440	10	1.536
21	Retail trade, except of motor vehicles and motorcycles; repair of household goods	3	3.170	2	1.251	1	0.661	5	2.445

(continued)

(continued)

	Sector	Rank	Gross output	Rank	GDP multiplier	Rank	Income multiplier	Rank	Consumption multiplier
22	Hotels and restaurants	31	1.422	30	0.107	25	0.066	17	0.969
23	Inland transport	10	2.465	14	0.429	14	0.193	3	3.028
24	Water transport	36	1.036	36	0.016	36	0.007	33	0.066
25	Air transport	17	2.030	16	0.365	16	0.166	32	0.072
26	Other supporting and auxiliary transport activities; activities of travel agencies	9	2.508	9	0.604	10	0.275	28	0.225
27	Post and telecommunications	7	2.635	6	0.798	7	0.385	24	0.469
28	Financial intermediation	6	2.661	5	0.851	6	0.403	8	1.792
29	Real estate activities	22	1.851	13	0.479	17	0.158	6	2.190
30	Renting of M&Eq and other business activities	13	2.330	8	0.671	11	0.257	14	1.238
31	Public admin and defense; compulsory social security	8	2.542	4	0.932	3	0.483	36	0.001
32	Education	21	1.893	12	0.501	9	0.291	16	1.001
33	Health and social work	26	1.761	17	0.358	15	0.186	21	0.673
34	Other community, social and personal services	11	2.439	7	0.795	4	0.451	25	0.425
35	Private households with employed persons	34	1.132	33	0.069	31	0.039	34	0.034
36	Solar PV deployment	1	5.541	11	0.537	13	0.206	35	0.005

Appendix 5: Estimated Multipliers for Open Category Projects

	Sector	Rank	Gross output	Rank	GDP multiplier	Rank	Income multiplier	Rank	Consumption multiplier
1	Agriculture, hunting, forestry and fishing	10	2.272	9	0.559	18	0.089	1	3.736
2	Mining and quarrying	33	1.222	31	0.100	30	0.035	13	1.160
3	Food, beverages and tobacco	8	2.400	19	0.270	14	0.136	10	1.462
4	Textiles and textile products	27	1.609	32	0.096	34	0.016	9	1.602
5	Leather, leather, and footwear	34	1.200	34	0.062	27	0.041	30	0.119
6	Wood and products of wood and cork	18	2.091	13	0.346	11	0.198	31	0.113
7	Pulp, paper, paper, printing, and publishing	22	1.904	33	0.087	28	0.039	26	0.346
8	Coke, refined petroleum, and nuclear fuel	17	2.097	29	0.114	24	0.047	7	1.663
9	Chemicals and chemical products	26	1.691	25	0.159	32	0.028	15	1.006
10	Rubber and plastics	30	1.528	28	0.121	20	0.064	27	0.344
11	Other non-metallic mineral	13	2.141	14	0.335	12	0.185	24	0.416
12	Basic metals and fabricated metal	9	2.376	22	0.185	21	0.058	5	2.090
13	machinery, nec	31	1.474	30	0.100	31	0.033	20	0.645
14	Electrical and optical equipment	25	1.797	27	0.140	23	0.052	22	0.580
15	Transport equipment	21	1.971	23	0.181	22	0.054	18	0.764
16	Manufacturing, nec; recycling	24	1.817	24	0.170	19	0.088	12	1.288
17	Electricity, gas and water supply	5	3.757	4	1.195	3	0.838	19	0.735
18	Construction	12	2.235	20	0.239	29	0.039	3	2.383
19	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	32	1.300	26	0.152	16	0.108	29	0.130
20	Wholesale trade and commission trade, except of motor vehicles and motorcycles	2	5.298	1	2.191	1	1.362	11	1.379
21	Retail trade, except of motor vehicles s	20	2.021	11	0.536	17	0.092	4	2.196
22	Hotels and restaurants	23	1.848	15	0.310	9	0.215	17	0.910

(continued)

(continued)

	Sector	Rank	Gross output	Rank	GDP multiplier	Rank	Income multiplier	Rank	Consumption multiplier
23	Inland transport	16	2.120	21	0.215	33	0.023	2	2.492
24	Water transport	36	1.036	36	0.014	36	0.006	34	0.066
25	Air transport	6	2.927	6	0.790	5	0.478	33	0.067
26	Other supporting and auxiliary transport activities; activities of travel agencies	4	4.000	3	1.310	4	0.793	28	0.208
27	Post and telecommunications	3	4.696	2	1.793	2	1.119	23	0.422
28	Financial intermediation	11	2.270	8	0.578	13	0.180	8	1.609
29	Real estate activities	19	2.063	10	0.558	10	0.211	6	2.082
30	Renting of M&Eq and other business activities	7	2.898	5	0.925	6	0.440	14	1.137
31	Public admin and defense; compulsory social security	14	2.132	7	0.633	8	0.235	36	0.001
32	Education	29	1.572	16	0.284	15	0.115	16	0.951
33	Health and social work	15	2.126	12	0.516	7	0.297	21	0.639
34	Other community, social and personal services	28	1.601	17	0.280	26	0.042	25	0.392
35	Private households with employed persons		1.066	35	0.028	35	0.006	35	0.031
36	Solar PV deployment	1	5.789	18	0.274	25	0.042	32	0.091

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Part V
Environmental Modelling

Comparison of Carbon Hotspots of India and China: An Analysis of Upstream and Downstream Supply Chains

Priyanka Tariyal

Abstract The present study enables the analysis of carbon hotspots responsible for CO_2 emissions in India and China. The hotspot approach indicates the contribution of the various sectors to direct emissions of CO_2 and carbon footprints with a focus only on single pollutant, CO_2. The direct emissions considered in this study refer to the CO_2 emissions generated by a sector to meet its own final demand and demand from all other sectors of the economy, while footprints pertain to the total volume of CO_2 emissions embodied in the upstream supply chain of a sector (Katris 2015). Using the direct and embodied CO_2 emissions, a hotspot is identified as a point on a sector's supply chain (either upstream or downstream) that represents emissions above some standard level. The analysis uses the World Input–Output Database (Timmer et al. 2015) for data on India and China. For the purpose of analysis, only initial and final years, i.e. 1995 and 2009 of this database, have been considered. However, the study further extends the hotspot analysis of Indian economy for the year 2011 by using OECD Intercountry Input–Output Database (OECD 2015). The analysis allows us to identify the sectors that deserve more consideration for mitigation for the success of CO_2 emission reduction strategy.

Keywords CO_2 emissions · Input–output analysis · Carbon footprint
Direct emissions

JEL Code E1 · O11 · O25 · P5 · Q4 · R11

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1 Introduction

The economic system of an economy is not isolated from the ecological system (Machado et al. 2001), and thus, the former may damage its own sustainability by ignoring the latter. Therefore, sustainability of development patterns followed by the largest and the fourth largest greenhouse gases emitter, China and India respectively, has significant socio-economic and environmental implications for the two countries and for rest of the world. Under the Paris Agreement, all countries must commit and adhere to aggressive cuts in carbon emissions which will be toughest for India and China, the world's two most populous countries. In India, which is home to about 1.3 billion people, there is a push to create more jobs in the manufacturing sector which would result in massive energy demands whereas China, on the other hand, is trying to move from a manufacturing-centric workforce to a service-oriented society. But its needs are growing too, as more and more of its population enters the middle class. India's emissions are low when compared with China, as India accounts for only 4% of the global cumulative energy-related emissions since 1850, which is 15% for China (C2ES 2015). But there is an increased pressure on developing countries like India to participate, in the global mitigation efforts to stabilize the climate. Both India and China have set a framework for low carbon development at national level which is evident from incorporation of carbon emission intensity targets by China in 2012 into their five-year plan and development of National Action Plan on Climate Change (NAPCC) by India in 2008 and 2009 wherein the States were directed to develop their own plans.

Thus, this paper attempts to identify the sectors responsible for carbon emissions in the Indian and Chinese economy. The specific objectives of the study are:

- To identifying CO_2 'hotspots' in downstream and upstream supply chains using environmental input–output framework for India and China.

The study employs the hotspot approach that shows the contribution of the various sectors to direct emissions and carbon footprints. The direct emissions for this study considered are the CO_2 emissions generated by a sector to meet its own final demand and demand from all other sectors of the economy (Katris 2015). A widely accepted and concrete definition for the carbon footprint does not exist at present. However, for this study, the total volume of CO_2 emissions which are embodied in the upstream supply chain of a sector has been considered as footprints. Further, a hotspot is identified as a point on a sector's supply chain (either upstream or downstream) that represents the CO_2 emissions above some standard level. Thus, the analysis allows us to identify the sectors that deserve more consideration for mitigation policies. The input–output methodology is used to identify and compare CO_2 'hotspots' in downstream and upstream supply chains in India and China. In order to analyse the emissions generated by various industrial sectors in a specific economy or worldwide, the input–output frameworks have been used by various researchers. An editorial by Wiedmann (2009) provided a transitory historic context of the connection between input–output analysis and environmental research. The environmentally extended input–output analysis is widely used to assess the environmental impacts in the form of emissions embodied in goods and services that are traded between nations (Kitzes 2013). This application holds important prospects for designing mitigation policies depending on the nature of the environmental impact. The literature available for identification of 'hotspots' either focuses on a particular economic sector or applies difference methods/techniques to scrutinize various environmental effects. For instance, Acquaye et al. (2011) performed the life-cycle assessment (LCA) by making use of input–output analysis to identify hotspots along the biodiesel supply chain. Turner et al. (2012) by using a CGE model determined hotspots in metal manufacture within the Welsh economy and attempted to construct a sectoral emission account for the key pollutant CO_2 using a 'bottom-up' methodology. On the other hand, Minx et al. (2009) applied multiregional input–output models to carbon footprinting in areas including trade, supply chains, emission driver. By extending the applications of the conventional demand-driven input–output model, Court et al. (2015) identified hazardous waste hotspots in the supply chains of different final consumption good and consumption groups. After reflecting upon the review of the studies, Sect. 2 discusses the methodology of the study. In Sect. 3, we discuss empirical results followed by the conclusion in final section.

2 Data Sources and Methodology

The carbon hotspot analysis for China and India has been carried out by using the World Input–Output Database (Timmer et al. 2015). The WIOD database comprises the input–output transactions among 35 industries for 40 countries from 1995 to 2011. For the purpose of analysis, only initial and final years, i.e. 1995 and 2009 of this database, have been considered. Thus, carbon emitter's analysis is facilitated with the help of two wide data sets obtained from WIOD, namely National Input–Output Tables (NIOT) in current dollars at purchaser's prices for 35 industries for Indian economy and environment accounts from WIOD (Genty et al. 2012) which provides data on CO_2 emissions at the industry level among other parameters of emissions. The study further extends the hotspot analysis of Indian economy for the year 2011 by using OECD Intercountry Input–Output Database (OECD 2015). This database includes 57 OECD and non-OECD member countries along with rest of the world and shares the same sector grouping as WIOD.

In the beginning, Leontief (1936) demand-driven model in open input–output framework is constructed that follows the methodology presented with Miller and Blair (2009). Then, the conventional input–output table is extended to environmental input–output framework using sectoral emission output coefficients with the help of satellites emission data obtained from WIOD (Genty et al. 2012). The study focuses only on the carbon emission; therefore, only CO_2 emissions have been taken into account for the purpose of analysis. As the emission data from WIOD project (Genty et al. 2012) for various industries are available only till the year 2009, the same is forecasted for the year 2011 by using appropriate univariate ARIMA models for different industries.

2.1 Single Region Input–Output Framework

I–O tables record sales by one producing sector to another and to the final users. The sector's distribution of output throughout the economy is represented in the form of the rows of the interindustry transactions table. On the other hand, the columns of the interindustry transaction table represent the supply of inputs by various sectors of the economy to a particular sector to produce its output.

An input–output framework with n industries for an economy can be expressed in the form of the following expressions:

$$X_i = \sum_{j=1}^{n} X_{ij} + Y_i \quad i = 1, 2, 3 \tag{1}$$

where X_{ij} is the output produced by sector i which is consumed as an input in sector j and Y_i denotes final demand. Furthermore, the proportion of each input to the output of sector j is denoted by

$$a_{Lij} = \frac{X_{ij}}{X_j} \quad i,j = 1, n \tag{2}$$

a_{Lij} give the input of the ith sector required directly for producing one unit of output of jth sector and are called input or technical coefficients.

Thus, above-mentioned Eq. (1) is formulated with Eq. (2) as Leontief production function Eq. (3):

$$X_i = \sum_{j=1}^{n} a_{Lij} X_j + Y_i \quad i = 1, n \tag{3}$$

where X is endogenous and the column final demand and Y is exogenous. In matrix notation, Eq. (3) can be written as:

$$X = A_L X + Y \tag{4}$$

where A_L is the $n \times n$ coefficient matrix consisting of standardized elements of a_{Lij} obtained in Eq. (2). This equation is a fundamental equation of the open Leontief model. Further, Eq. (4) can be written as:

$$X = (I - A_L)^{-1} * Y = L_{ij} * Y \tag{5}$$

where Y is a diagonal matrix and $(I - A_L)^{-1}$ is $n \times n$ matrix known as Leontief (1936) inverse or output multiplier and gives both direct and indirect requirements of inputs. While direct inputs are those purchased by the sector under consideration, indirect inputs are those purchased by all other sectors in which production has to adjust in order to supply inputs to a specific sector.

2.2 Environmental Input–Output Framework: Application of Hotspot Approach

The methodology for hotspot detection is similar to one adopted in studies by Okamoto (2005) and Katris (2015). Firstly, the output emissions coefficient for each sector is calculated which is given by

$$e_{ij} = \frac{E_j}{X_i} \quad i = j \tag{6}$$

where E_j is the total CO_2 emissions from industry j and X_j is gross output of industry j. The E matrix which contains the output emissions coefficient along the diagonal is pre-multiplied to the Leontief inverse from Eq. (5) for obtaining equation for the environmental input–output model which is given as:

$$EX = E(I - A_L)^{-1} * Y \tag{7}$$

The emission multiplier of industry j gives the total CO_2 emissions generated by all the sectors to meet one monetary unit worth of sector j final demand.

$$E_{\mathrm{m}} = \sum_{i=1}^{n} e_{ij} * (I - A_L)^{-1} \quad i = 1, n \tag{8}$$

Thus, the column sum in Eq. (8) gives the CO_2 emissions Type I multiplier. Further, with the multiplication of final demand matrix Y with Eq. (8), we get CO_2 emissions matrix (C_{em}).

$$C_{\mathrm{em}} = \sum_{i=1}^{n} e_{ij} * (I - A_L)^{-1} Y \quad i = 1, n \tag{9}$$

It provides a decomposition of the CO_2 emissions generated by each sector. The sum of the rows in the matrix gives the direct emissions of CO_2 for each sector, while the column sum gives the carbon footprint. Analysing the elements of (9) enables the 'hotspots' detection in downstream and upstream supply chains. Using the estimates of the direct emission obtained for different industries from (9), Type (A) hotspots are identified that generate higher emissions in comparison with other sectors in an economy. While by using the estimates obtained for carbon footprint of different industries, Type (B) hotspots are identified that generate more carbon footprint compared to other industries in an economy. Finally, Type (C) hotspots are identified on the supply chain of a sector as those sectors that embody emissions above the row maximum average (that has been set as the threshold level for the study) in serving all types of final consumption demand (Okamoto 2005).

2.3 ARIMA Model

Auto-regressive integrated moving average (ARIMA) models are useful in time series forecasting as they unfold the autocorrelations in the data. Many researchers have useel for forecasting time series data. In this study, we apply the automatic ARIMA methodology which forecasts a value in a time series as a linear combination of its own past values and errors both. However, one of the limitations of using this model is that it does not elucidate the arrangement of the fundamental data mechanism while approximating historical patterns. ARIMA comprises three order parameters, i.e. (p, d, q).

An auto-regressive [AR(p)] component refers to the use of past values in the regression equation for the series Y. Here, parameter 'p' implies the number of lags used in the model. Suppose if $p = 3$, ARIMA (3,0,0) is denoted as:

$$Y_t = c + a_1 Y_{t-1} + a_2 Y_{t-2} + a_3 Y_{t-3} + e_t \tag{10}$$

where a_1, a_2 and a_3 are parameters for the model.

The parameter 'd' implies the degree of differencing in the integrated [$I(d)$] component. The said parameter is used to make the time series stationary by subtracting the current and previous values in the time series d times.

Furthermore, a moving average [MA(q)] element implies the error of the model as a combination of previous error terms e_t. The third parameter 'q' specifies the total number of terms to be included in the model.

$$Y_t = c + a_1 e_{t-1} + a_2 e_{t-2} + \cdots + a_3 e_{t-q} \tag{11}$$

Then, the combination of three components of ARIMA model, namely differencing, auto-regressive and moving average can be written as a linear equation:

$$Y_t = c + a_1 Y_{dt-1} + a_p Y_{dt-2} + \cdots + a_1 e_{t-1} + a_q e_{t-q} + e_t \tag{12}$$

In this paper, time series yearly data on emissions of CO_2 in India are considered for each of the 34 industries obtained from WIOD (Genty et al. 2012). Therefore, there is no seasonal variation in the data. ARIMA models have been used for forecasting of carbon emissions for each of these industries. This analysis has been facilitated with the help of automatic ARIMA forecasting function in E-views 9. Appendix Table 21 provides the best-fitted ARIMA models that are used to forecast the emissions for the year 2011 along with the emissions forecasted.

3 Results and Discussion

3.1 Results Carbon Hotspots Detection in Upstream and Downstream Supply Chain for the Years 1995 and 2009 for Chinese Economy

This section discusses the direct CO_2 emissions and footprints of Chinese economic sectors for the years 1995 and 2009 to identify the Type (A) and Type (B) carbon hotspots, respectively. Further, Type (C) hotspots are identified from the downstream supply chain of the sector with highest direct emissions and upstream supply chain of the sector with the highest carbon footprint for the years 1995 and 2009.

3.1.1 Direct CO_2 Emissions

The top 15 most polluting sectors of the Chinese economy in terms of direct emissions of CO_2 in 1995 are shown in Table 1. The direct emissions are based on the row sums for each of the sectors in carbon emission matrix, i.e. Equation (9). In Table 1, from column 5 it can be seen that percentage share in direct emissions for 'electricity, gas and water supply (EGWS)', 'other non-metallic mineral', 'basic metals and fabricated metal', 'chemicals and chemical products' is 72.85%, and thus, these four sectors are classified as Type (A) hotspots. 'Electricity, gas and water supply' has the highest direct CO_2 emissions. The reasons for these relatively higher emissions in the first two Type (A) hotspots sectors, i.e. for 'electricity, gas and water supply', 'other non-metallic mineral', could be attributed to the high emission intensity of 29.92 and 4.55, respectively. But high emission intensity is not an absolute driver of carbon emissions since the emission intensity of Type (A) hotspot 'chemicals and chemical products' is relatively lower than 'basic metals and fabricated metals' in spite of relatively high carbon emissions by the latter. Thus, high emissions from 'basic metals and fabricated metal' are due to the high value of total output given in column 8. Similarly, in case of 'agriculture, hunting, fishing and forestry' and 'food and beverages', high value of total output is responsible for high direct carbon emissions, instead of emission intensity. Thus, carbon emission intensity and high value of total output could lead to high emissions by the sector.

The results from Table 2 show that three sectors, namely 'textiles and textile products', 'rubber and plastics' and 'education' among the top 15 direct emitters in 1995 have been replaced by 'water transport', air transport and 'other community, social and personal services' in 2009 for the Chinese economy. Apart from this, the quantity of total direct emissions by top 15 sectors has increased from 2,123,368.61 kt of CO_2 in 1995 to 4,700,966.56 kt in 2009. The percentage share in total direct emissions for 'electricity, gas and water supply', 'other non-metallic mineral' and 'basic metals and fabricated metal' is 75.97% and thus identified as Type (A) hotspots. Further, Type (A) hotspot in 2009 is same as those appear in

Table 1 Top 15 direct emitters of Chinese economy for the year 1995

S. No. (1)	WIOD sector code (2)	Sector name (3)	Direct emissions of CO_2 (in kiloton) (4)	Percent share of total direct emissions (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output (in million $) (8)
1	E	Electricity, gas water supply	830,166.36	39.04	29.92	2757.74	49,172.34
2	26	Other non-metallic mineral	329,392.70	15.49	4.55	8616.44	72,419.71
3	27t28	Basic metals and fabricated metal	218,481.67	10.27	1.99	9903.69	110,066.23
4	24	Chemicals and chemical products	171,096.45	8.05	2.71	9887.13	63,246.94
5	AtB	Agriculture, hunting, forestry and fishing	90,846.04	4.27	0.44	107,412.30	205,154.54
6	C	Mining and quarrying	72,160.08	3.39	1.65	2876.13	43,654.46
7	15t16	Food, beverages and tobacco	67,483.01	3.17	0.65	67,262.37	104,234.64
8	23	Coke, refined petroleum and nuclear fuel	38,628.20	1.82	1.54	1300.37	25,074.35
9	60	Inland transport	34,363.43	1.62	0.96	8164.69	35,950.79
10	29	Machinery, nec	34,358.12	1.62	0.55	27,893.15	62,643.11
11	21t22	Pulp, paper, paper, printing and publishing	31,207.27	1.47	1.13	3585.05	27,564.67
12	19	Textiles and textile products	25,790.61	1.21	0.53	22,969.76	49,075.71
13	25	Rubber and plastics	17,769.33	0.84	0.66	4064.71	26,732.58
14	M	Education	17,472.16	0.82	0.72	22,970.28	24,427.71
15	F	Construction	16,320.26	0.77	0.11	146,035.13	151,970.77

(continued)

Table 1 (continued)

S. No. (1)	WIOD sector code (2)	Sector name (3)	Direct emissions of CO_2 (in kiloton) (4)	Percent share of total direct emissions (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output (in million $) (8)
		Total emission of top 15 sectors	1,995,535.69	93.84			
		Emissions by other sectors	131,102.92	6.16			
		Total emission	2,126,638.61	100.00			

Source Author's own calculation based on WIOD

Table 2 Top 15 direct emitters of Chinese economy for the year 2009

S. No (1)	WIOD sector code (2)	Sector name (3)	Direct emissions (in kiloton) (4)	Percent share of total direct emission (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output (in million $) (8)
1	E	Electricity, gas water supply	2,512,023.50	53.44	6.90	21,454.40	363,879.27
2	26	Other non-metallic mineral	623,445.76	13.26	1.77	3347.18	351,927.26
3	27t28	Basic metals and fabricated metals	435,683.57	9.27	0.48	33,907.63	915,911.26
4	24	Chemicals and chemical products	177,760.37	3.78	0.33	23,010.03	532,189.06
5	C	Mining and quarrying	143,535.50	3.05	0.42	6875.27	342,209.61
6	AtB	Agriculture, hunting, forestry and fishing	99,390.17	2.11	0.13	270,727.92	740,728.96
7	60	Inland transport	77,063.68	1.64	0.36	35,042.90	211,715.37
8	23	Coke, refined petroleum and nuclear fuel	72,289.80	1.54	0.39	1300.37	184,223.09
9	F	Construction	70,969.11	1.51	0.05	1,367,790.46	1,408,068.51
10	15t16	Food, beverages and tobacco	60,563.44	1.29	0.09	314,470.22	666,255.37
11	61	Water transport	57,419.19	1.22	0.92	7722.75	62,392.16
12	21t22	Pulp, paper, paper, printing and publishing	38,433.36	0.82	0.22	2005.88	174,869.73
13	62	Air transport	38,024.18	0.81	1.79	2470.47	21,234.04
14	O	Other community, social and personal services	34,016.55	0.72	0.15	104,482.96	229,216.74
15	29	Machinery, nec	28,290.48	0.60	0.06	216,487.51	491,984.98
		Total emission of top 15 sectors	4,468,908.68	95.06			
		Emissions by other sectors	232,057.88	4.94			
		Total emissions	4,700,966.56	100.00			

Source Author's own calculation based on WIOD

1995 but without 'chemical and chemical products'. Among the three Type (A) hotspots recognized, carbon emission intensity given by column 6 is not the sole reason for high direct emissions by 'basic metals and fabricated metals' as it is in case of other two Type (A) carbon hotspots. The high value of total output of the sector is responsible for high direct emissions by the sector. Thus, analysing emission intensity along with volume of production helps in drawing a conclusion regarding the major driver for CO_2 emissions by a particular sector.

Table 3 exhibits the results for the downstream supply chain of the top Type (C) hotspot sector, i.e. 'electricity, gas and water supply' in 1995. Using Table 1, it can be seen that the sector uses only 17.83% of its total output to meet its final demand but from column 5 of Table 3 it may be noticed that only 12.27% of the sector's emissions are generated for its own final demand. Thus, Type (C) hotspots on this sector's downstream supply chain are identified.

Table 3 shows that the embodied emissions are the elements of each sector in electricity, gas and water supply sector row in Eq. (8). Column 6 shows the elements of each sector on the row of 'electricity, gas and water supply' in emission multiplier matrix given as Eq. (8). Those elements of India's CO_2 emission matrix in Eq. (9) are identified as Type (C) hotspots which are above the average of the row maximums of (9), which is in our case is 20,682.22 kt of $CO_{2.}$ Thus, there are 13 sectors identified in the downstream supply chain of 'electricity, gas and water supply' as Type (C) hotspots. These 13 sectors contribute 82.56% of the total emission in the sector. The 'construction' sector has the largest share, i.e. 25.25% in

Table 3 Carbon hotspots on China's downstream supply chain of 'electricity, gas and water supply' for the year 1995

S. No (1)	WIOD sector code (2)	Sectors name (3)	Embodied CO_2 emissions (4)	Percent share of EGWS total direct emission (5)	CO_2 emission multiplier (6)	Total final demand (Y_j) (7)
1	AtB	Agriculture, hunting, forestry and fishing	57,478.52	6.92	0.54	107,412.30
2	15t16	Food, beverages and tobacco	51,427.04	6.19	0.76	67,262.37
3	24	Chemicals and chemical products	22,812.69	2.75	2.31	9887.13
4	27t28	Basic metals and fabricated metal	24,804.02	2.99	2.50	9903.69

(continued)

Table 3 (continued)

S. No (1)	WIOD sector code (2)	Sectors name (3)	Embodied CO_2 emissions (4)	Percent share of EGWS total direct emission (5)	CO_2 emission multiplier (6)	Total final demand (Y_j) (7)
5	29	Machinery, nec	42,038.82	5.06	1.51	27,893.15
6	30t33	Electrical and optical equipment	25,434.15	3.06	1.25	20,314.10
7	34t35	Transport equipment	29,762.43	3.59	1.33	22,419.87
8	E	Electricity, gas and water supply	101,879.92	12.27	32.19	3165.19
9	F	Construction	209,634.24	25.25	1.44	146,035.13
10	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	20,709.59	2.49	0.76	27,190.78
11	L	Public admin and defence; compulsory social security	37,870.14	4.56	1.08	35,051.28
12	M	Education	36,337.59	4.38	1.58	22,970.28
13	N	Health and social work	25,178.13	3.03	1.45	17,406.49
		Total emission by 13 sectors	685,367.28	82.56		
		Emissions by other sectors	144,799.08	17.44		
		Total emission	830,166.36	100.00		

Source Author's own calculation based on WIOD

the total direct emissions of EGWS. CO_2 emissions multiplier (column 6) shows that EGWS has the highest requirement of its own output to meet its final demand followed by basic metals and fabricate metals with second highest emission multiplier of 2.50.

Similarly, Table 4 shows the results for the top Type (C) hotspot sector 'electricity, gas and water supply downstream supply chain' in 2009. Using Table 2, it can be seen that the sector uses only 16.96% of its total output to meet its final

Table 4 Carbon hotspots on China's downstream supply chain of 'electricity, gas and water supply' for the year 2009

S. No (1)	WIOD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of EGWS total direct emission (5)	CO_2 emission multiplier (6)	Total final demand (Y_j) (7)
1	15t16	Food, beverages and tobacco	101,116.78	4.03	0.32	314,470.22
2	29	Machinery, nec	163,759.43	6.52	0.76	216,487.51
3	30t33	Electrical and optical equipment	108,251.85	4.31	0.57	189,584.83
4	34t35	Transport equipment	130,777.58	5.21	0.60	217,004.27
5	E	Electricity, gas and water supply	219,164.24	8.72	10.22	21,454.40
6	F	Construction	988,763.75	39.36	0.72	1,367,790.46
7	L	Public admin and defence; compulsory social security	111,353.32	4.43	0.33	336,448.38
8	M	Education	104,909.43	4.18	0.44	238,331.64
9	N	Health and social work	122,972.29	4.90	0.60	206,058.38
		Total emission by nine sectors	2,051,068.67	81.65		
		Emissions by other sectors	460,954.83	18.35		
		Total emission	2,512,023.50	100.00		

Source Author's own calculation based on WIOD

demand but from column 5 of Table 4 it may be noticed that the sector generates only 8.72% of the sector's total emissions, to meet its own final demand. Thus, Type (C) hotspots on this sector's downstream supply chain are identified. There are nine sectors identified in the downstream supply chain of electricity, gas and water supply as Type (C) hotspots which are above the average of the row maximums of Eq. (9), which is 68,048.94 of CO_2 in 2009. These nine sectors contribute 81.65% of the total emission in the sector. The largest share is of the 'construction' sector which contributes 39.36% of the total direct emissions of EGWS. CO_2 emissions multiplier column (6) shows that highest requirement for the output by the electricity, gas and water supply is for its own output in order to meet its final demand.

3.1.2 CO_2 Footprints

The results from Table 5 show the top 15 sectors in terms of carbon footprints for the Chinese economy in 1995. The elements in column 5 are the column sums for each sector in CO_2 emission matrix given as Eq. (9). There are three Type (B) hotspots identified in terms of high carbon footprints. These sectors are ‘construction’, ‘agriculture, hunting, forestry and fishing’ and ‘food, beverages and tobacco’. The footprint and direct emission ranks reveal that the ‘construction’ sector has the highest carbon footprint followed by ‘agriculture, hunting, forestry’ among others, indicating that the emissions in these sectors are higher to meet the final demand rather than their direct emissions. Thus, these sectors themselves generate less pollution from their production activities.

In quest to identify the reason behind the high footprint of each of the Type (B) hotspot identified sectors, we use column 7 of Table 5 which gives the emission multiplier for each sector taken from Eq. (7) and is the column sum of the elements of each sector in Eq. (7). The total final demand is given in column 8. The emission multiplier for ‘electricity, gas and water supply’ is highest followed by ‘other non-metallic mineral’, but footprint for each of these sectors is lower than the ‘construction’ and ‘agriculture, hunting, forestry and fishing’, ‘food and beverages’ and ‘machinery, nec’. Thus, relatively higher footprint in the latter sectors is due to high value of total final demand. Thus, emission multiplier is not the sole driver of high footprints in the sectors but final demand also plays an important role in identifying Type (B) hotspots.

Table 6 shows the top 15 sectors in terms of carbon footprints for the Chinese economy in 2009. There are seven Type (B) hotspots identified in terms of high carbon footprints. These are ‘construction’, ‘machinery, nec’, ‘transport equipment’, ‘electricity, gas and water supply’, ‘health and social work’, ‘food, beverages and tobacco’ and ‘public administration and defence’. The construction sector has highest footprint rank but has low rank in direct emissions which reveals that the sector itself generates less pollution from its production activities but is responsible for high direct emissions generated by other sectors to meet its final demand construction. The emission multiplier in column 7 of Table 6 shows that the emission multipliers for ‘electricity, gas and water supply’ are highest followed by ‘construction’.

Table 7 shows the results for the top Type (C) hotspot on the upstream supply chain of the ‘construction’ sector. There are four Type (C) hotspots identified on the ‘construction’ upstream supply chain, namely ‘mining and quarrying’, ‘other non-metallic mineral’, ‘basic metals and fabricated metals’ and ‘electricity, gas and water supply’. These sectors are elements in ‘construction’ sector column in Eq. (9), having values higher than the average obtained for the row maximums, i.e. 20,682.22 kt of CO_2). Table 7 apart from showing the Type (C) hotspots also presents the row maximums appearing on the upstream supply chain of the ‘construction’ sector. The embodied emissions in column 3 reveals that ‘construction’ own production to meet its final demand is 2.53% to the sector’s footprint while ‘electricity, gas and water supply’ and ‘other non-metallic mineral’ followed by

Table 5 Top 15 sectors in terms of carbon footprint for the year 1995 in Chinese economy

Footprint rank (1)	Direct emission rank (2)	WIOD sector code (3)	Sector (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (8)
1	15	F	Construction	622,500.80	29.27	4.26	146,035.13
2	5	AtB	Agriculture, hunting, forestry and fishing	179,934.27	8.46	1.68	107,412.30
3	7	15t16	Food, beverages and tobacco	164,978.16	7.76	2.45	67,262.37
4	10	29	Machinery, nec	105,915.38	4.98	3.80	27,893.15
5	1	E	Electricity, gas and water supply	105,634.34	4.97	33.37	3165.19
6	19	L	Public admin and defence; compulsory social security	83,962.38	3.95	2.40	35,051.28
7	2	26	Other non-metallic mineral	77,304.30	3.64	8.97	8616.44
8	16	34t35	Transport equipment	75,860.30	3.57	3.38	22,419.87
9	14	M	Education	72,189.35	3.39	3.14	22,970.28
10	4	24	Chemicals and chemical products	68,211.56	3.21	6.90	9887.13
11	3	27t28	Basic metals and fabricated metal	66,964.64	3.15	6.76	9903.69
12	22	30t33	Electrical and optical equipment	64,606.76	3.04	3.18	9903.69
13	28	N	Health and social work	62,237.47	2.93	3.58	17,406.49
14	12	17t18	Textiles and textile products	60,895.66	2.86	2.65	22,969.76
15	18	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	49,464.00	2.33	1.82	27,190.78
			Total emission of top 15 sectors	1,860,659.36	87.49		
			Emissions by other sectors	265,979.25	12.51		
			Total emission	2,126,638.61	100.00		

Source Author's own calculation based on WIOD

Table 6 Top 15 sectors in terms of carbon footprint for the year 2009 in Chinese economy

Footprint rank (1)	Direct emission rank (2)	WIOD sector code (3)	Sector name (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (8)
1	9	F	Construction	2,129,973.17	45.31	1.56	1,367,790.5
2	15	29	Machinery, nec	276,701.48	5.89	1.28	216,487.51
3	20	34t35	Transport equipment	228,716.27	4.87	1.05	217,004.27
4	1	E	Electricity, gas and water supply	225,115.53	4.79	10.49	21,454.404
5	19	N	Health and social work	215,204.27	4.58	1.04	206,058.38
6	10	15t16	Food, beverages and tobacco	209,800.56	4.46	0.67	314,470.22
7	17	L	Public admin and defence; compulsory social security	199,343.70	4.24	0.59	336,448.38
8	26	30t33	Electrical and optical equipment	187,501.84	3.99	0.99	189,584.83
9	21	M	Education	162,439.14	3.46	0.68	238,331.64
10	6	AtB	Agriculture, hunting, forestry and fishing	141,840.36	3.02	0.52	270,727.92
11	27	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	84,237.69	1.79	0.43	195,391.09
12	14	63	Other community, social and personal services	77,483.17	1.65	0.74	104,482.96
13	18	17t18	Textiles and textile products	73,664.44	1.57	0.92	80,233.427
14	3	27t28	Basic metals and fabricated metal	71,189.34	1.51	2.1	33,907.633
15	23	H	Hotels and restaurants	64,559.71	1.37	0.7	92,675.031
			Total emission of top 15	4,347,770.67	92.49		
			Emissions by other sectors	353,195.90	7.51		
			Total emission	4,700,966.56	100.00		

Source Author's own calculation based on WIOD

Table 7 Carbon hotspots on China's 'construction' upstream supply chain in 1995

Category (1)	WIOD sector code (2)	Sector name (2)	Embodied CO_2 emissions (kt of CO_2) (3)	Percent share of construction footprint (4)	CO_2 emission multiplier (5)	Output multiplier ($m of output/$m of final demand) (6)
Hotspot	C	Mining and quarrying	25,254.05	4.06	0.17	0.02
Hotspot	26	Other non-metallic mineral	204,692.23	32.88	1.40	0.24
Hotspot	27t28	Basic metals and fabricated metals	82,356.69	13.23	0.56	0.13
Hotspot	E	Electricity, gas and water supply	209,634.24	33.68	1.44	0.01
Row maximum	F	Construction	15,760.35	2.53	0.11	0.00
Row maximum	64	Post and telecommunications	243.44	0.04	0.00	0.01
Row maximum	23	Coke, refined petroleum and nuclear fuel	12,065.76	1.94	0.08	0.02
		Total emission of 7 sectors	550,006.76	88.35		
		Emissions by other sectors	72,494.04	11.65		
		Total emission	622,500.80	100		

Source Author's own calculation based on WIOD

'basic metals and fabricated metals' as intermediate inputs for 'construction' make substantial contribution to sector's footprint.

It is pertinent to examine whether the Type (C) hotspots identified in the upstream supply chain of 'construction' sector are determined by each sectors CO_2 intensity or construction high requirements for output. Thus, examining the emission multiplier in column 6 of Table 7 reveals that requirements of output from 'electricity, gas and water supply' and 'other non-metallic mineral' have larger emission multiplier, which due to the large final demands results in large amount of emissions. Thus, 'construction' requires large amount of input from both the sectors.

From Table 8, there are five Type (C) hotspots identified along with ten row maximum on the upstream supply chain of construction sector. The five Type (C) hotspots are mining and quarrying, 'other non-metallic mineral', 'basic metals and fabricated metals', 'electricity, gas and water supply' and 'construction' itself. These sectors are elements in construction sector column in Eq. (9), having values higher than the average obtained for row maximums (68,048.94 kt of CO_2). The embodied emissions in column 4 reveal that 'electricity, gas and water supply'

Table 8 Carbon hotspots on China's construction upstream supply chain in 2009

Category (1)	WIOD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of construction footprint (4)	CO_2 Emission multiplier (6)	Output multiplier ($m of output/$m of final demand) (7)
Hotspot	C	Mining and quarrying	72,942.63	3.42	0.05	0.02
Hotspot	26	Other non-metallic mineral	539,221.15	25.32	0.39	0.18
Hotspot	27t28	Basic metals and fabricated metal	233,646.96	10.97	0.17	0.17
Hotspot	E	Electricity, gas and water supply	988,763.75	46.42	0.72	0.01
Hotspot	F	Construction	69,827.45	3.28	0.05	0.01
Row maximum	60	Inland transport	29,863.11	1.40	0.02	0.03
Row maximum	61	Water transport	19,523.79	0.92	0.01	0.00
Row maximum	62	Air transport	7214.37	0.34	0.01	0.00
Row maximum	63	Other supporting and auxiliary transport activities; activities of travel agencies	16,577.46	0.78	0.01	0.04
Row maximum	71t74	Renting of M&Eq and other business activities	4695.51	0.22	0.00	0.02
Row maximum	20	Wood and products of wood and cork	5470.45	0.26	0.00	0.03
Row maximum	21t22	Pulp, paper, paper, printing and publishing	9519.33	0.45	0.01	0.00
Row maximum	23	Coke, refined petroleum and nuclear fuel	31,064.93	1.46	0.02	0.01
Row maximum	24	Chemicals and chemical products	54,660.64	2.57	0.04	0.03
Row maximum	25	Rubber and plastics	4344.89	0.20	0.00	0.01

(continued)

Table 8 (continued)

Category (1)	WIOD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of construction footprint (4)	CO_2 Emission multiplier (6)	Output multiplier ($m of output/$m of final demand) (7)
		Total emission of 15 sectors	2,087,336.43	98.00		
		Emissions by other sectors	42,636.74	2.00		
		Total emission	2,129,973.17	100.00		

Source Author's own calculation based on WIOD

makes substantial contribution to the footprint of the 'construction' sector as an intermediate input. Table 8 shows similar trend in results for the sector obtained in terms of output multipliers.

3.2 Results of Carbon Hotspots Detection in Upstream and Downstream Supply Chain for the Years 1995 and 2009 for Indian Economy

This section discusses the direct CO_2 emissions and footprints of Indian economic sectors for the years 1995 and 2009 to identify the Type (A) and Type (B) carbon hotspots, respectively. Further, Type (C) hotspots are identified from the downstream supply chain of the sector with highest direct emissions and upstream supply chain of the sector with the highest carbon footprint for the years 1995 and 2009.

3.2.1 Direct CO_2 Emissions

The top 15 most polluting sectors of the Indian economy in terms of direct emissions of CO_2 in 1995 are shown in Table 9. The direct emissions are based on the row sums in Eq. (9). The sector 'electricity, gas and water supply' has been identified as the highest CO_2 emitter, while the sector 'wood and products of wood and cork' is the sector having lowest direct emissions among the top 15 direct emitters. Column 6 showing the carbon intensity is nothing but output emission coefficients for each of the sectors in Table 9 obtained from Eq. (6). The final column of total output has been obtained from sum of the rows elements of each sector in Eq. (5). From column 5, it can be seen that percentage share in direct emissions for 'electricity, gas and water supply', 'other non-metallic mineral' and 'basic metals and fabricated metal' is 65.55%, and thus, these three sectors are

Table 9 Top 15 direct emitters of Indian economy for the year 1995

WIOD sector code (1)	Rank (2)	Sector (3)	Direct emissions of CO_2 (in kiloton) (4)	Percent share of total direct emission (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output, $L * Y_j$ (in million \$) (8)
E	1	Electricity, gas and water supply	335,033.93	49.56	14.26	2757.74	23,499.37
27t28	3	Basic metals and fabricated metal	53,124.74	7.86	1.14	39,141.31	46,536.90
C	7	Mining and quarrying	22,612.7	3.34	2.98	1141.88	7592.92
26	2	Other non-metallic mineral	54,958.03	8.13	4.55	4501.602	12,071.25
15t16	10	Food, beverages and tobacco	14,248.16	2.11	0.34	34,165.83	42,316.74
AtB	5	Agriculture, hunting, forestry and fishing	31,723.31	4.69	0.29	73,000.45	110,571.73
23	9	Coke, refined petroleum and nuclear fuel	18,232.24	2.70	0.90	4565.50	20,344.04
24	4	Chemicals and chemical products	40,208.04	5.95	1.49	9130.13	27,044.94
60	6	Inland transport	29,050.86	4.30	0.67	19,728.7	43,234.27
H	8	Hotels and restaurants	18,671.09	2.76	1.72	9367.446	10,827.99
F	13	Construction	6061.44	0.90	0.12	41,993.69	49,049.11
20	15	Wood and products of wood and cork	921.75	0.14	0.12	1785.392	7740.07
14	14	Transport equipment	2343.71	0.35	0.08	18,498.5	29,372.66
17Tt18	11	Textiles and textile products	10,833.14	1.60	0.27	26,251.15	39,449.33

(continued)

Table 9 (continued)

WIOD sector code (1)	Rank (2)	Sector (3)	Direct emissions of CO_2 (in kiloton) (4)	Percent share of total direct emission (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output, $L * Y_j$ (in million \$) (8)
21t22	12	Pulp, paper, paper, printing and publishing	6635.39	0.98	0.65	4411.524	10,130.45
		Total emission of top 15	644,658.61	95.35			
		Emissions by other sectors	31,420.61	4.65			
		Total emission	676,079.22	100.00			

Source Author's own calculation based on WIOD

classified as Type (A) hotspots. The reason identified for the relatively higher emissions in the first two Type (A) hotspots sectors is the relatively higher CO_2 emission intensity of 14.26 and 4.55. While in case of third Type (A) hotspot sector, that is 'basic metals and fabricated metal', high emissions result from high value of total output in column 8. Thus, carbon emission intensity cannot be the sole driver of high direct emissions of CO_2 for a particular sector. This point becomes more clear when sectors 'hotels and restaurants' and 'mining and quarrying' having relatively higher emission intensity, among the non-hotspot sectors, generate less direct emissions than 'agriculture, hunting, forestry and fishing' and 'inland transport' sectors (sectors with low emission intensity among non-hotspot sectors) because the volume of production in column 8 is lower for the former sectors.

In Table 10, the top 15 direct emitters remain same in the year 2009 although the quantity of total direct emissions generated by them has increased from 644,658.61 kt of CO_2 in 1995 to 1,653,329 kt in 2009. From column 5, it can be seen that percentage share in total direct emissions for 'electricity, gas and water supply', 'basic metals and fabricated metal' and 'mining and quarrying' is 65.55% and identified as Type (A) hotspots. Further, Type (A) hotspot in 1995, 'other Non-metallic mineral', has been replaced by 'mining and quarrying' Type (A) hotspot in 2009. Among the three Type (A) hotspots recognized, carbon emission intensity given by column 5 is not the sole reason for high direct emissions by basic metals and fabricated metals as it is in case of other two Type (A) carbon hotspots. The major factor responsible for the high direct emissions by the sector is the high value of total final demand. Thus, analysing emission intensity along with total final demand helps in drawing a conclusion regarding the major driver for CO_2 emissions by a particular sector.

Table 10 Top 15 direct emitter of Indian economy for the year 2009

WIOD sector (1)	Rank (2)	Sector name (3)	Direct emissions (kt of CO_2) (4)	Percent share of total direct emission (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output (in million $) (8)
E	1	Electricity, gas and water supply	812,874.51	49.17	12.49	11,281.92	65,068.59
27t28	2	Basic metals and fabricated metal	122,430.00	7.41	0.76	39,141.31	160,455.36
C	3	Mining and quarrying	108,726.94	6.58	2.63	12,879.62	41,301.38
26	4	Other non-metallic mineral	89,049.42	5.39	2.46	2539.37	36,168.52
15T16	5	Food, beverages and tobacco	67,762.66	4.10	0.53	101,653.95	127,099.98
AtB	6	Agriculture, hunting, forestry and fishing	50,449.30	3.05	0.18	170,781.12	273,470.89
23	7	Coke, refined petroleum and nuclear fuel	47,740.16	2.89	0.43	25,498.08	111,126.42
24	8	Chemicals and chemical products	47,060.11	2.85	0.54	33,361.00	86,874.02
60	9	Inland transport	33,428.65	2.02	0.17	89,438.29	196,046.76
H	10	Hotels and restaurants	20,276.81	1.23	0.43	39,724.18	46,767.47
F	11	Construction	11,966.46	0.72	0.04	246,441.36	297,747.88
20	12	Wood and wood products	11,833.55	0.72	1.07	1831.83	11,049.46
34t35	13	Transport equipment	11,090.70	0.67	0.15	50,492.51	72,593.24
17t18	14	Textiles and textile products	10,540.32	0.64	0.12	64,581.74	89,669.66

(continued)

Table 10 (continued)

WIOD sector (1)	Rank (2)	Sector name (3)	Direct emissions (kt of CO_2) (4)	Percent share of total direct emission (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output (in million $) (8)
21t22	15	Pulp, paper, paper, printing and publishing	8737.51	0.53	0.43	39,724.18	20,111.89
		Total emission of top 15 sectors	1,453,967.11	87.94			
		Emissions by other sectors	199,362.36	12.06			
		Total emission	1,653,329.47	100.00			

Source Author's own calculation based on WIOD

Table 11 shows the results for the top Type (C) hotspot sector in the downstream supply chain of the 'electricity, gas and water supply' sector in 1995. Using Table 9, it can be seen that the sector uses only 8.52% of its total output to meet its final demand. But from column 4 of Table 11, it may be noticed that the sector generates only 15.73% of the sector's total emissions, to meet its own final demand. Thus, Type (C) hotspots on this sector's downstream supply chain are identified. Table 11 shows the embodied emissions which are the elements of each sector in 'electricity, gas and water supply' sector row in Eq. (8). Column 6 shows the elements of each sector listed on the row of 'electricity, gas and water supply' in emission multiplier matrix given as Eq. (8). Those elements of India's CO_2 emission matrix in Eq. (9) are identified as Type (C) hotspots which have values higher than the average obtained for the row maximums of (9), which is in our case is 6306.313 kt of CO_2. Thus, there are 12 sectors identified in the downstream supply chain of electricity, gas and water supply as Type (C) hotspots. These 12 sectors contribute 83.57% of the total emission in the sector. The largest share is of the sector itself which is 15.73% of the total direct emissions followed by construction. CO_2 emissions multiplier in column 5 shows that 'electricity, gas and water supply' has the highest requirement of its own sector's output to meet its final demand followed by 'transport and equipment' with second highest emission multiplier of 1.64.

Similarly, Table 12 shows the results for the top Type (C) hotspot sector 'electricity, gas and water supply' downstream supply chain in 2009. Using Table 12, it can be seen that the sector uses only 5.76% of its total output to meet its final demand but from column 4 of Table 12 it may be noticed that the sector generates only 22.20% of the sector's total emissions, to meet its own final demand.

Table 11 Carbon hotspots on India's downstream supply chain of 'electricity, gas and water supply' for the year 1995

WIOD sector code (1)	Sector (2)	Embodied CO_2 emissions (in kiloton) (3)	Percent share of EGWS total direct emission (4)	CO_2 emission multiplier (5)	Total final demand (Y_j) (6)
E	Agriculture, hunting, forestry and fishing	23,975.14	7.16	0.33	73,000.45
15t16	Food, beverages and tobacco	20,432.44	6.10	0.60	34,165.83
17t18	Textiles and textile products	30,686.37	9.16	1.17	26,251.15
24	Chemicals and chemical products	9463.03	2.82	1.04	9130.13
27t28	Basic metals and fabricated metal	10,825.19	3.23	1.56	39,141.31
29	Machinery, nec	16,900.67	5.04	1.31	12,864.38
34t35	Transport equipment	30,316.03	9.05	1.64	18,498.50
36t37	Manufacturing, nec; recycling	15,904.20	4.75	1.37	12,864.38
E	Electricity, gas and water supply	52,713.61	15.73	19.11	2757.74
F	Construction	32,578.95	9.72	0.78	41,993.69
H	Hotels and restaurants	6674.19	1.99	0.71	9367.45
60	Inland transport	29,519.13	8.81	1.50	19,728.70
	Total of 12 sectors	279,988.94	83.57		
	All other sectors	55,044.99	16.43		
	Total	335,033.93	100.00		

Source Author's own calculation based on WIOD

Thus, Type (C) hotspots on this sector's downstream supply chain are identified. There are 12 sectors identified in the downstream supply chain of 'electricity, gas and water supply' as Type (C) hotspots having values higher than the average obtained for the row maximums of (9), i.e. 20,278.86 kt of CO_2 in 2009. These 12 sectors contribute 86.34% of the total emission in the sector. The largest share is of

Table 12 Carbon hotspots on India's downstream supply chain of 'electricity, gas and water supply' for the year 2009

WIOD sector code (1)	Sector (2)	Embodied CO_2 emissions (in kiloton) (3)	% share of EGWS total direct emission (4)	CO_2 emission multiplier (5)	Total final demand (Y_j) (6)
AtB	Agriculture, hunting, forestry and fishing	37,878.84	4.66	0.22	170,781.12
15t16	Food, beverages and tobacco	39,546.04	4.86	0.39	101,653.95
17t18	Textiles and textile products	52,880.31	6.51	0.82	64,581.74
24	Chemicals and chemical products	24,312.72	2.99	0.73	33,361.00
27t28	Basic metals and fabricated metal	53,821.83	6.62	1.38	39,141.31
29	Machinery, nec	23,539.80	2.90	0.67	35,065.18
34t35	Transport equipment	41,722.51	5.13	0.83	50,492.51
30t33	Electrical and optical equipment	29,663.32	3.65	0.62	48,008.05
E	Electricity, gas and water supply	180,459.24	22.20	16.00	11,281.92
F	Construction	169,090.22	20.80	0.69	246,441.36
60	Inland transport	46,772.23	5.75	0.52	89,438.29
51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	2116.01	0.26	0.07	31,985.02
	Total of 12 sectors	701,803.09	86.34		
	All other sectors	111,071.42	13.66		
	Total	812,874.51	100.00		

Source Author's own calculation based on WIOD

the sector itself which is 22.20 kt of CO_2 of the total direct emissions followed by 'construction' with 20.80 kt of CO_2. CO_2 emissions multiplier column 5 shows that electricity, gas and water supply has the highest requirement of its own sector's output to meet its final demand followed by 'basic metal and fabricated metal' with second highest emission multiplier of 1.38.

3.2.2 CO_2 Footprints

The results from Table 13 show the top 15 sectors of the Indian economy in terms of carbon footprints in 1995. The elements in column 5 are the column sums for

Table 13 Top 15 sectors in terms of carbon footprint for the year 1995 in Indian economy

Footprint rank (1)	Direct emission rank (2)	WIOD sector code (3)	Sector name (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (8)
1	14	F	Construction	82,479.34	12.20	1.96	41,993.69
2	5	AtB	Agriculture, hunting, forestry and fishing	57,853.74	8.56	0.79	73,000.45
3	1	E	Electricity, gas and water supply	54,282.32	8.03	19.68	2757.74
4	11	17t18	Textiles and textile products	52,304.24	7.74	1.99	26,251.1477
5	6	60	Inland transport	51,286.05	7.59	2.60	19,728.7026
6	10	15t16	Food, beverages and tobacco	49,292.32	7.29	1.44	34,165.8298
7	18	34t35	Transport equipment	47,332.48	7.00	2.56	18,498.50
8	4	24	Chemicals and chemical products	30,682.96	4.54	3.36	9130.13
9	24	35t37	Manufacturing, nec; recycling	30,266.02	4.48	2.61	11,604.7955
10	2	26	Other non-metallic mineral	30,175.04	4.46	6.70	4501.60212
11	20	29	Machinery, nec	29,550.97	4.37	2.30	12,864.3834
12	8	H	Hotels and restaurants	26,299.62	3.89	2.81	9367.44561
13	3	27t28	Basic metals and fabricated metal	26,015.11	3.85	3.75	6933.85646
14	12	21t22	Pulp, paper, paper, printing and publishing	11,284.77	1.67	2.56	4411.52407

(continued)

Table 13 (continued)

Footprint rank (1)	Direct emission rank (2)	WIOD sector code (3)	Sector name (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (8)
15	28	30t33	Electrical and optical equipment	10,610.66	1.57	1.48	7191.00165
			Total emission of top 15	589,715.63	87.23		
			Emissions by other sectors	86,363.59	12.77		
			Total emission	676,079.22	100.00		

Source Author's own calculation based on WIOD

each sector in CO_2 emission matrix given as Eq. (9). There are seven Type (B) hotspots identified in terms of high carbon footprints. These sectors are 'construction', 'agriculture, hunting, forestry and fishing', 'electricity, gas and water supply', 'textiles and textile products', 'inland transport', 'food, beverages and tobacco' and, finally, 'transport equipment'. The footprint and direct emission ranks reveal that the construction sector has the highest carbon footprint followed by 'agriculture, hunting, forestry' among others, indicating that the emissions in these sectors are higher to meet the final demand rather than their direct emissions. Thus, these sectors themselves generate less pollution from their production activities.

In quest to identify the reason behind the high footprint of each of the Type (B) hotspot identified sectors, we use column 7 of Table 13 which gives the emission multiplier for each sector taken from Eq. (7). The emission multiplier for 'electricity, gas and water supply' is highest followed by 'other non-metallic mineral', but footprint for each of these sectors is lower than the 'construction' and 'agriculture, hunting, forestry and fishing'. Thus, the relatively higher footprint in the latter sectors is due to high value of total final demand. Thus, emission multiplier is not the sole driver of high footprints in the sectors but final demand also plays an important role in identifying Type (B) hotspots.

Table 14 shows the top 15 sectors of the Indian economy in terms of carbon footprints in 2009. There are two Type (B) hotspots identified in terms of high carbon foot prints. They are 'construction' and 'electricity, gas and water supply'. The construction sector has highest footprint rank but low rank in direct emissions which reveals that the sector itself generate less pollution from its production activities and all other sectors generate high emissions in order to meet the final demand for construction sector. The emission multiplier in column 7 of Table 14 shows that the emission multipliers for 'electricity, gas and water supply' is highest followed by 'mining and quarrying' but footprint for each of these sectors is lower than the construction, implying high footprint in the latter due to high value of total final demand in the sector.

Table 15 shows the results for the top Type (C) hotspot on 'construction' sector upstream supply chain. There are two Type (C) hotspots identified on the 'construction' upstream supply chain, namely 'other non-metallic mineral' and 'electricity, gas and water supply'. These sectors are elements in 'construction' sector column in Eq. (9), having values higher than the average obtained for the row maximums (6306.313 kt of CO_2). Table 15 apart from showing the Type (C) hotspot also presents the row maximums appearing on the upstream supply chain of the construction sector. The embodied emissions in column 4 reveals that 'construction' own production to meet its final demand is 6.38% to the sector's footprint while 'electricity, gas and water supply' and 'other non-metallic mineral' followed by 'mining and quarrying' as an intermediate input for construction make substantial contribution to sector's footprint.

It is pertinent to examine whether the Type (C) hotspots identified in 'construction' upstream supply chain are determined by each sector's CO_2 intensity or 'construction' high requirements for output of 'electricity, gas and water supply' and 'other non-metallic mineral'. Thus, examining the emission multiplier in

Table 14 Top 15 sectors in terms of carbon footprint for the year 2009 in Indian economy

Footprint rank (1)	Direct emission rank (2)	WIOD sector code (3)	Sector (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (6)
1	11	F	Construction	329,874.97	21.98	1.34	246,441.36
2	1	E	Electricity, gas and water supply	185,051.09	12.33	16.40	11,281.92
3	5	15t16	Food, beverages and tobacco	101,653.95	6.77	1.25	101,653.95
4	3	27T28	Basic metals and fabricated metal	111,319.23	7.42	2.84	39,141.36
5	9	60	Inland transport	92,084.40	6.14	1.03	89,438.28
6	6	AtB	Agriculture, hunting, forestry and fishing	84,385.12	5.62	0.49	170,781.12
7	14	17t18	Textiles and textile products	77,927.13	5.19	1.21	64,581.74
8	13	34t35	Transport equipment	69,086.22	4.60	1.37	50,492.51
9	8	24	Chemicals and chemical products	55,824.94	3.72	1.67	33,361.002
10	20	30t33	Electrical and optical equipment	52,573.79	3.50	1.10	48,008.051
11	17	29	Machinery, nec	44,426.96	2.96	0.00	35,065.181
12	10	H	Hotels and restaurants	41,561.21	2.77	1.05	39,724.176
13	2	C	Mining and quarrying	41,441.50	2.76	3.22	12,879.619
14	7	23	Coke, refined petroleum and nuclear fuel	39,729.71	2.65	1.67	25,498.084

(continued)

Table 14 (continued)

Footprint rank (1)	Direct emission rank (2)	WIOD sector code (3)	Sector (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (6)
15	28	36t37	Manufacturing, nec; recycling	23,293.65	1.55	0.35	65,772.929
			Total emission of top 15	1,350,233.85	89.98		
			Emissions by other sectors	150,417.56	10.02		
			Total emission	1,500,651.41	100.00		

Source Author's own calculation based on WIOD

Table 15 Carbon hotspots on India's construction upstream supply chain in 1995

Category (1)	WIOD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of construction footprint (5)	CO_2 emission multiplier (6)	Output multiplier (7)
Hotspot	26	Other non-metallic mineral	25,157.69	30.50	0.60	0.13
Hotspot	E	Electricity, gas and water supply	32,578.95	39.50	0.78	0.05
Row maximum	C	Mining and quarrying	3867.22	4.69	0.09	0.03
Row maximum	20	Wood and products of wood and cork	291.02	0.35	0.01	0.06
Row maximum	F	Construction	5262.81	6.38	0.13	1.01
Row maximum	64	Post and telecommunications	129.63	0.16	0.00	0.01
		Total emission of 6 sectors	67,287.31	81.58		
		Emissions by other sectors	15,192.03	18.42		
		Total emissions	82,479.34	100.00		

Source Author's own calculation based on World Input–Output Database, 2015

column 6 of Table 16 reveals that requirements of output from EGWS and 'other non-metallic mineral' have larger emission multiplier. Thus, construction requires a large amount of input from both the sectors.

Examining the output multiplier which is column sum of the elements in Leontief inverse in Eq. (5) reveals that the 'electricity, gas and water supply' and 'other non-metallic mineral' require less output/$m of final demand in comparison with 'construction' and 'other non-metallic mineral'.

From Table 16, there are three Type (C) hotspots identified along with one row maximum on the upstream supply chain of the construction sector, namely 'other non-metallic mineral', 'basic metals and fabricated metals' and 'electricity, gas and water supply' which have values above the row maximums in 'construction' sector in Eq. (9). The embodied emissions in column 4 reveal that 'electricity, gas and water supply' makes substantial contribution to the footprint of the construction sector as an intermediate input. The table shows a similar trend in results for the sector obtained in terms of output multipliers.

Table 16 Carbon hotspots on India's construction upstream supply chain in 2009

Category (1)	WIOD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of construction footprint (5)	CO_2 emission multiplier (6)	Output multiplier (7)
Hotspot	26	Other non-metallic mineral	66,669.05	20.21	0.27	0.11
Hotspot	27t28	Basic metals and fabricated metal	37,172.80	11.27	0.15	0.11
Hotspot	E	Electricity, gas and water supply	169,090.22	51.26	0.69	0.11
Row Maximum	F	Construction	10,553.10	3.20	0.69	1.07
		Total emission of four sectors	283,485.17	85.94		
		Emissions by other sectors	46,389.80	14.06		
		Total emission	329,874.97	100.00		

Source Author's own calculation based on WIOD

3.3 Results of Carbon Hotspots Detection in Upstream and Downstream Supply Chain Based on OECD Input–Output Database for the Year 2011 for Indian Economy

3.3.1 Direct CO_2 Emissions

The comparison of the result obtained for the top 15 direct CO_2 emitters year 2009 with those obtained for the year 2011 (as given in Table 17) reveals that the top 15 direct carbon emitters contribute 98.72% of the total direct carbon emissions in the economy which is 10% higher that what top 15 direct emitters contributed in the year 2009, i.e. 87.44%. Further, the top 15 direct emitters have remained same in 2011 except that 'transport and equipment' and 'inland transport' that were among the top 15 emitters in 2009 have been replaced by 'wholesale and retail trade; repairs' and transport and storage in 2011.

The Type (A) hotspots identified for the year 2011 are 'electricity, gas and water supply', 'other non-metallic mineral' and 'basic metals and fabricated metals'. The shares of these sectors have increased to 70.97% in 2011 from 65.55% in the year 2009. Furthermore, carbon emission intensity is not the only reason for high emissions generated by the sector, the high total final demand in the sector has also

Table 17 Top 15 direct emitters of Indian economy for the year 2011

OECD sector code (1)	Rank (2)	Sector (3)	Direct CO_2 emissions (in kiloton) (4)	Percent share of total direct emissions (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output, $L_{ij} * Y_j$ (8)
C40T41	1	Electricity, gas and water supply	543,602.87	54.78	10.46	10,369.73	51,981.80
C26	2	Other non-metallic mineral	83,118.65	8.38	2.00	5591.31	41,642.62
C27&C28	3	Basic metals and fabricated metal	77,506.22	7.81	0.54	47,766.14	144,280.97
C10T14	4	Mining and quarrying	56,370.66	5.68	1.78	3106.02	31,655.11
C15T16	5	Food products, beverages and tobacco	51,674.01	5.21	0.37	99,153.55	141,520.18
C01T05	6	Agriculture, hunting, forestry and fishing	45,501.71	4.59	0.13	223,461.43	363,104.22
C23	7	Coke, refined petroleum and nuclear fuel	33,700.18	3.40	0.28	63,833.50	119,190.90
C24	8	Chemical and chemical products	25,970.95	2.62	0.31	22,334.26	83,048.46
C60T63	9	Transport and storage	23,148.51	2.33	0.13	112,323.54	183,861.71
C45	10	Construction	10,092.68	1.02	0.03	338,046.45	403,152.99
C20	11	Wood and products of wood and cork	8964.24	0.90	2.69	1898.51	3336.51
C21	12	Pulp, paper products, printing and publishing	6736.65	0.68	0.37	6834.16	18,162.59
C17T19	13	Textiles, textile products, leather and footwear	6227.99	0.63	0.09	51,555.86	73,015.64
C55	14	Hotels and restaurants	3652.28	0.37	0.05	49,278.34	75,042.81

(continued)

Table 17 (continued)

OECD sector code (1)	Rank (2)	Sector (3)	Direct CO_2 emissions (in kiloton) (4)	Percent share of total direct emissions (5)	CO_2 emission intensity (6)	Total final demand (Y_j) (7)	Total output, $L_{ij} * Y_j$ (8)
C50T52	15	Wholesale and retail trade; repairs	3393.11	0.34	0.01	133,972.36	234,548.03
		Total Emission of top 15 sectors	979,660.71	98.72			
		Emissions by other sectors	12,668.81	1.28			
		Total emissions	992,329.52	100.00			

Source Authors calculation based on WIOD been found responsible for the generation of high volume of final demand. It has been further noticed that the construction has remained a sector with lowest direct carbon emissions but highest volume of final demand.

The results from Table 18 for the Type C hotspots sectors in electricity, gas and water supply downstream supply chains reveal that there are 11 Type C hotspots identified, which are above the row maximum average of Eq. (9), which is 15,000 kt of CO_2 in 2011. These 11 sectors contribute 91.49% of the total emissions in the sector. In comparison to the result obtained for the year 2009, in 2011, the largest share in terms of total direct emissions generated by the 'electricity, gas and water supply, if of the 'electricity, gas and water supply' itself instead of 'construction'. However, the observation from CO_2 emissions multiplier column 6 remains same for the year 2009 and 2011 that electricity, gas and water supply has the highest requirement of its own sector's output to meet its final demand.

It is further clear from Table 18 that the requirements from the 'construction' sector lead to the generation of 23.91% of the EGWS emissions. Furthermore, the emission multiplier of 0.31 of construction shows that the sector has low output requirement from EGWS to meet its final demand. But what is important to note here is that the significant emissions generated by the 'construction' sector result from its the high volume of final demand.

Table 18 Carbon hotspots on India's downstream supply chain of electricity, gas and water supply for the year 2011

S. No. (1)	OECD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of EGWS total direct emission (5)	CO_2 emission multiplier (6)	Total final demand (Y_j) (7)
1	C01T05	Agriculture, hunting, forestry and fishing	37,713.17	6.94	0.17	223,461.43
2	C15T16	Food, beverages and tobacco	47,805.81	8.79	0.48	99,153.55
3	C17T19	Textiles and textile products	33,300.47	6.13	1.17	51,555.86
4	C27T28	Basic metals and fabricated metal products	18,130.44	3.34	0.38	47,766.14
7	C55	Hotels and restaurants	18,985.20	3.49	0.39	49,278.34
8	C40T41	Electricity, gas and water supply	130,542.48	29.36	12.59	10,369.73
9	C45	Construction	106,296.80	23.91	0.31	338,046.45
10	C60T63	Transport and storage	34,382.97	6.33	0.31	112,323.54

(continued)

Table 18 (continued)

S. No. (1)	OECD sector code (2)	Sector name (3)	Embodied CO_2 emissions (in kiloton) (4)	Percent share of EGWS total direct emission (5)	CO_2 emission multiplier (6)	Total final demand (Y_j) (7)
11	C75	Public admin and defence; compulsory social security	17,473.90	3.21	0.14	125,510.75
		Total of top 11 sectors	444,631.23	91.49		
		All other sectors	98,971.64	18.21		
		Total	543,602.87	100.00		

Source Authors calculation based on WIOD

3.3.2 CO_2 Footprints

Table 19 shows the top 15 sectors in terms of carbon footprints for the Indian economy in 2011. It has been observed that five of the sectors with high carbon footprints in the year 2009, namely 'inland transport', 'transport equipment', 'electrical and optical equipments', 'mining and quarrying' and 'manufacturing nec, recycling', have been replaced by 'transport and storage', 'public administration and defence; compulsory social security', 'wholesale and retail trade; repairs', other non-metallic mineral and 'health and social work' in 2011. There are three Type (B) hotspots identified in terms of high carbon footprints in 2011 against only two in 2009. These are 'construction', 'electricity, gas and water supply' and food products, beverages and tobacco. The construction has remained the sector with highest footprint rank but low ranking in terms of direct emissions. Further, the emission multiplier in column 7 of Table 19 shows that the emission multipliers for 'electricity, gas and water supply' are highest reflecting upon the fact that the sector is responsible for generating emissions in other sectors of the economy in order to meet its final demand.

The results for Type C hotspot on the construction upstream supply chain remained same for the year 2009 and 2011. From Table 20, it is found that in 2011, three Type (C) hotspots have been identified along with one row maximum on the upstream supply chain of the 'construction' sector, namely 'other non-metallic mineral', 'basic metals and fabricated metals' and 'electricity, gas and water supply' which have values above the row maximums in 'construction' sector in Eq. (9). The embodied emissions in column 3 reveal that again 'electricity, gas and water supply' makes substantial contribution to the footprint of the construction sector. Further, 3.91% to the construction sector's footprint is due to its own production in order to meet its final demand. However, requirements of output from 'electricity, gas and water supply' followed by 'other non-metallic mineral' make substantial contribution to 'construction' footprint. The analysis of emission multiplier and output multiplier reveals that the high embodied emissions in the electricity, gas and

Table 19 Top 15 sectors in terms of carbon footprint for the year 2011 in Indian economy

Footprint rank (1)	Direct emission rank (2)	OECD sector code (3)	Sector name (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (8)
1	10	C45	Construction	243,853.54	24.57	0.72	338,046.45
2	1	C40T41	Electricity, gas and water supply	131,912.38	13.29	12.72	10,369.73
3	5	C15T16	Food products, beverages and tobacco	103,908.69	10.47	1.05	99,153.55
4	6	C01T05	Agriculture, hunting, forestry and fishing	76,249.69	7.68	0.34	223,461.43
5	9	C60T63	Transport and storage	63,343.12	6.38	0.56	112,323.54
6	3	C27T28	Basic metals and fabricated metal products	59,473.02	5.99	1.25	47,766.14
7	7	C23	Coke, refined petroleum and nuclear fuel	46,320.96	4.67	0.73	63,833.50
8	13	C17T19	Textiles, textile products, leather and footwear	45,632.04	4.60	0.89	51,555.86
9	14	C55	Hotels and restaurants	30,850.37	3.11	0.63	49,278.34
10	8	C24	Chemical and chemical products	22,939.21	2.31	1.03	22,334.26
11	23	C75	Public admin and defence; compulsory social security	20,600.52	2.08	0.16	125,510.75
12	16	C29	Machinery and equipment, nec	18,103.19	1.82	0.55	32,904.45
13	15	C50T52	Wholesale and retail trade; repairs	17,342.51	1.75	0.13	133,972.36

(continued)

Table 19 (continued)

Footprint rank (1)	Direct emission rank (2)	OECD sector code (3)	Sector name (4)	Footprint (kt of CO_2) (5)	Percent share of total domestic footprint (6)	Type 1 emission multiplier (7)	Total final demand (Y_j) (8)
14	2	C26	Other non-metallic mineral	15,986.99	1.61	2.56	5591.31
15	22	C85	Health and social work	12,597.16	1.27	0.26	47,645.36
			Total emission of top 15 sectors	909,113.40	91.61		
			Emissions by other sectors	83,216.13	8.39		
			Total emission	992,329.52	100.00		

Source Authors calculation based on OECD Intercountry Input–Output table

Table 20 Carbon hotspots on India's construction upstream supply chain for the year 2011

S. No.	OECD sector code	Sector	Embodied emissions (kt of CO_2)	% share of construction footprint	CO_2 emission multiplier (kt of CO_2/ $m FD)	Output multiplier ($m of output/$m of final demand)
1	C26	Other non-metallic mineral	65,545.75	26.88	0.19	0.10
2	C27T28	Basic metals and fabricated metal products	32,614.77	13.37	0.10	0.18
3	C40T41	Electricity, gas and water supply	106,296.80	43.59	0.31	0.03
4	C45	Construction	9543.35	3.91	0.03	1.13
		Total emission of top 4	214,000.66	87.76		
		Emissions by other sectors	29,852.88	12.24		
		Total emission	243,853.54	100.00		

Source Authors calculation based on OECD Intercountry Input–Output table

water supply are because the sector is itself emission intensive as the construction requirement of output from the sector is less.

4 Conclusion

By disaggregating the supply chains, this study allows us to identify the sectors that are responsible for significantly contributing to the total direct CO_2 emissions or footprints. The study thus analyses the direct CO_2 emissions and footprints of the Indian and Chinese economic sectors for the years 1995 and 2009 to identify the Type (A) and Type (B) carbon hotspots, respectively, by using the World Input–Output Database. Further, Type (C) hotspots are identified from the downstream supply chain of the sector with highest direct emissions and upstream supply chain of the sector with the highest carbon footprint for the years 1995 and 2009. The carbon hotspot analysis for India has been further extended to the year 2011 by using OCED Intercountry Database, 2015.

The analysis of the results reveals that in both the years, i.e. 1995 and 2009, the ‘construction’ sector has retained the position for having the highest domestic CO_2 footprint in India and China, while the electricity, gas and water supply has remained the largest direct emitter among all sectors in India and China in 2005 and 2009. Similar results have been obtained for the year 2011 for India. High direct emissions by Type A hotspots of India and China cannot be solely attributed to the high emission intensity of the sectors but also to the relatively higher value of output produced by them. Similarly, high carbon footprints by Type B hotspots for India and China cannot be solely attributed to high value of emission multiplier but relatively high value of output. Type C hotspot analysis reflects upon the fact that the largest contributor to the construction carbon footprint is ‘electricity, gas and water supply’ followed by ‘other non-metallic mineral’ throughout the period of analysis. However, ‘construction’ requirements have been responsible for driving emissions embodied in the downstream supply chains of the electricity, gas and water supply.

Both India and China have taken constructive steps to curb national carbon emissions and are well ahead of the goals set under the Paris agreement. India, in particular, has made a push towards a lower carbon economic transition as it plans to double its existing renewable energy capacity by 2022. China is no behind and has invested heavily in green technologies such as electric cars, wind turbines and solar panels. The finding from the study further reveals that Indian and Chinese ‘electricity, gas and water supply’ sector being the largest carbon emitter contributes significantly to the Indian and Chinese ‘construction’ sector footprint, and therefore an area of considerable emissions reductions. Further, substantial gains can be made in reducing CO_2 emissions, if the requirement of output of ‘construction’ sector from ‘electricity, gas and water supply’ is reduced. Alternatively, measures could be taken to make the ‘electricity, gas and water supply’ less emission intensive. A possible way in this direction could be more renewable energy sources for the ‘electricity, gas and water supply’ sector, and the energy consumed within construction needs to be sourced from these renewable technologies.

The study also identifies for India and China, sectors that do not themselves generate higher emissions but are responsible for driving emissions in their supply chains. These sectors are ‘food products, beverages and tobacco’, ‘agriculture, hunting, forestry and fishing’ and ‘basic metals and fabricated metals’. There is a need that units/industries functioning in these economic sectors are firmly advised to continuously review and keep track of the indirect emissions generated in their supply chains, and this may include asking the suppliers to measure and report their carbon emissions and their reduction targets for the same.

The limitation of the study is that the supply chains are not confined in one specific region, and thus, extending the analysis to global supply chains holds importance to make any policy effort to reduce emissions embodied in the supply chains of any sectors.

Appendix

See Table 21.

Table 21 Selection of best-fitted ARIMA model for forecasting of CO_2 emissions, 2011

WIOD code	Sectors	Model	Forecasted emissions (kt of CO_2)
AtB	Agriculture, hunting, forestry and fishing	ARIMA (0,2,1)	49,929.50
C	Mining and quarrying	ARIMA (0,1,0)	96,740.00
15t16	Food, beverages and tobacco	ARIMA (4,1,0)	61,787.90
17t18	Textiles and textile products	ARIMA (2,1,3)	8722.41
19	Leather, leather and footwear	ARIMA (1,1,0)	265.95
20	Wood and products of wood and cork	ARIMA (1,1,0)	10,289.74
21t22	Pulp, paper, paper, printing and publishing	ARIMA (0,1,0)	8782.66
23	Coke, refined petroleum and nuclear fuel	ARIMA (0,1,0)	55,059.64
24	Chemicals and chemical products	ARIMA (0,1,1)	44,101.91
25	Rubber and plastics	ARIMA (4,1,2)	2496.53
26	Other non-metallic mineral	ARIMA (2,1,2)	92,007.80
27t28	Basic metals and fabricated metal	ARIMA (0,2,2)	119,591.33
29	Machinery, nec	ARIMA (1,1,0)	4299.56
30t33	Electrical and optical equipment	ARIMA (0,1,0)	3746.99
34t35	Transport equipment	ARIMA (1,1,0)	8299.16
36t37	Manufacturing, nec; recycling	ARIMA (1,0,0)	506.37
E	Electricity, gas and water supply	ARIMA (0,1,0)	757,083.00
F	Construction	ARIMA (2,2,0)	10,443.95

(continued)

Table 21 (continued)

WIOD code	Sectors	Model	Forecasted emissions (kt of CO_2)
50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	ARIMA (0,2,0)	353.13
51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	ARIMA (0,1,0)	809.97
52	Retail trade, except of motor vehicles and motorcycles; repair of household goods	ARIMA (0,1,0)	3633.04
H	Hotels and restaurants	ARIMA (1,1,0)	4527.82
60	Inland transport	ARIMA (2,2,0)	26,879.31
61	Water transport	ARIMA (0,1,1)	4554.08
62	Air transport	ARIMA (0,2,3)	2242.22
63	Other supporting and auxiliary transport activities; activities of travel agencies	ARIMA (0,0,3)	2771.55
64	Post and telecommunications	ARIMA (0,1,0)	1937.59
J	Financial intermediation	ARIMA (0,1,0)	493.01
70	Real estate activities	ARIMA (0,1,0)	72.19
71t74	Renting of M&Eq and other business activities	ARIMA (1,1,0)	1638.88
L	Public admin and defence; compulsory social security	ARIMA (0,1,0)	679.71
M	Education	ARIMA (0,2,2)	1264.47
N	Health and social work	ARIMA (0,2,0)	704.76
O	Other community, social and personal services	ARIMA (1,0,1)	2229.12

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Incidence of Environmental Taxes in India: Environmentally Extended Social Accounting Matrix-Based Analysis

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Abstract Command and control policies have failed miserably in the Indian context in preserving the environment. Thus, this paper looks at the implications of preserving environment through fiscal instruments such as environmental taxes. This has been done by using an environmentally extended social accounting matrix (ESAM) framework to design and analyse the incidence of these taxes on rural and urban household groups. Ecotaxes were found to be progressive for both the regions at 5 and 10% tax rates. However, these taxes were regressive for one household category of the rural area which could be made progressive through a minimal proportion of revenue transfer generated from the levy of these taxes.

Keywords Environmental taxes · Progressive taxes · Environmentally extended SAM

JEL Classification H23 · Q53 · Q58

1 Introduction

Environmental taxes or ecotaxes have been used extensively in the developed countries especially so in the Nordic countries for over two and a half decades, and their effects on the economy and the people bearing the cost of such levies are widely studied in these countries. However, such fiscal measures are either non-existent in India or those existing are not adequately designed so as to achieve environmental preservation (Verma 2016). Given the non-existence of such taxes in India, the question of analysing its impact on the economy and the people is not

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even a consideration. But such questions become imperative when the age-old methods of environmental preservation such as command and control (CAC) policies have failed miserably (Planning Commissions 2007). This is evident from the present dismal status of the environment in India; of the top 20 most polluting cities of the world, 13 cities are in India (World Bank 2014). This calls for the need of alternative policy options which could help in reducing the further damage to the environment. An alternative to CAC policies could be market-based fiscal economic instruments such as ecotaxes. Core to levying of such fiscal instruments is the question of how to define these taxes? i.e. the design of their tax base and further, whether such taxes are progressive or regressive? Even though ecotaxes have existed for over two and a half decades, still the former question remains unanswered and ambiguity prevails for the later. Therefore, the major objective of this study is to provide answers to these two fundamental questions: how the environmental taxes shall be designed and what is their incidence on the households?

The incidence of ecotaxes becomes a pressing question in the Indian context because still a majority of Indian population have low standard of living, and if the share of the burden of ecotaxes is borne more by this group, then the tax shall be deemed as inequitable, as per the canons of taxation laid by Smith (1904). Verma (2016)[1] found that the status of environmental taxes is dismal in India as there are in total 17 environmentally related taxes but of which only seven can be deemed as environmental taxes in the strict Pigouvian definition. However, of the seven environmental taxes identified by the author the rate structure does not seem to prohibit environmental pollution. On the other hand, the Supreme Court of India has taken a proactive role of regulating the environment in the recent past by implementing several measures without studying its impact on the economy or the environment. Therefore, this study finds its motivation from such a dismal status of ecotaxes in India and the executive role undertaken by the judiciary without understanding its effects. Further, this study also finds its relevance in the fight against the climate change in which India has recently committed in the Paris summit that it will reduce its carbon emissions by 33–35% by 2030 from its 2005 levels (Government of India 2015).

An ecotax is considered to be regressive if the relative burden of the taxation is borne more by the lower income households than by the higher income households. Normally, the literature seems to be concentrated on the incidence of two major forms of environmental taxes: carbon taxes and fuel taxes. Carbon tax is levied on products in proportion to their carbon emissions, whereas fuel taxes are levied on environmentally polluting fuels such as diesel, petrol. Irrespective of the outcome of incidence of these taxes, the results in the literature are explained on the basis of the budget share of the households. Larger the proportion of income or expenditure being spent on the taxed product (i.e. higher budget share being spent on taxed commodity), higher would be the relative incidence of the tax on these households.

[1]Please refer to this paper for a comprehensive definition of ecotaxes.

Therefore, if the budget share of the taxed commodity is higher for the low income/expenditure households the tax would be regressive.

Lee and Sanger (2008) assess the carbon tax policy of the state of the British Columbia in Canada using Social Policy Simulation Database/Model (SPSD/M) which is a static accounting framework similar to social accounting matrix (SAM). They found that even though the tax is regressive this could be made progressive by reducing the taxes on personal and corporate incomes. However, with the increase in the tax rate this tax would become regressive; thus, it could be deduced that the results are sensitive to the changes in the tax rates. Murray and Rivers (2015) in their extensive review of the literature of the studies that have assessed the impacts of the British Columbia's carbon tax found that the analysis provided by Beck et al. (2015b) and that of Beck et al. (2015a) differs from that of Lee and Sangers (2008). This is mostly because of the superior methodology used by these authors, i.e. CGE in which not all the tax was assumed to be passed to the consumers. This is in contrast to the assumption of full pass-through by Lee and Sanger (2008). Beck et al. (2015b) found that the ecotax in British Columbia is progressive even without any revenue transfers. On the other hand, Beck et al. (2015a) analysed the distributional impacts on rural and urban consumer groups and found the tax to be regressive initially for the rural group but was made progressive due to the tax credit been provided by the government from the generated revenue. Thus, it is evident that the results depend upon the manner in which the taxes are modelled. Ruggeri and Bourgeois (2009) analyses similar policy as that of the British Columbia to be implemented for the state of New Brunswick in Canada. The authors found that the carbon tax at the rate of $30/tonne would be regressive even after the proceeds from its levy are used for reducing other forms of direct taxes. On the other hand, a study conducted by Somani (2013) for India finds carbon tax to be regressive in relative terms. This implies that the tax is found to be regressive only when the relative measure of equality is considered.

In the case of fuel taxes, the results are sensitive to the indicator used for normalizing the budget shares for understanding the incidence of these taxes. Total expenditure is considered to be a better measure of household's well-being than total annual income; thus, Porterba (1991) suggests that the former shall be used for not only normalizing the budget share of the households but also for ranking the households. The author proved this to be the case for the USA wherein the extent of regressivity declines markedly when the budget shares of gasoline taxes were taken with respect to their expenditures. According to the author, this is because the basis for the consumption decision by the consumers is their lifetime income, i.e. wealth, rather than their annual income. This is also depicted for the European countries and also for the USA in the book that has been compiled and edited by Sterner (2012), as cited in Morris and Sterner (2013), which consists of case studies for over 20 countries. The results for all the developed and Latin American countries either depict neutral scenario or the fuel tax is progressive, except for Italy. In the case of developing countries (African and major Asian countries), the fuel taxes are found to be strongly progressive on a whole and this is also the case when the budget share for fuels is taken with respect to income. Thus, for the developing countries the indicator used for normalization does not matter. Datta (2010) shows this to be the case in India for various fuel taxes through an input–output framework. The only fuel for which a fuel tax would be regressive is kerosene. On the other hand, Cao (2012) depicts the fuel taxes to be progressive even in the case of China. Blackman et al. (2009) depict the gasoline taxes to be progressive, in the case of Costa Rica, but diesel taxes to be regressive. According to the authors, this is because diesel is extensively used as a fuel for public transport. Mutua et al. (2009) also depict that the transport fuel taxation in Kenya is progressive. The primary reason for the fuel taxes being progressive for the developing countries is that still a majority of the population do not have access to private vehicles unlike the case in USA where these taxes are regressive but could easily be made progressive through the transfer of the revenue to the affected households (Sterner 2012 as cited in Morris and Sterner 2013).

Ecotax, like any other tax, has a potential for generating revenue, but it is imperative to understand the basic notion behind the implementation of these taxes and thus recognizing the appropriate manner in which the revenue could be used. Ecotax shall not be considered as revenue-generating fiscal tool, as is the case with other taxes, rather it should primarily be viewed as a tool for preserving environment. Hence, the objective shall not be to maximize the revenue but it shall be to reduce the pollution to the optimal level, i.e. level at which the marginal social damage shall equate to the marginal private benefit (Pigou 1932). Since revenue would be generated as a by-product of the levy of ecotaxes, therefore it would be useful to have criteria for its possible utilization. The literature on revenue recycling of the ecotaxes normally confines itself to four major uses of revenue: first, to reduce the incidence of environmental taxes (as cited above); second, for other developmental goals and environmental purposes; third, reducing the existing distortions in other taxes and fourth, revenue neutral rate for wider political acceptance. The manner in which the proceeds from the levy of these taxes could be used shall depend upon the environmental, political and economic conditions of a country. However, there could still be some criteria that could be proposed on the basis of which the revenue could be used. This criterion shall primarily be based on the objective for levying such taxes, i.e. for the betterment of the societal welfare by preserving the environment. This criterion shall follow the same order, as prescribed above for the manner in which the revenue could be used. This is because the equity concerns shall always precede than any other reasons for utilizing the revenue from any tax, as per the canons of taxation laid by Smith (1904). Therefore, if a tax is deemed to be inequitable (i.e. regressive) then it would imply that the burden of environmental preservation is more on the poor than on the rich. This can never be justified in any country no matter what shall be the status of its environment, political or economic conditions. Therefore, if an ecotax is regressive then its proceeds shall first be used to make it progressive or at least less regressive. Thereafter, the proceeds could be used for other environmental objectives such as reducing environmental damage in other sectors, provisioning of environmental goods or for other concerns such as reducing poverty. Reducing distortions in other forms of taxes and shifting the tax base from '*goods*' (income, earnings, etc.) to '*bads*' (environmental polluting products) shall be the goal of revenue recycling if the above two conditions are pre-existing in the country (Weizsacker 1992 as cited in Srivastava and Kumar 2014). Reducing distortions in the prevailing tax system per se does not necessitate that all the revenue generated shall be utilized, i.e. revenue neutrality. But it is the fourth option, the need of political acceptance for the levy of a new tax on polluting products that necessitates revenue neutrality. This is the primary reason why this study separates these two utilization purposes of the revenue from the ecotaxes, even though they are normally used together in the literature. Srivastava and Kumar (2014) provide an alternative reasoning for the use of revenue neutral rate in the developed countries. According to them, the tax–GDP ratio for these countries is already high, so also the provisioning of environmental public goods; therefore, these countries could afford to use the proceeds for reducing existing tax distortions. They further caution that since the developing countries normally do not meet the conditions of high tax–GDP ratio and existence of environmental public goods, therefore the proceeds in these countries shall be used for environmental purposes rather than reducing distortions in other taxes.

Most of the available research studies on the impact of environmental taxes reviewed above considered either carbon tax as a fiscal instrument or were limited to fuel/energy taxes. These existing studies thus lack answering the research questions and concerns, posed earlier in this section, especially so with respect to India. Hence, this study aims to propose a design of ecotaxes in India and its implications on the rural and urban consumers. This paper is organized as follows: Section 2 gives the details about the data used and the methods followed for analysing the incidence of environmental tax. Section 3 consists of three subsections that discusses the results of pre- and post-revenue transfer from the levy of ecotax. The section also comprises of the analysis of these results. This is followed by the concluding remarks and a few policy recommendations before stating the major limitations of the study in Section 5.

2 Data and Methods

The fundamental data set that has been constructed for analysing the incidence of ecotax is the ESAM 2007–08 using the methodology of Pal et al. (2015). A 33 sector ESAM has been constructed by aggregating the sectors of the SAM of Pradhan et al. (2013) which provides a detail of 78 sectors in India for the year 2007–08. According to the Environment (Protection) Act 1986, air, water and land are three major components of the environment. Therefore, an attempt has been made to extend the ESAM 2006–07 by Pal et al. (2015) to ESAM 2007–08 by including all the three environmental components—air, water and land (refer to Appendix). Data sources such as TERI (2009), MoEF (2010), Pal et al. (2015), National Remote Sensing Centre (2011), Ministry of Statistics and Programme Implementation (2008), DES (2012) have been used to construct the environmental part of the ESAM. It is important to note that so far none of the available studies on

ESAM have taken environmental indicators which would depict all the three major forms of pollution. Thus, this study would attempt to fill this gap in the literature by analysing the incidence of ecotaxes by addressing all the three forms of pollution (Resosudarmo and Thorbecke 1996; Weale 1997; Xie 2000; Alarcón et al. 2000; Lenzen and Schaeffer 2004; Gallardo and Mardones (2013); Pal and Pohit 2014). NSS 64th round has been used for obtaining the data on population of the nine household occupation categories concomitant with the households classification given in the existing SAM of the year 2007–08 (NSSO 2010).

The choice of the tax base in this study is dependent upon the value of the pollution coefficients across sectors measured as gross emissions per unit of their output. On this basis, the five most polluting sectors have been identified for each of the three environmental components. Thereafter, modal frequency[2] for these polluting sectors was computed and five polluting sectors having maximum modal values were selected. All these five sectors had a value of two. The sectors thus selected are: thermal (NHY—non-hydro), fertilizers and pesticides (FER), iron and steel and non-ferrous basic metals (MET), paper and paper products (PAP) and textile and leather (TEX) (Table 1). All these sectors represent at least three of the five most polluting sectors of each of the environmental category, i.e. air, water and land. Thus, this gives a comprehensive definition of the tax base for analysing all the three forms of pollution.

There are three different ways in which ecotaxes can be levied—input tax, output tax or on proxies (Chelliah et al. 2007). In addition to that, ecotax might also be levied directly on the emissions. However, such types of ecotax are difficult to implement as it involves difficulties in computing the tax base. For example, emissions from a non-point source such as vehicles would involve a high cost of monitoring. Therefore, the ecotaxes are modelled as output taxes in this study and it is levied directly on the value of output of a sector excluding indirect taxes paid by that sector. Indirect taxes have been removed from the calculation of the value of output because this is how any ad-valorem tax is practically levied. Since the taxes are modelled in a social accounting matrix framework in which one sector's output is other sector's input, thus indirectly input taxes are also modelled in the study. This is because the taxed commodity would also be an input for some other sector thereby affecting the value of output of that sector due to an increase in the cost of inputs. The major assumption of this model is that the supply curve of the commodities has been considered to be perfectly elastic; thus, the entire tax burden would be shifted to the consumers. Therefore, it is important to interpret the results as an upper bound because in reality the supply curve is not perfectly elastic and the suppliers also bear some burden of the tax. In addition to this, the relative composition of demand would also change after the ecotax has been levied. That factor

[2]Modal frequency gives the number of times a sector appears in the three forms of pollution: air and water pollution and land degradation. For example, if a sector has a modal frequency or value of two it implies that of the three forms of pollution, the sector contributes in two of them.

Table 1 Five most polluting sectors in India

Sectors	Pollution coefficients		
	Net GHG emissions (tons/lakh of output)	Net wastewater disposed (L/day/lakh of output)	Net land degraded (square feet/lakh of output)
Textile (TEX)	0.06	49.96	1.86
Paper and products (PAP)	1.00	323.87	3.31
Fertilizer (FER)	4.70	22.91	NA
Metals (MET)	2.08	3.65	2.64
Thermal (NHY)	53.09	5183.55	NA

Source Author's calculations using MOEF (2010), National Remote Sensing Centre (2011), Ministry of Statistics and Programme Implementation (2008), DES (2012) and TERI (2009)

is also not considered in the following analysis of tax burden. Post-ecotax change in prices is computed using a 'price vector model':

$$P_{33\times 1} = \left(I - A^{\mathrm{T}}\right)^{-1}_{33\times 33} \cdot V_{33\times 1} \tag{1}$$

A^{T} is the transpose of the input coefficient matrix
V is the matrix of the share in value added of the exogenous vectors
P is the price vector

The incidence of ecotax is computed by altering the methodology proposed by Datta (2010). This is because in this study the ecotax is modelled as a component of the share of the value added whereas Datta (2010) modelled the ecotax as an explicit component in the price vector model. Therefore, the prices in this study change due to the levy of ecotax which are modelled in the share of value added:

$$\mathrm{d}P_{33\times 1} = \left(I - A^{\mathrm{T}}\right)^{-1}_{33\times 33} \cdot \mathrm{d}V_{33\times 1} \tag{2}$$

This also changes the formula for the tax burden. Since Datta (2010) had an explicit tax structure in the price vector model, therefore the value-added term did not change due to the levy of an ecotax. But in this case it is only the value added that will change so as to incorporate the changes due to the levy of ecotax. Thus, the formula would then be:

$$(\mathrm{TB}_k)_{1\times 1} = \left\{\frac{X_k}{Y_k}\right\}_{1\times 33} \cdot \mathrm{d}P_{33\times 1} \tag{3}$$

TB_k is the tax burden borne by kth household

$\left\{\frac{X_k}{Y_k}\right\}$ is the share[3] of kth household's expenditure on the 33 sector commodities of ESAM

The relative price changes (dP) of commodities and the share of expenditure for all the sectors in the respective households' total consumption expenditure have been used to compute the tax burden or incidence of the ecotax on the rural and urban households. The budget share of the commodities has been taken with respect to their total expenditure because the literature on ecotaxes argues that expenditure is a better measure of a household's well-being, as also discussed in the previous section (Porterba 1991).

There are five categories of the rural and four categories of urban consumer groups (Table 2) which are categorized according to their occupational characteristics in the ESAM 2007–08. The per capita incidence of ecotax has been analysed for all these nine household groups using two different tax rates 5 and 10%, and the population of the respective groups has been obtained from the 64th round of NSS (NSSO 2010). Further, the change in the incidence of ecotax—pre- and post-revenue transfer—has also been analysed after transferring the revenue from the levy of ecotax to the household which is relatively bearing more burden than higher income household. Five percentage of the revenue generated at both 5 and 10% tax rate has been modelled as a per capita revenue transfer. The justification for the amount of transfer has been provided in the next section. This detail on the approach adopted for the incidence of ecotax is also depicted in Fig. 1.

Per capita tax burden has been calculated by computing the change in the per capita expenditure for the household classes due to the levy of an ecotax. The tax burden, computed using Eq. (3), for every household category has been multiplied by the initial expenditure made by the households to obtain the final expenditure for these household categories. In order to arrive at the change in total expenditure of these households categories due to ecotax, difference between the final and initial expenditures has been computed (refer to numerator of Eq. 4). This gives the final expenditure of the households which has been subtracted by the initial expenditure to obtain the increase in the expenditure due to ecotax. This resultant is then divided by the population of each household to obtain their per capita tax burden (Eq. 4). Population has been taken as a weight to compute the tax burden because it is important to understand the number of people who have been affected due to the levy of ecotax. More importantly, the change in total expenditure is taken as a measure of final tax burden on the households; therefore, it is imperative to normalize this with their respective population because expenditure and population are correlated.

[3]This budget share has been assumed to be constant pre- and post-ecotax. This is because the objective of the paper is to examine the incidence of ecotax; thus, post-tax implications, i.e. feedback effects, have not been modelled.

Table 2 List of household categories

Household code	Description
RNASE	Rural non-agricultural self-employed
AGL	Agricultural labour
RNAL	Rural non-agricultural labour
RASE	Rural agricultural self-employed
ROH	Rural other households
USE	Urban self-employed
USC	Urban salaried class
UCL	Urban casual labour
UOH	Urban other households

Source Pal et al. (2015)

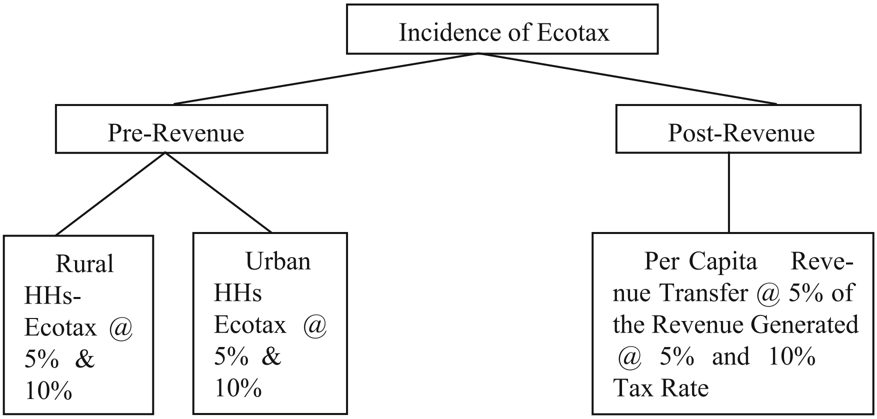

Fig. 1 Analyses structure of incidence of ecotax. *Source* Author's construction

$$\text{Per Capita Tax Burden} = \frac{\text{Initial Expenditure} \cdot \text{Tax Burden} - \text{Initial Expenditure}}{\text{Population}} \tag{4}$$

To understand the incidence of the ecotax on the households, the households in both rural and urban areas were arranged in increasing order of their annual per capita income. This has been computed from the ESAM. The proposition of Porterba (1991) has also been incorporated in the study, and the households have also been ranked in the increasing order of their expenditure so as to understand the difference in the pattern of the incidence of ecotax, if any. Further, 'range of incidence' has been used as a measure to evaluate the overall incidence of ecotax in a region. It is computed by subtracting the per capita tax burden of the lowest income class from the per capita tax burden of the highest income class. If the value is negative, then this implies that the ecotax is regressive as the per capita tax burden of the lowest class is more than that of the highest class and vice versa.

3 Results

The sequence depicted in Fig. 1 has been followed in this section to explain the results of the incidence of ecotax. This section has been broadly classified into three categories: incidence of ecotax in pre-revenue transfer scenario and post-revenue transfer scenario and analysing the incidence of ecotax on households.

3.1 Incidence of Ecotax in Pre-revenue Transfer Scenario

Figures 2 and 3 depict the per capita tax burden of the households in rural and urban areas for both 5 and 10% levy of ecotax, respectively. The households' categories in both rural and urban areas have been arranged in increasing order of their per capita incomes. This has been done so as to understand the incidence of ecotax; i.e. if all throughout these classes per capita tax burden is increasing, then this would imply that ecotax is progressive and vice versa. As is evident from Fig. 2, ecotax is overall progressive in the rural areas for both 5 and 10% rates of ecotaxation. This is because the highest income category of the rural household—rural other households (ROH)—is bearing more per capita tax burden than the lowest income category—rural agricultural labour (AGL). The range or the difference in the per capita tax burden is positive which amounts to Rs. 604. Similar results are obtained when the tax rate is doubled to 10% as the overall progressiveness is almost doubled to Rs. 1153 as measured by the range of incidence between ROH and AGL. The only household class for which ecotax is regressive is

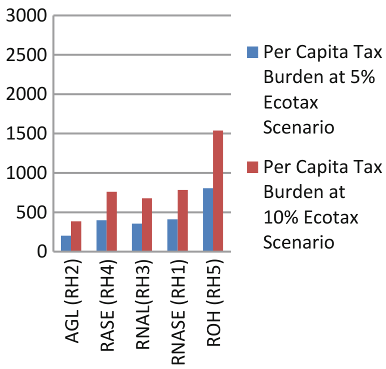

Fig. 2 Per capita tax burden (Rs.) of rural households. *Source* Author's construction using ESAM 2007–08

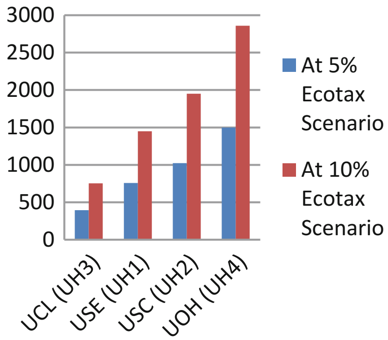

Fig. 3 Per capita tax burden (Rs.) of urban households. *Source* Author's construction using ESAM 2007–08

rural agricultural self-employed (RASE). This is because RASE is relatively lower income household category than RNAL, and at 5% tax rate, the per capita tax burden borne by the former household category is Rs. 398 which is Rs. 42 more than the category of rural non-agricultural labour (RNAL). Thus, the households belonging to RASE have to bear relatively more burden of the ecotax. Similar is also the case for 10% tax rate wherein the higher income household group—RNAL—has to spend less money in terms of its post-tax total expenditure.

For the urban areas as well, ecotax is overall progressive for both 5 and 10% rates of ecotaxation because the highest income household category—urban other household (UOH)—bears more per capita burden of the taxes than the lowest income household—urban casual labour (UCL). The range or the difference in the per capita tax burden is Rs. 1104 for 5% rate of ecotax and is Rs. 2106 for 10%. The factor by which the incidence for the two rates of taxation differs is 1.91, and this factor remains the same across the two regions, i.e. rural and urban. Thus, this implies that the rates do not play a significant role in determining the burden of ecotaxation as it just alters the absolute value of the incidence/burden on the households but does not change its pattern (Figs. 2 and 3). This result could be because of the limitations of the linearity assumption of the SAM method. Further, ecotax is seen to be progressive within all the categories of urban household unlike the rural households' category. For 10% tax rate scenario, the results are similar to that of 5% rate of ecotax which was also the case for rural households.

Following the proposition of Porterba (1991), Figs. 4 and 5 also depict the incidence of ecotax when the households are arranged in the increasing order of their total expenditure. As is evident, the pattern of incidence changes in both rural and urban areas. The incidence of ecotax in both the regions is no more progressive when compared between the households. Even then, the ecotax still remains overall progressive with the difference in the per capita tax burden between the highest and the lowest expenditure class being positive (compare Figs. 2 and 4; Figs. 3 and 5). However, if the total expenditure of every household category is normalized with their respective population then the incidence would depict same pattern for the urban household category as shown in Fig. 3, but for rural households' category the progressiveness could be seen even for RASE. This implies that per capita total

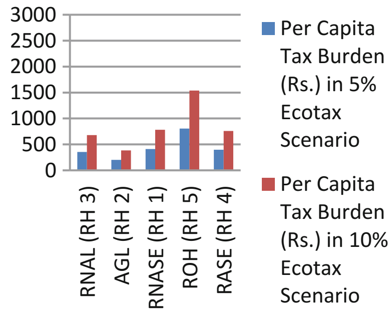

Fig. 4 Per capita tax burden (Rs.) of rural households arranged through expenditures. *Source* Author's construction using ESAM 2007–08

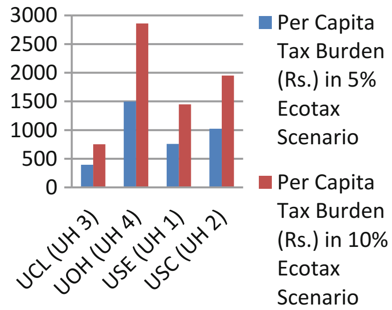

Fig. 5 Per capita tax burden (Rs.) of urban households arranged through expenditures. *Source* Author's construction using ESAM 2007–08

expenditure as a parameter for arranging the households is a better indicator than total annual expenditure and per capita annual income.

3.2 Incidence of Ecotax in Post-revenue Transfer Scenario

Revenue is a by-product of levying ecotax, and thus, the important question that arises is how to best use this revenue. As argued before, it is imperative to first remove the regressivity of the ecotax, if present, than utilizing the revenue for any other purpose. Thus, in this section an attempt will be made to understand as to how the revenue from the levy of ecotax could be used to make the tax progressive for RASE group for which the ecotax was found to be regressive.

Figure 2 clearly depicts that RASE has to share relatively more burden of the ecotax at both the rates—5 and 10%—when compared to higher income category household RNAL. On the other hand, its incidence from the lower income category household AGL is only a bit higher. Therefore, while transferring the revenue from the levy of ecotax it is imperative to transfer an amount which should be less than the difference of the incidence between AGL and RASE at the same time it should be greater than the difference of the incidence between RNAL and RASE. If this condition is not met, then either the transfer would be more and hence would make the category of AGL households to bear relatively more burden or the transfer would be insufficient to remove the regressivity. It is precisely because of this reason a range for revenue transfer has been provided. The incidence of ecotax borne by AGL, RASE and RNAL are Rs. 202, Rs. 398 and Rs. 356 at 5% tax rate, respectively. Thus, the range of per capita has to be between Rs. 43 and Rs. 196 at 5% tax rate scenario. Similarly, at 10% the range thus computed should be between Rs. 81 and Rs. 375 which is almost double than the former case. This is because the burden at 10% rate is almost double than that of 5% rate, and therefore, the range also increased by the same factor. The costs of these revenue transfers to the government have been computed at both the rates and have been tabulated in Table 3. As is evident, the total cost of the transfer ranges from around Rs. 126 lakhs to Rs. 558 lakhs for 5% levy and from around Rs. 234 lakhs to Rs. 1000 lakhs for a 10% levy. This comes to around 2–10% of the total revenue generated in both the tax rates scenarios.

In order to understand the impact of such transfer on the regressivity of the ecotax, 5% of the total tax revenue generated was chosen as the amount to be transferred for both the tax rates. This was done for the sake of simplicity as the actual transfer amount could be easily indexed to this rate. Figures 6 and 7 depict the impact of such transfer. As is evident from the graphs, the incidence for RASE has declined relatively to RNAL and it bears less burden than RNAL. Also, since the condition of the transfer was met, i.e. the transfer amount was between 2 and 10%, therefore the RASE has to still bear more burden than AGL which is relatively lower income household category. This ensures progressivity even between the household categories. In this case, since 95% of the revenue generated from ecotaxes is still with the government, therefore the government could also decide to spend this revenue in line with the criteria proposed earlier in the paper. This is because the major requirement of the ecotax not being regressive could be fulfilled by 5% revenue transfer as depicted by Figs. 6 and 7. The leftover revenue could be utilized for other developmental and environmental goals such as providing subsidies for cleaner generation of electricity, constructing of common effluent treatment plants. Further, the revenue could also be used for reducing distortions in other forms of taxes such as income tax, corporation taxes which are normally considered to reduce the incentive to earn.

3.3 Analysing the Incidence of Ecotaxes on Households

It is imperative to examine the tax burden and the average share of total expenditure of the households in rural and urban areas. This is because these measures help in understanding the reason for the ecotax being progressive, and further, a comparison could also be made between the patterns depicted by per capita tax burden and tax burden. The tax burden is obtained by using Eq. (2), as mentioned in Sect. 2, for both the tax rates. This is depicted in Figs. 8 and 9 for rural and urban

Table 3 Range of revenue transfer required for making ecotax progressive

Tax rate scenario	Minimum absolute revenue transfer (Rs. Lakhs)	Maximum absolute revenue transfer (Rs. Lakhs)	Minimum revenue transfer (%)	Maximum revenue transfer (%)	Per capita transfer at 5% of total tax revenue generated (Rs.)
5% tax rate	126,001	558,415	2	10	94
10% tax rate	234,821	1,071,011	2	11	171

Source Author's construction using ESAM 2007–08

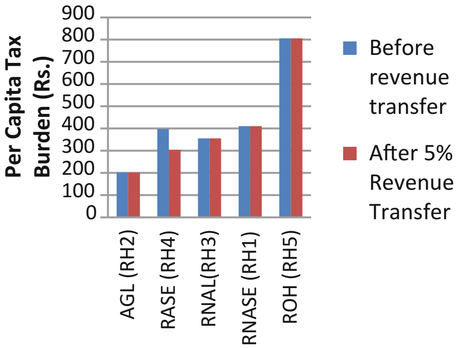

Fig. 6 Per capita tax burden in rural HHs at 5% tax rate pre- and post-transfers. *Source* Author's construction using ESAM 2007–08

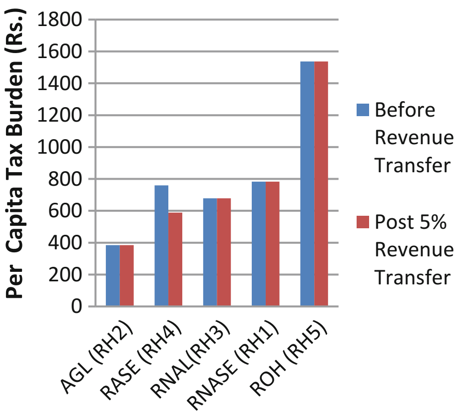

Fig. 7 Per capita tax burden in rural HHs at 10% tax rate pre- and post-transfers. *Source* Author's construction using ESAM 2007–08

households, respectively. The households are again arranged in increasing order of their per capita income. This was done so as to compare tax burden with the per capita tax burden depicted in Figs. 2 and 3. These figures clearly depict that there exist differences in the pattern of the two tax incidences.[4] The primary reason for this is the computational method adopted for calculating the per capita tax burden. The per capita tax burden is computed by normalizing the increase in total expenditure of every household by their respective population. The increase in total expenditure, which can be understood as additional burden due to ecotax, is obtained by subtracting the initial expenditure from the final expenditure. And the final expenditure is obtained by multiplying the initial expenditure with the tax burden. Therefore, the per capita tax burden could be said to fundamentally depend upon the total expenditure and the population of the households.[5] This is the precise reason as to why the pattern of per capita tax burden is different from that of tax burden (compare Figs. 2, 3 and Figs. 8, 9) which is further explained in detail below.

For the rural area, the difference exists between two households: RNASE and ROH (Figs. 2 and 8). This could be easily explained by examining their population and initial total expenditure (refer to Table 4). The reason why there is an increase in the per capita tax burden for RNASE is that the population and initial expenditure both are more (refer to Table 4), when compared with the previous household on the horizontal axis of Fig. 2; however, initial expenditure is proportionately higher than population. This, thus, leads to higher ratio in relation to RNAL, and the burden depicts an increase. Similarly, ROH has the least population amongst the rural households; therefore, its per capita tax burden is the highest.

In the case of urban households, the dissimilarity arises for all the households' categories as the per capita burden is increasing all throughout whereas tax burden declines as the per capita income increases (compare Figs. 3 and 9). Again the explanation could be provided using Table 4. The ratio of the expenditure to population across the households increases as their per capita income increases, therefore depicting a higher per capita tax burden which is perverse to the scenario of tax burden. Figure 3 shows an overall progressive picture of the ecotax, whereas Fig. 9 depicts ecotax to be regressive. This reinforces the argument of normalizing the tax burden with the ratio of initial total expenditure and population.

The pattern of the tax burden for both rural and urban households depicted in Figs. 10 and 11, respectively, could be explained by the average budget share of the taxed commodities by these households. This is because the budget share of any commodity gives the proportion of the total expenditure incurred for that commodity. If this share is high, then the household is dependent more on this

[4]These results remain same when the tax burden of the households is ranked in increasing order of their total expenditure and then are compared with Figs. 3 and 4. Thus, they are not depicted here.

[5]

$$\begin{aligned}\text{Per Capita Tax Burden} &= \frac{\text{Initial Expenditure} \cdot \text{Tax Burden} - \text{Initial Expenditure}}{\text{Population}} \\ &= \frac{\text{Initial Expenditure}}{\text{Population}} \cdot (\text{Tax Burden} - 1)\end{aligned}$$

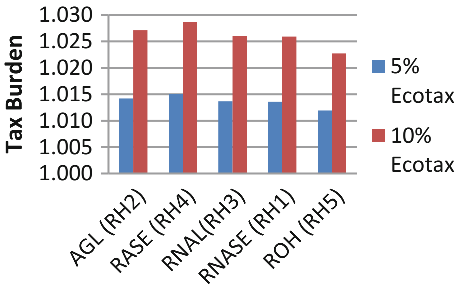

Fig. 8 Tax burden in rural households. *Source* Author's construction using ESAM 2007–08

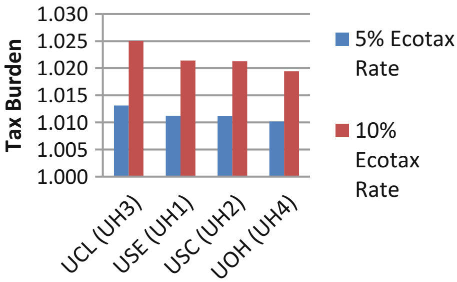

Fig. 9 Tax burden in urban households. *Source* Author's construction using ESAM 2007–08

Table 4 Population and expenditure details of the HHs

Household category	Total population (Million)	Total expenditure (Rs. Trillion)
AGL (RH2)	203.91	2.90
RASE (RH4)	286.37	7.58
RNAL(RH3)	80.88	2.11
RNASE (RH1)	115.37	3.49
ROH (RH5)	66.77	4.52
UCL (UH3)	34.35	1.03
USE (UH1)	111.96	7.56
USC (UH2)	105.45	9.66
UOH (UH4)	15.12	2.22

Source Author's construction using ESAM 2007–08

commodity or the demand for this commodity could be termed as relatively inelastic. Also, the tax burden is computed using Eq. (3) where this budget share was an integral part. Thus, it is imperative to examine the pattern of the tax burden using the share of total expenditure of the commodities/sectors taxed. In total, ecotax has been levied on five commodities/sectors: TEX, PAP, FER, MET and NHY. Of these five, the information on the budget share is not available for FER and MET. This might be because the households normally do not consume the products from these sectors directly. In order to understand the pattern of tax burden, the average of the budget shares of all these three sectors (TEX, PAP and

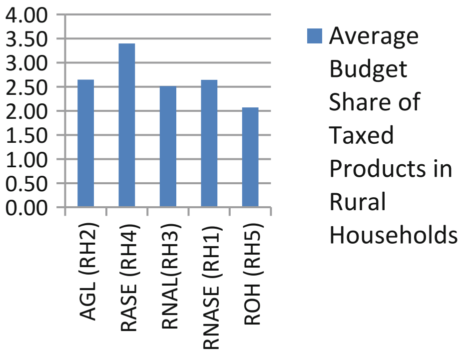

Fig. 10 Average share of total expenditure by rural HHs. *Source* Author's construction using ESAM 2007–08

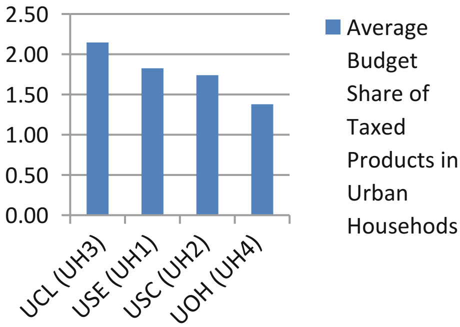

Fig. 11 Average share of total expenditure by urban HHs. *Source* Author's construction using ESAM 2007–08

NHY) was obtained and these were plotted for the rural and urban households in Figs. 10 and 11, respectively. As is evident by comparing Fig. 8 with 10 and Fig. 9 with 11, the pattern appears to be very similar. The figures clearly depict that the average of the share of the tax burden declines for the three household categories in rural areas after RASE. Similar is the case for the households of the urban area except that the share declines for every household as the per capita income increases.

4 Conclusion and Recommendations

Environmental taxes have been into existence for over two and a half decade, but still some of the fundamental questions regarding ecotaxes remain unanswered: how to define the environment tax, i.e. the design of their tax base and for some questions ambiguity prevails: whether the environmental taxes are progressive or regressive? An attempt has been made to answer these two questions using an environmentally extended social accounting matrix (ESAM) for India 2007–08. These questions find its relevance in the Indian context because still a majority of Indian population have low standard of living, and if the share of the burden of ecotaxes is borne more by this group, then the tax shall be deemed as inequitable, as per the canons of taxation laid by Smith (1904). Further, the dismal status of ecotaxes in India, as found by Verma (2016), gives a thrust for exploring the issues related to the design and the effects of these taxes on Indian households.

In order to answer the first question related to the design of ecotaxes, polluting tax bases was identified by using pollution coefficients of the sectors from the ESAM so as to represent all the three sectors of environment—air, water and land—as identified by the Environment (Protection) Act 1986. The five most polluting tax bases identified were thermal (NHY—non-hydro), fertilizers and pesticides (FER), iron and steel and non-ferrous basic metals (MET), paper and paper products (PAP) and textile and leather (TEX). Ecotax was levied on these five sectors as a tax on the value of output of these sectors excluding indirect tax payments by these sectors. Such an ecotax could be categorized under output tax. Tax simulations with 5 and 10% rates of ecotaxation were attempted to. Incidence of these taxes was studied on five categories of rural households and four categories of urban households using a price vector model, as proposed by Datta (2010). This methodology was altered to accommodate the manner in which the ecotax has been designed in this study. Thereafter, policy simulation for 5% transfer of the revenue generated from the levy of ecotax was also examined.

The study found that the per capita tax burden for the rural households is more for the highest income class as compared to the lowest income class (i.e. ecotax is progressive) at both 5 and 10% rates. This result was obtained using the range of incidence as a measure. In the case of urban households, the per capita tax incidence was also found to be progressive. Thereafter, policy simulation of per capita revenue transfer was also studied for the rural households because the ecotax was found to be regressive for RASE. It was found that a range of 2–10% of the revenue generated from the levy at both 5 and 10% rates shall be transferred to this household in order to make the ecotax progressive at every household category in the rural area. Such a transfer accomplishes the primary objective of the government, i.e. to let the higher income households bear more tax burden and thus make the tax equitable. On the other hand, for the households of the urban area it was found that no such revenue transfer to the households is required as the ecotax is progressive at every household category.

There exists difference between the pattern of the per capita tax burden and tax burden. This primarily arises due to the normalization of the tax burden with the ratio of initial total annual expenditure and population. The pattern obtained in tax burden is reverse of that obtained in per capita tax burden. Since, per capita tax burden normalizes the tax burden and hence makes it comparable across the households; therefore, it was used as a measure to understand the effect of ecotax on households. Further, the pattern in the tax burden could be explained by taking mean of the budget share of the taxed commodities by the households.

4.1 Recommendations

i. The government shall levy ecotax on the value of output from the polluting sectors which could be incorporated under the present GST framework. The five most polluting sectors in India that cover all the three forms of environmental pollution are: thermal (NHY—non-hydro), fertilizers and pesticides (FER), iron and steel and non-ferrous basic metals (MET), paper and paper products (PAP) and textile and leather (TEX). Such a tax design would also undertake low monitoring and implementation cost.
ii. To begin with, ecotax could be levied at a modest rate of 5%. This is because an increased tax rate only increases the absolute burden on the consumers without affecting the pattern of incidence. Also, this would ensure the acceptance amongst the stakeholders because of its low rate.
iii. It is imperative for the government to transfer back the revenue generated from the levy of ecotax to the poor households, RASE group, i.e. the farmers. These transfers could be directly linked to the accounts of the beneficiaries, and thus, a direct benefit transfer system could be adopted. The 90–95% of the revenue that is left after the transfer could be used for other environmental purposes such as investment in clean energy, cleaning of rivers, afforestation.

5 Limitations

There are two major limitations of the methodology used for examining the incidence of ecotaxes in this study:

i. Feedback effect of the ecotaxes and the revenue transfers were not examined. This is because the methodology used is constrained by the fixed coefficients.
ii. The substitution of the environmental polluting technology with an environmentally sound technology was also not been analysed. This is also because the technological effects cannot be captured in a short run SAM analysis.

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			Production	Factors of production	Institutions	Indirect taxes	Capital account	Rest of the world	Damaging substances (pollutants)		Depletable/degraded natural resource			Environmental theme		
									GHGs	Wastewater disposed	Renewal of energy resource	Renewal of land	Reduction of degraded land	Greenhouse effect	Water pollution	Land pollution
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Production		1	Intermediate consumption		Consumption of goods and services		Change in stocks and capital formation	Exports	Emission of pollutants from production	Wastewater disposed						
Factors of production		2	Payment for factors					Net factor income from abroad			Renewal of energy capital	Renewal of land capital	Reduction of degraded land			
Institutions		3		Value-added income	Transfer from other institutions	Total tax received		Net current transfers	Emission of pollutants from consumption	Wastewater disposed by households						
Indirect taxes		4	Taxes on intermediate		Taxes on purchase		Taxes on investment									
Capital account		5		Depreciation	Savings			Foreign savings								
Rest of the world		6	Imports													
Damaging substances (pollutants)	GHGs	7	Absorption of substances in production		Absorption of substances in consumption							Removal of substances		Accumulation of substances	Amount of wastewater generated	Extent of land degradation
	Wastewater disposed	8	Treatment of wastewater through industries		Treatment of wastewater through government institutions											
Depletable/degraded natural resources	Depletion of energy resources	9		Depletion of energy stock										Reduction in natural stock		
	Depletion of land	10		Depletion of land through conservation					Emission from land use change							
	Degradation of land	11		Degradation of land										Reduction on land's productivity		
Environmental theme	Greenhouse effect	12		Accumulation of GHGs												
	Water pollution	13		Amount of wastewater generated												
	Land pollution	14		Extent of land degradation												

Source Pal et al. (2015)

Appendix: Basic Structure of Environmentally Extended Social Accounting Matrix

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Part VI
International Trade Modelling

Global Value Chain and Effects of Trade Policy Instruments—A Case of India

Chandrima Sikdar

Abstract GVCs have led to greater integration among economies of the world with each economy often specializing in specific activities and stages of value chains, rather than in the entire production process. Asia, as a region, has been a major participant in GVCs. India, one of fastest growing countries of the region, has, however, had a very dismal participation in the GVCs. One of the major reasons that explains this non-participation is India's trade-related policies and procedures. Against this backdrop, the present paper analyses the direct and indirect effects of trade policy instruments, particularly non-tariff measures (NTMs) on the country's manufacturing sector. Using imports of processed food from China into India as a representative case, the results show that import restriction on a sector leads to both direct and indirect impacts along the value chains. The results further show that NTMs on a sector magnify these direct and indirect impacts. Further, if NTMs are measured including the trade costs at borders, then the direct and indirect trade restrictiveness indices due to import restriction on a sector are reported to be much higher. This is a very important finding of the paper as it indicates that to assess the impact of NTMs on an economy, trade costs should not be ignored. For countries like India, which have elaborated procedural and documentation requirement laid down by different regulatory bodies, ignoring such trade costs at borders may lead to substantial underestimation of the impact of a trade policy restriction.

Keywords GVC · NTMs · Tariff · Trade restrictiveness

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1 Introduction

In the present era of globalization, global value chains (GVCs) connect geographical and local production processes. Growth of these GVCs has led to greater integration among economies of the world with each economy often specializing in specific activities and stages of value chains, rather than in the entire production process. Over 70% of global trade is in intermediate goods and services and in capital goods. Income created within the GVCs has doubled, on an average, during the last 15 years. China, one of the major participants in GVCs, has witnessed a sixfold growth in its income associated with GVCs (OECD, WTO and World Bank Group 2014).

Participation in GVCs comes with several benefits—firms have the scope to enter markets while specializing only in niche intermediate production within a chain; the suppliers are allowed to upgrade production into the higher-value segments of their industries; producers learn new processes; higher-quality standards are met which result in greater market access; exports and imports in intra-firm trade are facilitated; usage of network technology is encouraged and new sources of capital tapped. On the domestic front, countries participating in GVCs are able to specialize in lines of their comparative advantages. This enhances productivity growth leading to better domestic wages and income generation. However, the benefits from participating in GVCs are not automatic. An economy needs to have strong social, environmental and governance frameworks and policies in place to get the maximum benefit out of GVC activities.

Thus, not all countries and firms are equally involved in GVCs. Some participate as host country leading firms, while others participate as suppliers of specific products/services and while there are still others which hardly participate.

Asia, as a region, has been a major participant in GVCs. During 1995–2013, the regions' trade in intermediate goods grew by a factor of six, greater than its trade in final goods, which grew around four times (Cheng et al. 2015). China, Korea, Japan, Indonesia are some of the leading participants in the GVCs in the Asian region. India, one of fastest growing countries of the region and the world, has, however, a very dismal participation in the GVCs. In particular, the country's manufacturing sector is marked by near non-participation in most of the GVCs. GVCs in manufacturing are mostly focussed on electronic, telecom or high technology products, and India does not manufacture these products but imports them in large quantities. But participating in high value-added activities of GVCs is critical for Indian manufacturing as the products manufactured in GVCs account for as much as 70% of total world trade in non-fuel manufacturing products. Besides, manufacturing as a sector in India has witnessed a declining share in GDP (17% of GDP in 2016) and manufacturing exports have also stagnated at about 10% (Srivastava 2016). The sector needs an enormous push to reach a 25% share of GDP by 2025, a target set by the Government of India. Make in India, Startup India are initiatives by the government which are currently working towards realizing this target. These efforts could receive a further boost if India increases its participation in GVCs, thereby giving the much-needed thrust to its manufacturing sector.

One of the major reasons that explains India's non-participation in GVCs is its trade-related policies and procedures. Trade policies and procedures in countries need adjustment to accommodate for successful integration into GVCs. Imports need to be equally valued as exports; tariffs as well as time to trade need to be reduced, and regulatory measures need to be checked at both behind the borders and at the borders. Due to the reduction in tariff rates across the world, tariff as a trade policy tool is no longer as important as it was earlier, yet even the slightest rate of tariff can have a multiplier effect due to the structure of GVCs. Trade facilitation by cutting trade costs and avoiding unnecessary delays and reducing uncertainty helps in successful GVC participation. GVCs are also very sensitive to quality and efficiency of services, particularly logistic services. Thus, trade policies and procedures in a country need to be realigned for effective participation in GVCs. In India, while it is realized that GVC participation will go a long way to boost the performance of its manufacturing sector, yet a major concern is the country's trade policy and procedures which are not conducive for effective participation in these value chains.

With this backdrop, the present paper analyses the direct and indirect effects of trade policy instruments, particularly non-tariff measures (NTMs) on the manufacturing sector of the Indian economy. It calculates the cumulative impacts of the trade policy measures for India along the GVCs. The impact of the NTMs is analysed and demonstrated by considering a representative manufacturing sector, namely processed food. The rest of the paper is organized as follows: Sect. 2 presents a review of the literature and identifies the research gap. Section 3 discusses the methodological framework. The data are discussed in Sect. 4. Section 5 presents the results. The paper finally concludes in Sect. 6 with a summary of the findings and their policy implications.

2 The Literature Review and Research Gap

There are a number of works which have attempted the study of effect of non-tariff measures, used by countries as a trade policy measure. Some recent works are those by Moore and Zanardi (2011), Ghodsi (2015), Rosendorff (1996), Vandenbussche and Zanardi (2008), Almeida et al. (2012). These scholars discuss the various motives and the general impact of imposition of non-tariff measures on a country's trade front. However, they do not come up with any consensus regarding the general impact of each type of NTMs. Other scholars who focus on analysing the causes and effects of different types of NTMs rather than offering general conclusion about the different effects of NTMs are—Kee et al. (2008, 2009), Beghin et al. (2014), Bratt (2014), Ghodsi and Grübler (2015).

Kee et al. (2009) estimate the ad valorem equivalent (AVE) for NTMs by using cross-sectional trade data at six-digit level of the harmonized system (HS) for 2002. But the results of this study are limited to only the positive AVEs which point at the hampering effect of NTMs on trade. Later, Beghin et al. (2014) and Bratt (2014) use this approach but also incorporate the negative AVEs and hence accommodate for the promotional effect of NTMs on trade. The drawbacks of these studies are—the estimates at product level provide only one estimator of the impact of NTMs across all countries. Besides, the studies use unilateral non-tariff elasticities of trade estimated by Kee et al. (2008) and these are made to vary across countries only by varying the import–GDP share of the given product across countries. Thus, the impact of the NTMs imposed by different countries on a single product is considered uniform and hence captured by a single estimator. Ghodsi and Grübler (2015) extend this approach to include bilateral trade flows so that the varying impacts of the NTMs as per the importing countries can be captured.

A very recent comprehensive work on non-tariff measures is that by Ghodsi and Stehrer (2016). This study analyses the indirect effects of these trade policy instruments in the global economy. It follows a four-stage approach to quantify the cumulative impacts of trade policy measures along GVCs using the world input–output database (WIOD). First, bilateral import demand elasticities consistent with WIOD classification are estimated. Second, bilateral ad valorem equivalents (AVEs) of nine types of NTMs[1] that are notified by the different countries to the World Trade Organization (WTO) till the end of 2011 (WTO database) are quantified. Thereafter, cumulative bilateral-trade restrictiveness indices (BRIs) are calculated using the AVEs of NTMs and tariffs while taking into account backward linkages. Finally, in the fourth stage the impact of trade policy measures on the average annual growth of labour productivity is assessed.

The present paper is inspired by this work. Though the former is for 43 countries, this paper focuses only and more closely on India. There is hardly any paper on India which attempts an exercise as this. Given the rise of GVCs and India's increased participation in it, such a study is undoubtedly the need of the hour.

In terms of methodology, the present paper draws inspiration from Ghodsi and Stehrer (2016), but the value addition of this paper is the scope of the non-tariff barriers that it considers. In Ghodsi and Stehrer (2016), non-tariff barriers refer to the number of non-tariff barriers as notified by respective countries to World Trade Organization (WTO) and available at WTO I-TIP notifications database. The present paper along with this number of NTMs considers NTMs in the form of trading costs across borders. In India, these NTMs have huge impact on trade due to existing procedural and documental complexities and involvement of too many regulatory authorities. For example, for a simple plant product to be imported there are around 21 forms to be filled up related to licence, quarantine facilities, etc. For an animal food product, the regulatory departments involved are the Department of Animal Husbandry and Food Safety and Standards Authority of India with each department having its elaborate procedure and documentation requirement in place.

[1]Sanitary and phytosanitary [SPS]; Technical Barriers to Trade [TBT]; anti-dumping [ADP]; countervailing [CV]; safeguards [SG]; special safeguards [SSG]; quantitative restrictions [QR]; tariff rate quotas [TRQ]; export subsidies.

Thus, for India, more than the numbers of NTMs imposed on a product, the procedural and documentation complexities connected to those NTMs represent a larger part of barriers to trade.

When a country imposes NTMs, like SPS and TBT, the objective is to ensure quality and standards for the imported products. But such trade regulations affect not only trade flows but also the prices of the products at different stages of production. Added to such regulations, if there are procedural and documentation complexities involved, then the effect of the NTMs on the different sectors of the economy is only likely to multiply.

3 Methodology

This paper uses the following steps to analyse the indirect impact of the NTMs imposed on the import of a particular sector of the economy.

- First, the bilateral import demand elasticity with respect to import in the sector from an import partner is estimated.
- Then, using the latest list of notified NTMs to WTO by India and using the country's trade cost data from World Bank, the ad valorem equivalents (AVEs) of these NTMs are quantified.
- Thereafter, the cumulative bilateral-trade restrictiveness indices (BRIs) using the AVEs of these NTMs and weighted average of tariffs during 2010–2016 are calculated taking into account the inter-sector linkages.
- Thus, the present paper provides the detailed bilateral-trade restrictiveness indices (BRIs) for the inputs of the selected manufacturing sector in India over time and hence investigates the path of NTMs and the tariffs to the downstream industries and the final absorption in the context of the Indian economy.

3.1 Bilateral Import Demand Elasticities

As a first step towards assessing the impact of the NTMs on the quantity of imports in a selected manufacturing sector, the imports demand elasticity of that particular sector is estimated. This import demand elasticity measures the responsiveness of quantity of import of a good to changes in its price. Following Ghodsi and Stehrer (2016), the present study starts with a flexible GDP function which includes prices of imported products differentiated by country of origin and factors of production. Then, this GDP function is extended into a semi-flexible function which includes only one price indicator for estimation. This price indicator is defined as a ratio of price of the imported good g to country i from country j, relative to the average price of all other goods demanded in the GDP of country i.

The resulting benchmark equation to be estimated by product–exporter gj is as follows:

$$\begin{aligned} & s^t_{gij} = a_{0n} + a_{gij} + a^t_g + a^t_{ggj} \ln \frac{p^t_{gij}}{p^t_{-gi}} + \sum_{m \neq l, m=1}^{M} c^t_{gm} \ln \frac{v^t_{mi}}{v^t_{li}} + u^t_{gij}, \\ & \forall g = 1, \ldots\ldots, G, \quad \forall i = 1, \ldots\ldots, I, \quad \forall j = 1, \ldots\ldots, J \\ & k^t_{gi} = a_{gi} + a^t_g + a_{gj} + u^t_{gi} \end{aligned} \tag{1}$$

where

s^t_{gij} is share of import value of product g from country j to country i in the GDP of country i at time t.
p^t_{gij} is the price (unit value) of the imported product.
v^t_{mi} and v^t_{li} refer to factors m and l in production of GDP of country i.
k^t_{gi} are the individual-specific effects; time-invariant importer-specific effect (a_{gi}); time-invariant exporter-specific effect (a_{gj}); time-specific effect (a^t_g) and the idiosyncratic error/time-varying error.
p^t_{-gi} is the Tornqvist price index (Caves et al. 1982) of all other goods.

The Tornqvist price index is constructed using the GDP deflator p^t as follows:

$$\ln p^t_{-g} = \left(\ln p^t - \overline{s^t_h} \ln p^t_g \right) \Big/ (1 - \overline{s^t_g}), \quad \overline{s^t_g} = \overline{s^t_g + s^{t-1}_g} \Big/ 2 \tag{2}$$

If the study includes more than one product imported by a country from different countries (as done in Ghodsi and Stehrer 2016), the import demand elasticities are to be obtained for all products imported into a country. However, estimating Eq. (1) by each product–exporter pair likely reduces the consistency of the estimates due to small number of observations. So, in such a case to increase the efficiency of the estimates, the estimation is run by each product (Ghodsi and Stehrer 2016). To capture the country of origin of each product, the price indicator $\frac{p^t_{gij}}{p^t_{-gi}}$ is interacted by the exporter dummies.

Thus, Eq. (1) is transformed into the following equation:

$$\begin{aligned} & s^t_{gij} = a_{0n} + a_{gij} + a^t_g + \sum_{j=1}^{J} a_{ggj} \ln \frac{p^t_{gij}}{p^t_{-gi}} a_{gj} + \sum_{m \neq l, m=1}^{M} c^t_{hm} \ln \frac{v^t_{mi}}{v^t_{li}} + u^t_{gij}, \\ & \forall g = 1, \ldots\ldots, G, \forall i = 1, \ldots\ldots, I, \forall j = 1, \ldots\ldots, J \\ & k^t_{gi} = a_{gi} + a^t_g + a_{gj} + u^t_{gi} \end{aligned} \tag{3}$$

Equation (3) is to be estimated for each individual six-digit product, and estimate is obtained for parameters a_{ggj} where 'J' denotes the number of exporters. Fixed effect estimation technique is used to control individual-specific effects. The resulting estimates obtained are consistent estimates of the parameters which represent elasticities through the changes of variables over time. The share of imports in GDP is negative ($s^t_{gij} < 0$) (by construction). Thus, the import demand elasticity of good *gj* as derived from the GDP maximizing demand function is as follows:

$$\begin{aligned} &\widehat{\varepsilon}_{ggij} = \frac{\partial q^t_{gij}}{\partial p^t_{gij}} \frac{p^t_{gij}}{q^t_{gij}} + \frac{\hat{a}_{ggj}}{\bar{S}_{gij}} + \bar{S}_{gij} - 1 \\ &s^t_{gij} < 0 \\ &\varepsilon_{ggij} \begin{cases} < \; -1 \;\text{ if }\; a^t_{ggj} > 0 \\ = \; -1 \;\text{ if }\; a^t_{ggj} = 0 \\ > \; -1 \;\text{ if }\; a^t_{ggj} < 0 \end{cases} \end{aligned} \tag{4}$$

For calculating the AVEs of the NTMs, the world input–output database (WIOD) classification is used. The functional forms of parameters for the HS six-digit products within each WIOD category are assumed to be homogeneous, and fixed effect estimators are used for controlling their heterogeneity. Thus, Eq. (3) may be estimated for each WIOD industry encompassing all six-digit products via the relevant concordance tables.

3.2 Ad Valorem Equivalents (AVEs) for NTMs

To estimate the impact of NTMs (nine types as per WTO database) on bilateral import demand quantities between countries, the following gravity framework [proposed by Kee et al. (2009)] is used.

$$\begin{aligned} \ln\left(m_{ijgt}\right) = &\alpha_{ig} + \sum_k \alpha_{1k} C^k_{ijt} + a_{1gt} \ln\left(1 + T_{ijgt}\right) \\ &+ \sum_{ij=1}^{IJ} \sum_{n=1}^{N} w_{ij} \beta_{1ng} \mathrm{NTM}_{ijgt} + w_{1ijg} + w_{1t} + \mu_{1ijgt} \end{aligned} \tag{5}$$

where $\ln\left(m_{ijgt}\right)$ is the natural log of the import quantity of product *g* to country *i* from country *j* in time *t*; C^k_{ijt} is the country-pair characteristics and consists of classical gravity variables and factor that include endowments.

3.2.1 The Classical Gravity Variables and Factor Endowment Variables in the Gravity Equation

The classical gravity variables and factor endowment variables included in C^k_{ijt} are described:

- The traditional market potential of trade partners which is the summation of both countries' GDP:

$$Y_{ijt} = \ln\left(\mathrm{GDP}_{it} + \mathrm{GDP}_{jt}\right)$$

- The economic development distance similarly used by Baltagi et al. (2003):

$$Y_{ijt} = \left\{\frac{\mathrm{GDP}_{it}^2}{\left(\mathrm{GDP}_{pcit} + \mathrm{GDP}_{pcjt}\right)^2} + \frac{\mathrm{GDP}_{it}^2}{\left(\mathrm{GDP}_{pcit} + \mathrm{GDP}_{pcjt}\right)^2}\right\}$$

- C_{ijt}^k also includes distance between the trading partners with respect to three relative factors—labour force 'L'; capital stock 'K'; and area of agricultural land A. This distance is given as

$$f_{mijt} = \ln\left(F_{mjt}/\mathrm{GDP}_{jt}\right) - \ln\left(F_{mit}/\mathrm{GDP}_{it}\right), \quad F_m \in \{\mathrm{L},\ \mathrm{K},\ \mathrm{A}\}$$

Additional gravity variables included in the estimating Eq. (5) are log of capital city distances between a country and its trade partner and a number of dummy variables indicating common borders, common language, common colonial history and existence of preferential trade agreement (PTA) between the trade partners.

Estimating gravity Eq. (5) for country-pair using fixed effect model drops out the time-invariant variables from the equations. The respective country-pair product and time fixed effects are represented by w_{1ijg} + w_{1t} in Eq. (5).

As in the case of estimation of import demand elasticities, the estimations in this case too are run by WIOD categories encompassing all corresponded six-digit products of the HS.

3.2.2 The Tariff and NTMs in the Gravity Equation

The gravity Eq. (5) incorporates data on tariff and non-tariff measures. They are explained as follows:

- The coefficient capturing the impact of tariffs on import is given by α_{1gt}, and the coefficient capturing the impact of non-tariff measures on imports is given by $w_{ij}\beta_{1ng}$

- For tariffs T_{ijgt}, the data on AVEs (using UNCTAD WTO methodology) are prioritized as—preferential tariff rates (PRF), then AVEs on most favoured nation rates (MFN) and then effectively applied rates (AHS).
- NTM_{nijgt} include count variables for all 'n' types of NTMs mentioned earlier as well as the trade costs as captured by costs associated with border and documentary compliance.

3.2.3 AVEs for the NTMs

The coefficients of the NTMs $(w_{ij}\beta_{1ng})$ as obtained by estimating Eq. (5) are used along with the bilateral import demand elasticities (ε_{nijg}) as obtained from (4) to calculate the AVEs for the NTMs. The AVEs which are calculated using the expression below are obtained by differentiating the gravity equation with respect to each type of NTMs (including both count and associated trade costs).

$$\mathrm{AVE}_{nijg} = \frac{e^{wij\beta 1ng} - 1}{\varepsilon_{nijg}}$$

3.3 Bilateral-Trade Restrictiveness Indices (BRIs) and Cumulative AVEs in GVCs

The AVEs for the NTMs calculated in Sect. 3.2 along with the tariff data obtained from WTO represent the bilateral-trade restrictiveness indices (BRIs). When a country *i* imposes a BRI on a specific sector *g* imported from country *j*, the price of the imported product increases by BRI_{ijgt}. The domestic producers in the sector benefit from this direct BRI (DBRI). But, the downstream domestic sectors which utilize the product of the importing sector as input now face higher input price and thereby bear costs due to the BRI. Thus, there is an indirect cumulative BRI (IBRI) which is the costs along the later stages of production which use the importing sector's (subject to the BRI) output as inputs. The BRI and the IBRI following the imposition of tariffs and NTMs on a sector may be calculated as follows:

$$\mathrm{BRI} = \sum_{ks} a_{ksjg} \mathrm{BRI}_{jks}$$

where a_{ksjg} is the technical coefficient of the sector *s* from country *k* used in production of sector *g* in country *j* and $\mathrm{BRI}_{\mathrm{jks}}$ is the imposed BRI on import of industry *s* to country *j*. This calculation can be still extended backward to take into consideration the BRI imposed on the inputs of the stage calculated above. Using matrix algebra, the IBRI following the imposition of a non-tariff measure on an importing sector may be calculated as:

$$\text{IBRI} = \left[e \times B \times (I - A)^{-1}\right]$$

where A is a J × J matrix of technical coefficients, e is a row vector of ones, and B is a J × J matrix of element-by-element multiplication of technical coefficients and the tariffs and no tariffs.

$$B = A \times T.$$

Thus, in case of a study involving a large number of trade partners, trading in several goods, the IBRI is a column vector showing the IBRI for inputs in production of each country sector. The technical coefficients are calculated from the Leontief inverse obtained from WIOD.

The present paper does the entire analysis in terms of one manufacturing sector in India, namely food processing and one of its trade partners, China. Doing an analysis involving all the manufacturing sectors and all trade partners of the country would have resulted, undoubtedly, in a more comprehensive work, yet the paper chooses to focus on one sector and one of the exporting partners, mainly, because the objective of the current study is to demonstrate the method used to assess the impact of the NTMs imposed on import of a particular import and come up with a measure for the BRI and IBRI following the imposing of the NTMs. The analysis can be easily extended to incorporate all other sectors and all trade partners. The choice of the sector, food processing, is based on the fact that food products are subject to much larger number of non-tariff barriers (as compared to other sectors) due to involvement of agricultural products, animal products, chemicals, additives, etc., in the content. China is chosen as a trade partner as not only is China among India's top trade partners but also one of the largest sources of import for food products in India (fifth largest importer in 2016, UN Comtrade).

4 Data

The data required for calculating the BRI and IBRI associated with implementing NTMs on import of food products from China into India for the period 2010 to 2016 are as follows:

- Import of food products (HS code 17-22) in India and their respective prices obtained from WITS database (World Bank);
- GDP (real) of India and China and GDP deflator of India obtained from World Development Indicators;
- Total employment and capital in India obtained from Penn World Tables (the Centre for International Data, University of California, Davis);

- Total labour force, capital stock and area of agricultural land in India and China obtained from World Development Indicators;
- Gravity model variables from CEPII database;
- Tariff and non-tariff data from WTO I-TIP database;
- Trading across border data for India from World Bank Doing Business Database;
- World input–output database for calculating the IBRI.

5 Results

The present analysis yields the following set of results.

Based on the estimation of Eq. (3), the bilateral import demand elasticities of Indian imports (at six-digit HS code) from China for 7 years from 2010 to 2013 are estimated. The elasticities which are estimated at six-digit HS code showed an average figure of 16.9% for the entire period.

Second, using this bilateral import demand elasticities and the coefficient of NTMs from the gravity Eq. (5), the AVEs for the NTMs imposed on processed food products are estimated at six-digit HS code for the period of study. The AVEs are found to vary between 1.54 in the initial years (2010) and 0.43 in the latest years (2016). These figures represent the bilateral-trade restrictiveness indices imposed by NTMs. To these figures, if the restrictiveness imposed by tariffs is added, then the total bilateral-trade restrictiveness indices figures for each of the years increase and stand at 2.7 in 2010 and 0.50 in 2016. The results of the gravity model and the detailed AVEs of the NTMs at six-digit HS code for 7 years are reported in the Appendix.

Finally, at the third stage the IBRIs imposed on the downstream sectors by the BRI on the food processing sector are calculated using the WIOD and the BRI obtained at the second stage. The IBRI varies between 0.48 in case of only tariff on food imports and 1.15 in case of both tariff and non-tariff imposed on the importing sector. Figure 1 shows a comparison of the BRI and the IBRI imposed on the importing and the downstream sectors, respectively, due to the tariff and non-tariff measures.

The results indicate that there would be significant trade restrictiveness that would be imposed on the downstream sectors of the processed food sector when the latter is subject to import restrictions. As the import price of food increases by the extent of the tariff and the non-tariffs imposed, the downstream sectors using these food imports as inputs witness increase in their input prices resulting in an increase of their cost of production. Figure 2 shows the IBRI on some of the downstream sectors in India due to restrictions on import of processed food in the country. Some of the sectors which are majorly impacted are the other food manufacturing sectors, chemical manufacturers, accommodation and food service activities, textile, apparel

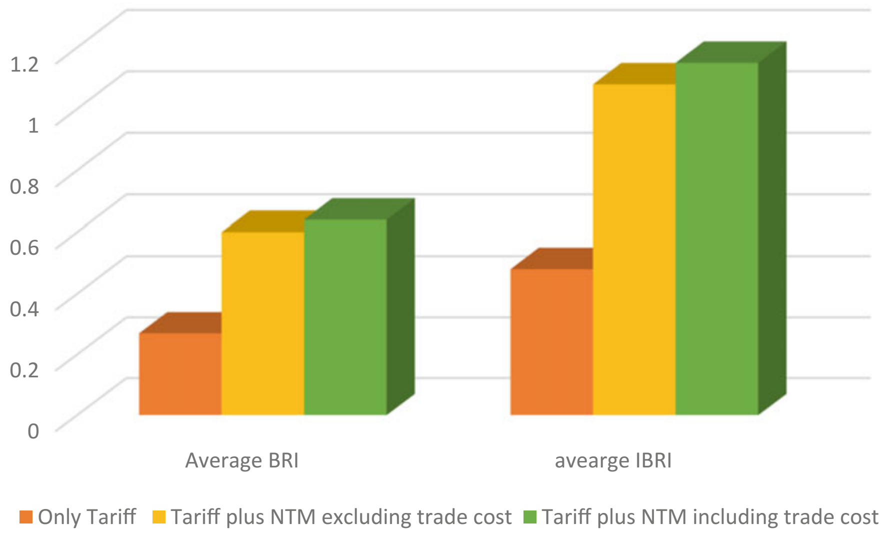

Fig. 1 Comparison of direct and indirect bilateral-trade restrictiveness indices under different trade policy measures. *Source* Based on Author's calculations

and leather manufacturers, crop and animal production and hunting-related activities and rubber and plastic manufacturers.

Thus, the sector, which is subject to import restrictions, impacts its downstream sectors. Upstream sectors may also be impacted as their supplies to the particular sector might suffer post the increase in the import price of the sector. Nowadays, when value chains and production networks spread across regions of a country and across different countries and regions of the world, an import restriction on an importing sector may hardly ever impact the importing sector alone. Rather, it is likely to have multiplier impact on different upstream and downstream sectors located across or within the country's geographical border.

Another important finding of the present study is imposition of NTMs brings about greater trade restrictiveness than do tariff measures (refer Fig. 1). This is an intuitive result given that NTMs have become more important trade policy instruments across the world today than are tariffs, which over time have been substantially lowered the world over.

While this finding is as per intuition, one of the major insights presented by the paper is the extent of trade restrictiveness that these NTMs impose on a sector or on the upstream and downstream sectors. This restrictiveness is found to vary significantly between the cases where NTMs are defined only as the number of non-tariff measures that an import is subject to (as considered by Ghodsi et al.) and the case where NTMs are not only defined as the number of measures but also included the trade cost figures (border and documentary compliance requirements in hours). As is evident from Figs. 1 and 3, the BRIs and the IBRIs are much higher when NTMs are measured as numbers of NTMs (reported by countries to WTO)

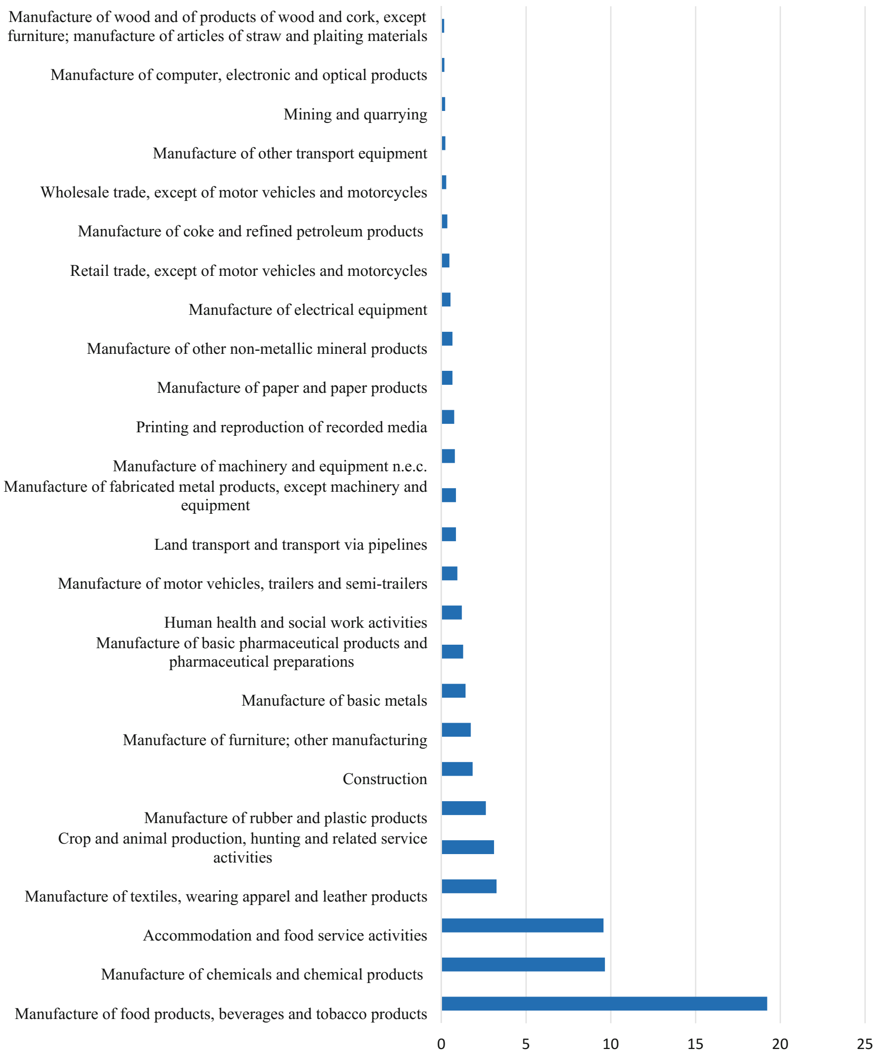

Fig. 2 IBRI on downstream sectors due to restrictions on food imports in India. *Source* Based on Author's calculations

plus the trade costs (measured as border and documentary compliance requirements measured in hours). For instance, the IBRI for other food manufacturers is 19.3 when the trade costs are included as NTMs as against 18.1 when NTMs refer to the nine non-tariff barriers imposed on food imports. The same is true for all the downstream sectors reporting high IBRI. In the six sectors shown in Fig. 3, the total IBRI is 0.2 more when trade costs are considered as a component of NTMs. The direct trade restrictiveness on the importing sectors also goes up by 0.04 when the

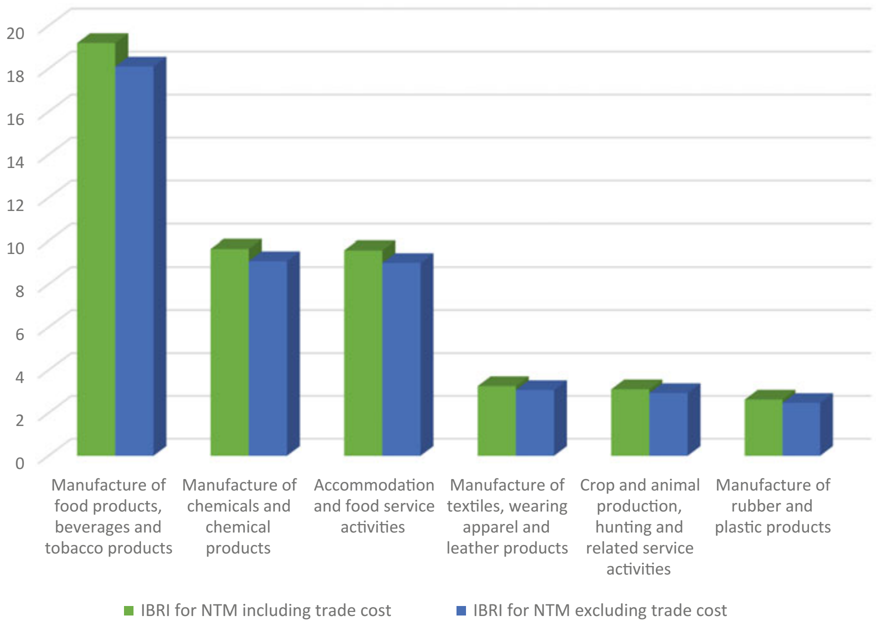

Fig. 3 IBRI for NTMs defined as numbers and defined as numbers plus trade cost. *Source* Based on Author's calculations

trade costs are included in measuring NTMs. This finding that trade costs increase both the direct trade restrictiveness and indirect trade restrictiveness is one of the major value additions of the present paper.

Thus, the study comes up with very important results:

(a) The imposition of import restriction in a given sector has a multiplier impact due to upstream and downstream linkages that a sector has within an economy as well as across the borders. With greater value chains and production networks, such inter-linkages are likely to be stronger in days to come. This in turn will lead to greater multiplier effect of a trade restriction on a sector.
(b) The trade restriction is not only due to tariff barriers but also due to non-tariff barriers. Rather, non-tariff barriers bring in greater trade restrictions than do tariff barriers.
(c) Non-tariff barriers exist not only in the form of quality and standard restrictions that regulatory authorities impose on imports into a country. But procedural and documentation complexities add further to these NTMs. Thus, considering the cost of trading at borders in terms of border and documentary compliance requirements is important to capture the right impact of the NTMs.

6 Conclusion and Policy Implications

Rising global value chains are an important feature of the present globalized world. Though Asia as a region has been a major participant in the GVCs, but India one of the fastest growing economies of the region has hardly been participating in such GVCs. One of the major reasons that explains this non-participation is the country's trade-related policies and procedures. Against this backdrop, the present paper examines the effect of trade restrictions due to tariff and non-tariff measures imposed on the imports of the country. It mainly focuses on the more talked about and widely used trade policy tools of NTMs. The paper considers imports of processed food from China into India as a representative case.

The results show that import restriction on a sector leads to both direct and indirect impacts along the value chains. The results further show that NTMs on a sector magnify these direct and indirect impacts. The most important contribution of the present paper is the measure of the NTMs that it considers. NTMs are measured as a number of non-tariff measures notified by a country to the WTO plus the non-tariff barriers imposed due to time spent in trading across borders of the importing country on account of documentary and border compliances. To the best of the knowledge of the present researcher, there is hardly any paper which considers trade cost in measuring NTMs. However, for countries like India, which have elaborated procedural and documentation requirement laid down by different regulatory bodies, ignoring such trade costs may lead to substantial underestimation of the impact of a trade policy restriction. The results present significant difference in the direct and indirect trade restrictiveness indices in the two cases where NTMs are defined only as numbers of measures as against NTMs defined as number of measures plus trade cost. The impact is much higher when NTMs include trade costs. This is a very important result as subjecting an import to non-tariff measures may have much larger effect than is anticipated if policy-makers fail to consider the costs at the border. In particular, for countries where such costs are substantially higher, ignoring them might lead to rather misleading assessment of the impact of an import restriction on the economy.

Appendix

See Tables 1, 2 and 3.

Table 1 AVEs of the non-tariff measures at six-digit HS code (2010–2016)

2010		2011		2012		2013	
Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS
170112	0.355	170111	0.029	170191	0.005	170191	0.512
170191	0.600	170191	0.073	170199	0.182	170211	0.569
170199	0.599	170199	0.406	170211	0.596	170230	0.589
170211	0.436	170211	0.599	170219	0.566	170240	0.586
170230	0.602	170219	0.576	170230	0.562	170250	0.546
170240	0.576	170230	0.601	170240	0.579	170260	0.597
170250	0.414	170240	0.569	170250	0.565	170290	0.529
170260	0.532	170250	0.562	170260	0.589	170390	0.249
170290	0.216	170260	0.564	170290	0.535	170410	0.554
170410	0.589	170290	0.569	170390	0.259	170490	0.596
170490	0.599	170390	0.182	170410	0.560	180500	0.581
180500	0.594	170410	0.566	170490	0.597	180690	0.573
180610	0.289	170490	0.600	180100	0.584	190120	0.019
180690	0.546	180100	0.600	180310	0.595	190190	0.525
190190	0.497	180310	0.569	180400	0.107	190219	0.324
190211	0.007	180400	0.597	180500	0.594	190230	0.120
190219	0.188	180500	0.600	180610	0.048	190240	0.189
190230	0.388	180610	0.112	180620	0.575	190300	0.553
190240	0.085	180620	0.592	180631	0.453	190410	0.193
190300	0.005	180632	0.043	180632	0.481	190420	0.086
190410	0.108	180690	0.599	180690	0.600	190490	0.099
190420	0.101	190110	0.552	190110	0.547	190520	0.032
190490	0.273	190120	0.235	190120	0.470	190532	0.446
190531	0.346	190190	0.567	190190	0.558	190540	0.459
190532	0.516	190219	0.411	190219	0.162	190590	0.596
190540	0.483	190220	0.332	190230	0.440	200190	0.245
190590	0.570	190230	0.484	190240	0.154	200210	0.218
200190	0.590	190240	0.061	190300	0.514	200290	0.602
200210	0.575	190410	0.466	190410	0.402	200310	0.448
200290	0.602	190420	0.259	190420	0.183	200390	0.090
200310	0.476	190490	0.388	190490	0.371	200510	0.311
200390	0.559	190510	0.022	190520	0.037	200540	0.250
200410	0.577	190520	0.033	190531	0.324	200559	0.101
200490	0.276	190531	0.498	190532	0.509	200570	0.003
200520	0.412	190532	0.573	190540	0.527	200580	0.001
200551	0.008	190540	0.541	190590	0.594	200590	0.521
200559	0.048	190590	0.589	200190	0.293	200600	0.572
200570	0.019	200110	0.008	200210	0.392	200799	0.524

(continued)

Table 1 (continued)

2010		2011		2012		2013	
Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS
200580	0.012	200190	0.569	200290	0.603	200840	0.316
200590	0.289	200210	0.589	200310	0.009	200870	0.436
200600	0.025	200290	0.602	200390	0.410	200880	0.295
200799	0.548	200410	0.564	200510	0.202	200979	0.603
200811	0.085	200490	0.357	200520	0.059	200980	0.577
200819	0.350	200520	0.263	200540	0.041	200990	0.569
200830	0.007	200540	0.392	200551	0.003	210111	0.448
200840	0.055	200551	0.172	200559	0.100	210120	0.541
200870	0.484	200559	0.190	200560	0.006	210210	0.602
200880	0.469	200570	0.410	200570	0.511	210220	0.229
200899	0.582	200580	0.453	200580	0.232	210230	0.010
200911	0.012	200590	0.489	200590	0.525	210310	0.483
200919	0.451	200600	0.546	200600	0.574	210320	0.568
200939	0.067	200710	0.159	200710	0.013	210390	0.569
200949	0.193	200799	0.554	200799	0.573	210410	0.304
200950	0.073	200811	0.015	200811	0.256	210610	0.551
200969	0.023	200819	0.506	200819	0.109	210690	0.594
200971	0.008	200850	0.325	200820	0.245	220210	0.200
200979	0.600	200860	0.503	200830	0.170	220290	0.261
200980	0.581	200870	0.439	200840	0.368	220300	0.481
210111	0.009	200880	0.009	200850	0.018	220421	0.576
210120	0.481	200891	0.010	200860	0.529	220429	0.058
210130	0.030	200892	0.163	200870	0.447	220820	0.586
210210	0.599	200899	0.511	200880	0.067	220840	0.013
210220	0.285	200911	0.586	200891	0.131	220890	0.428
210310	0.485	200919	0.534	200899	0.576	220900	0.206
210320	0.595	200929	0.397	200911	0.560		
210330	0.084	200939	0.569	200912	0.051		
210390	0.590	200949	0.364	200919	0.437		
210410	0.142	200969	0.535	200939	0.124		
210420	0.002	200971	0.036	200949	0.494		
210610	0.564	200979	0.602	200950	0.044		
210690	0.597	200980	0.591	200969	0.556		
220110	0.113	200990	0.330	200979	0.603		
220190	0.377	210111	0.481	200980	0.574		
220210	0.245	210120	0.544	200990	0.566		
220290	0.537	210130	0.048	210111	0.018		
220300	0.544	210210	0.600	210120	0.542		

(continued)

Table 1 (continued)

2010		2011		2012		2013	
Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS
220410	0.195	210220	0.152	210210	0.602		
220421	0.393	210230	0.342	210220	0.324		
220429	0.581	210310	0.496	210310	0.513		
220510	0.019	210320	0.596	210320	0.592		
220590	0.374	210330	0.090	210330	0.107		
220710	0.439	210390	0.595	210390	0.583		
220820	0.364	210420	0.075	210500	0.013		
220830	0.599	210500	0.277	210610	0.577		
220840	0.254	210610	0.582	210690	0.598		
220850	0.577	210690	0.601	220110	0.007		
220870	0.294	220110	0.513	220210	0.133		
220890	0.584	220190	0.037	220290	0.535		
220900	0.190	220210	0.447	220300	0.516		
		220290	0.589	220410	0.162		
		220300	0.499	220421	0.541		
		220410	0.549	220429	0.536		
		220421	0.553	220710	0.434		
		220429	0.592	220720	0.008		
		220590	0.034	220820	0.599		
		220710	0.029	220830	0.594		
		220720	0.405	220840	0.084		
		220820	0.501	220850	0.492		
		220830	0.599	220860	0.143		
		220840	0.373	220870	0.131		
		220850	0.578	220890	0.579		
		220860	0.204	220900	0.421		
		220870	0.300				
		220890	0.599				
		220900	0.372				

2014		2015		2016	
Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS
170191	0.546	170191	0.561	170191	0.496
170211	0.356	170199	0.011	170230	0.578
170230	0.579	170230	0.594	170240	0.553
170240	0.584	170240	0.577	170250	0.506
170250	0.539	170250	0.542	170260	0.600
170260	0.601	170260	0.603	170290	0.319

(continued)

Table 1 (continued)

2014		2015		2016	
Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS
170290	0.239	170290	0.548	170390	0.001
170410	0.547	170410	0.543	170410	0.508
170490	0.594	170490	0.594	170490	0.594
180500	0.595	180500	0.599	180500	0.598
180632	0.159	180690	0.572	180690	0.572
180690	0.576	190110	0.001	190190	0.391
190120	0.083	190190	0.283	190219	0.176
190190	0.456	190219	0.130	190230	0.366
190219	0.088	190230	0.163	190240	0.223
190230	0.281	190240	0.058	190300	0.047
190240	0.310	190300	0.261	190490	0.138
190300	0.428	190490	0.093	190532	0.456
190410	0.015	190510	0.108	190590	0.555
190420	0.001	190531	0.373	200190	0.424
190531	0.022	190532	0.470	200210	0.315
190532	0.281	190540	0.133	200290	0.600
190540	0.190	190590	0.593	200310	0.396
190590	0.597	200110	0.087	200390	0.133
200110	0.027	200190	0.379	200490	0.397
200190	0.245	200210	0.242	200540	0.248
200290	0.601	200290	0.601	200559	0.306
200310	0.474	200310	0.081	200590	0.517
200390	0.016	200390	0.306	200600	0.575
200410	0.208	200490	0.385	200799	0.596
200490	0.165	200540	0.309	200819	0.562
200510	0.014	200559	0.273	200830	0.440
200540	0.282	200590	0.526	200840	0.044
200559	0.144	200600	0.594	200860	0.226
200560	0.376	200799	0.594	200870	0.448
200580	0.037	200811	0.004	200892	0.450
200590	0.544	200819	0.454	200899	0.585
200600	0.579	200830	0.580	200919	0.023
200799	0.571	200840	0.195	200939	0.511
200819	0.243	200860	0.211	200949	0.550
200830	0.461	200870	0.463	200950	0.028
200850	0.030	200899	0.558	200979	0.602
200860	0.348	200949	0.554	200980	0.549
200870	0.514	200979	0.602	200990	0.545

(continued)

Table 1 (continued)

2014		2015		2016	
Product code	AVEs of NTMS	Product code	AVEs of NTMS	Product code	AVEs of NTMS
200899	0.557	200980	0.555	210111	0.560
200979	0.602	200990	0.031	210120	0.540
200980	0.538	210111	0.047	210130	0.002
200990	0.183	210120	0.500	210210	0.603
210120	0.373	210210	0.602	210230	0.022
210210	0.602	210220	0.293	210310	0.447
210220	0.307	210310	0.226	210320	0.553
210310	0.469	210390	0.590	210390	0.589
210320	0.582	210410	0.051	210610	0.594
210330	0.005	210610	0.596	210690	0.599
210390	0.592	210690	0.595	220110	0.019
210410	0.175	220210	0.007	220210	0.031
210610	0.581	220290	0.298	220290	0.318
210690	0.589	220300	0.507	220300	0.483
220290	0.322	220429	0.004	220410	0.016
220300	0.418	220720	0.253	220421	0.010
220720	0.230	220820	0.002	220830	0.005
220900	0.449	220890	0.368	220850	0.001
		220900	0.464	220860	0.002
				220900	0.506

Source Based on Author's calculation

Table 2 Gravity model results

Variables	Coefficients
Market potential	37.83 (0.20)***
Economic development distance	−1434.7 (0.10)
Distance between partners	
In terms of labour force In terms of capital stock In terms of agricultural land	53.9 (0.68) 19.6 (0.27) −317.5 (0.26)
NTMs	
Number of NTMs Compliance	−0.78 (0.023)* −0.06 (0.05)***
Tariff	−0.29 (1.6)
Adjusted R square Total panel (unbalanced) observations	0.60 560

Source Based on Author's calculation
Notes: Dependent variable: the import quantity of product g to country i from country j in time t: 2010–2016. *Standard errors are in parenthesis*
Significance *p <0.01, **p <0.05, ***p <0.1

Table 3 Average BRI and average IBRI (2010–2016) under different trade policy implementations in India

Under different trade policy implementations	Average BRI	Average IBRI
Only tariff	0.27	0.48
Tariff plus NTM excluding trade cost	0.6	1.08
Tariff plus NTM including trade cost	0.64	1.15

Source Based on Author's calculation

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India's Intra-industry Trade: Implication on Vertical Specialization, Environment and Employment

Paramita Dasgupta and Kakali Mukhopadhyay

Abstract India's IIT has grown in importance after the adoption of trade liberalization measures in 1991. This chapter tries to assess India's IIT by considering different aspects, like vertical specialization associated with IIT, the impact of IIT on environment and employment. The analysis focuses on India's bilateral IIT with the USA, EU (27) and China during 2001–02 to 2015–16. The study finds that share of IIT in total trade between India and its trade partners is increasing. India's IIT is dominated by the products which are differentiated vertically (VIIT). This might be an indication of vertical specialization and the country's increasing participation in global production network. Results also reveal low-quality VIIT dominates in trade with the USA and EU (27). In trade with China, both low-quality and high-quality VIITs are found to be equally important, though the share of low-quality varieties is rising. Regarding environmental impact of IIT, values of PTOT are greater than one in most of the cases implying India being a pollution haven. In trade with China, pollution intensity of export component of IIT has shown an upward trend over the study period. Regarding employment generation, IIT has a positive impact on the labour market, particularly in trade with EU (27) and China. As India is found to be specializing mostly in the varieties of lower quality which are unskilled labour-intensive, promotion of IIT could lead to an inclusive growth in an unskilled labour-surplus economy like India.

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JEL Classification F18 · Q560

1 Introduction

The earliest conception of international trade between countries can be traced back to Adam Smith's Absolute Advantage Theory, David Ricardo's Comparative Advantage Theory, and Heckscher and Ohlin's Factor Endowment Theory. According to these theories, trade between the countries takes place in commodities belonging to different industries and is referred to as inter-industry trade. Traditional trade models of Ricardo and Heckscher–Ohlin have explained this form of trade with the concept of comparative advantage involved in relative technology and factor endowments. However, these theories are inadequate in explaining the trade in similar commodities, referred to as intra-industry trade (IIT) which formed a large portion of world trade, particularly in the last few decades of the last century. In the late 1970s and 1980s, several models were proposed (Dixit and Stiglitz 1977; Krugman 1979, 1980, 1981; Lancaster 1980; Dixit and Norman 1980) within the framework of 'New Trade Theory' that attempt to explore trade in similar products between the countries. This theory emphasizes on existence of product differentiation, imperfect competition and economies of scale as the basic causes of occurrence of international trade in similar products.

Theoretical development focusing on IIT further continued when the economists found it important to give emphasis on differentiating total IIT between horizontal IIT and vertical IIT, as the determinants of IIT in horizontally differentiated goods are different from that in vertically differentiated goods (Turkcan and Ates 2010). Horizontal IIT has been defined as trade within an industry where the commodities are differentiated not in terms of quality but in terms of some other attributes. Dixit and Stiglitz (1977), Lancaster (1980), Krugman (1980, 1981), Helpman (1981), and Helpman and Krugman (1985) developed models explaining horizontal IIT where they emphasized on the importance of product differentiation, economies of scale and demand for variety in a monopolistic competition type of market structure as a basis of trade. In contrast, vertical IIT is defined as the trade in similar products having different qualities. So, the traded commodities are not the same in terms of unit cost of production as well as in terms of factor intensities. Theories have explained that differences in factor endowment across countries are the determinant of IIT in vertically differentiated goods (Falvey 1981; Falvey and Kierzkowski 1987). Falvey and Kierzkowski (1987) have shown that the capital–labour ratio used in the production of vertically differentiated goods reflects the quality of the commodities. Consequently, capital abundant countries produce higher-quality products and labour-abundant country produces lower-quality products, leading to an intra-industry trade in vertically differentiated goods where the capital abundant country exports higher-quality variety of the goods and imports lower-quality variety from the labour-abundant country. The vertical IIT models predict the rise in share of vertical IIT through increases in income and factor endowments differences between the trading partners.

In the last two or three decades, world production system has been changing rapidly in terms of rise of outsourcing, vertical specialization, offshoring and new sourcing strategy of the multinational companies with the advent of WTO. Splitting up the production of a good into different stages of production across various countries based on their comparative advantages has become a rising phenomenon (Örgün 2015). This phenomenon is widely referred to as 'the fragmentation of production processes' or 'global value chains' (GVCs) and reflects the twenty-first-century production involving countries at all stages of development which also provides potential mechanism for these countries to improve income, employment and productivity (OECD 2010, WTO and the World Bank Group 2014). This global network of production process has ushered into a significant change in global trade in the last few decades where trade took place mostly in intermediate goods rather than in final goods. The trade of intermediate inputs has increased at an average annual rate of 6.2% for commodity trade between 1995 and 2006 (Miroudot et al. 2009). In fact, trade involving production fragmentation has contributed to an increasing share of intra-industry trade (IIT) in manufactured goods and also that is mostly in the form of vertical IIT. Recent empirical researches have shown that vertical IIT not only reflects quality differences but also takes place due to vertical linkages in production resulting from international production fragmentation (Ando 2006; Turkcan and Ates 2010; Amighini 2012; Tewari et al. 2015). Thus, vertical specialization, that is, the international specialization in different production stages in the same industry, is growing as a new form of intra-industry trade. Athukorala (2011) estimated that this kind of trade contributed almost a half of total world manufacturing trade in 2007.

With the adoption of trade liberalization measures in the post-1991 period, India's merchandised trade has expanded multifold. During the last 25 years, India's exports have increased almost 15 times, from US$ 17.8 billion in 1991 to US$ 260.3 billion in 2016, and India's imports have increased 18 times, from US$ 19.5 billion in 1991 to US$ 356.7 billion in 2016 (WITS, World Bank). One of the factors behind this growth is the expansion in India's intra-industry trade (IIT). In the pre-reform period, the government followed an import substitution policy which prohibited competing imports to a large extent and did not provide much scope for IIT to grow (Veeramani 2003). Trade liberalization measures adopted since 1991 have ushered some noticeable changes in the structure of India's foreign trade including a commendable expansion of intra-industry trade (Veeramani 2001, 2003; Burange and Chaddha 2008). Just before the initiation of economic reforms, share of IIT in India's total trade with the rest of the world stood at 23.99% in 1990–91 which increased to 29.21% in 1999–00 (Burange and Chaddha 2008). Between 2001 and 2015, India's IIT with the rest of the world increased from 33.25 to 40.76%, with a fluctuation at regular intervals between 2005 and 2014 (Aggarwal and Chakraborty 2017). The growth of IIT seems to be moderate in the last 10 years, despite India's rising trade integration with the world during this period.

The inter-linkages of international product fragmentation, IIT and trade in intermediate goods provide scope for discussing the shares of different categories of goods by end-use in India's export and import baskets. Figure 1 gives the shares of different categories of goods in India's export basket over the period 1991–2016. The figure reflects that India's export basket has been dominated by the intermediate goods followed by household consumption goods. The share of intermediate goods in export basket steadily increased between 1999 and 2009 which, however, fluctuated in the subsequent years. The shares of intermediate goods in trade which could be taken as a proxy for participation on global value chain show that India's participation in international production fragmentation remained moderately high during the reform period whereas share of the intermediate goods in India's total commodity export has also not shown much growth. While intermediate goods account for more than 42% of China's export basket in 2016, the corresponding share for India is 37%. Barring a few years in the late 1990s, intermediate input accounted for more or less two-thirds of India's import basket between 1991 and 2016 (Fig. 2). In 2013, the share of this category of commodities crossed 70% and finally increased to 72% in 2014, reaching the highest in the last 25 years. China is way ahead in this respect also, as its share of import of intermediate input in total import varied between 70 and 76% since 2000. Thus, India's vertical specialization assessed in terms of role of intermediate goods in export and import baskets is rising.

The import content (direct and indirect) of export (Hummels et al. 2001) also provides a role in international fragmentation of production processes and vertical specialization. This measure which alternatively labelled as vertical specialization is broader as it takes into account the imported inputs used indirectly along with the direct use in the production of the goods exported. Mukhopadhyay (2017) has

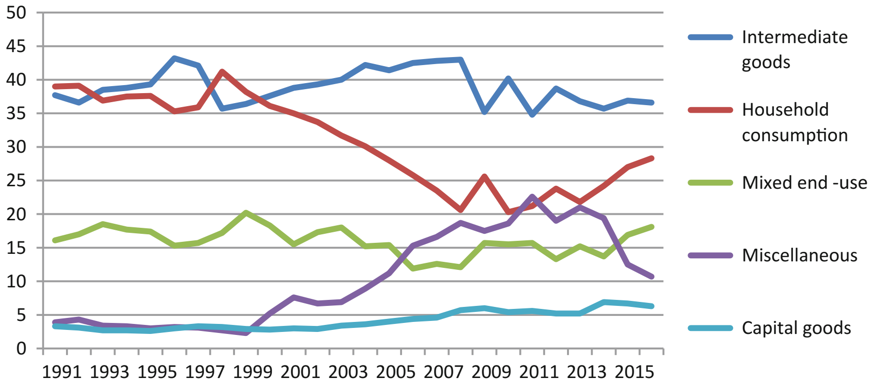

Fig. 1 Shares of different categories of goods in India's total export during 1991–2016. *Source* Based on the Data set: Bilateral Trade in Goods by Industry and End-use (BTDIxE), OECD (2017)

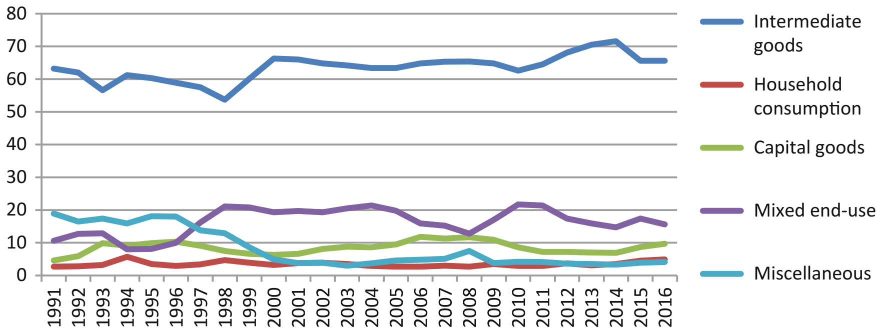

Fig. 2 Shares of different categories of goods in India's total import during 1991–2016. *Source* Based on the Data set: Bilateral Trade in Goods by Industry and End-use (BTDIxE), OECD (2017)

shown that India's total export in 2011 absorbed 27.6% of its imported intermediate input worth of US$ 422608 million, which means that little more than one-fourth of total imported input is further exported. China's import content of export is found to be almost 33% in 2011.

Given these facts, it seems that India's vertical specialization and participation in GVC are moderate. However, it could also be argued that India is not able to reap much benefit from the global network of production process as its share in world's merchandised export and import still hovers around only 1.6 and 2.2%, respectively. India's manufacturing sector still accounts for only 15% of its GDP. Researchers in recent years have shown that to become a fastest growing economy, it requires a specialization not only in production of final/finished products but also in each procedural steps taken during the production process which captures the capabilities and capacity of the country's physical and human capital employed efficiently (Tewari et al. 2015). That means, the country needs to specialize in vertically differentiated goods leading to an increase in intra-industry trade rather than trade in final products alone. Besides, India, unlike China and East Asian nations, did not benefit much from intra-regional trade integration and enhanced production network within the region. The strong regional trade linkages among East Asian nations in production network have also contributed to growth in the region and national industrial development (Medvedev 2012).

As discussed earlier, vertical specialization in trade associated with production fragmentation leads to an increase in IIT, mostly in the form of vertical IIT. The present paper has made an attempt to assess how far India's trade has become vertically specialized by measuring the country's total IIT and different forms of IIT, viz. horizontal IIT and vertical IIT. The study primarily focuses on India's bilateral trade with two partners from the developed block of countries, namely the United States of America (USA), and the European Union [EU (27)] and one partner from the group of developing countries, China. While the USA and EU (27) are India's traditional trade partners, China has emerged as a significant trade partner after the initiation of economic reforms in 1991. These three trade partners accounted for 36.08% of India's total export basket and almost 33% of India's total import basket in 2016. They together constitute the group top trade partners of India particularly during the second decade of reform period. A phenomenal rise has been witnessed in case of India's bilateral trade with China over the reform period, whose share in India's total trade (export + import) has jumped from 0.18% in 1991 to 11.24% in 2016 (UN Comtrade database).Besides, trade between India and these trade partners also involves a modest share of intermediate input flows. In 2011, India exported US$ 59723 million, US$ 44163 million and US$ 29037 million worth of intermediate input to EU (27), the USA and China, respectively. In the same year, the shares of total imported intermediate input sourced from China, the USA and EU (27) are 10, 5.2 and 13%, respectively (Mukhopadhyay 2017). The share of imported intermediate input sourced from China further exported to the world by India is 23% and exported back to China is 1.5%. The corresponding shares in case of India–USA trade are 25 and 5.15% and in case of India–EU trade are 22 and 5.3%, respectively (Mukhopadhyay 2017).

Globalization over the time has evolved as dynamic process impeding both negative and positive effects. While the increasing specialization, market competition has effectively generated macro level impact on employment, wages and resource allocation, the doomed side had been highlighted with countries developing into pollution haven overtime. This has raised the potential question on the trade-off between environment and growth (Mukhopadhyay and Chakraborty 2005). Given the ongoing structural changes in India's foreign trade where IIT is growing in importance in terms of share in total trade, it needs to assess such growth more intensively from the perspective of its impact on environment. Towards this goal, the present paper disaggregates the total trade into inter-industry and intra-industry components and investigates the environmental impact of IIT separately.

The patterns of vertical specialization in trade have major implications for industrial policy and consequently on the employment and overall development of a country. It also allows the assessment of the extent of vertical specialization in Indian trade and the associated inclusive growth and increase in job opportunities that with the involvement in the international production fragmentation is supposed to provide. The present paper uses the lens of India's IIT with China, the USA and EU to investigate the employment created with India's participation in global value trade.

To be precise, the objectives of the present study are many-fold. These are:

1. To investigate and assess India's participation in global value chain/international product fragmentation by estimating share of intra-industry trade in India's total trade with some important trade partners, namely China, the USA and EU, and further disaggregating the IIT into horizontal and vertical IITs.
2. To compute the impact of India's share of IIT on environment, as measured by CO_2. The aim is to investigate the existence of any sign of country developing pollution haven to industries shifting from developed regions of the world, trying to relocate and act as beneficiary to relaxed laws.

3. And lastly, to assess the employment opportunities created through India's share of IIT.

The analytical framework of the study is based on input–output technique. The investigation is conducted for 2 years 2001–02 and 2015–16, focusing more on the second decade onwards of the reform period as the potential impacts of trade liberalization policies have begun to realize properly only from the second decade of reform.

The remainder of the paper is organized as follows: Sect. 2 discusses the empirical literature concerning intra-industry trade. Section 3 calibrates the model of the study which is based on input–output framework. Section 4 provides the results and discusses them. Finally, Sect. 5 concludes with a few suggestions.

2 Literature Survey

IIT has shown significant traits of presence since 1960 when Verdona (1960) reported on intra-block transactions in the Benelux region of Europe. Balassa (1966)[1] showed that most of growth in manufacturing could be explained with the theoretical models of IIT. Grubel and Lloyd (1975) identified product differentiation as the factor resulting in IIT powered by economies of scale, location theory and monopolistic competition. They developed an index for measuring degree of IIT, known as the Grubel–Lloyd index. Krugman (1979), working on the same lines of increasing returns, developed a Chamberlinian monopolistic competition market model based on countries with identical characteristics.

Falvey (1981) showed commodities of the same industry but of different quality may be produced using different factor intensities. He argued that capital-intensive developed economies will export high-quality varieties which are mostly physical and human capital-intensive and import low-quality varieties which are unskilled labour-intensive from developing economies. Thus, trade in goods differentiated by quality has an engulfing and diversifying impact on factor demand and factor prices (Fukao et al. 2003). Fontagné et al. (2006) showed that most of the bilateral trade between OECD countries was in the form of IIT, which is mostly vertical in nature. Lapinska (2014) investigated country-specific determinants of IIT between Poland and EU countries for agricultural and food products during 2002–2011 using an econometric model establishing a positive relationship of IIT with intensity of trade and level of economic development of member states (accounted by GDP per capita). Kilavuz et al. (2013) found that intra-industry trade accounted for 60% of total trade of Turkey during 1990–2011. Estimating vertical and horizontal

[1]Balassa (1966) defined IIT as the inter-country exchange of commodities belonging to the same industry, observing a less disruptive effect in factor income distribution in adjustment to changes in intra-industry trade vs. adjustment to inter-industry trade.

intra-industry shares, they concluded the missing share of intra-industry trade values in highly intensified exporting sectors, producing low-quality products.

A number of studies investigated India's IIT covering both pre-reform and reform periods. Veeramani (1999, 2001, 2003) emphasized the increased intra-industry trade through trade liberalization, with further diversification into 19 commodity sections, bringing the growing share of trade with high-income countries as compared to low-income countries. Burange and Chaddha (2008) found that India's IIT expanded over the period from 1987–88 to 2005–06, though the growth had been low. IIT had expanded largely with Asia and Europe and had been growing at a faster pace with America, Middle East and Africa.

Eshleman and Kotcherlakota (2010) established high degree of IIT between India and its largest trading partner, the European Union, during 2000–2008 by using Grubel-Lloyd method, especially in more capital-intensive industries. Das and Dubey (2014) analysed the determinants of India's IIT and tried to highlight the economics of IIT in the context of FTAs. Using the tools of econometrics, they showed that India's active presence in an FTA among ASEAN+6 countries under RCEP would enhance intra-industry trade flows in the region.

Tewari et al. (2015) applied a detailed intra-industry analysis with harmonized system (HS)-6-digit level data set to estimate the production fragmentation in trade of manufactured goods between India and ASEAN, at firm level. It concluded that Indian import products are of a higher value or stage of processing than its exports to ASEAN, implying urgent need to upgrade at higher-quality ladder. Masali (2016) assessed the determinants of India's intra-industry trade in manufacturing with six major ASEAN economies during the period 1993–2013. The study found that there was no set pattern in India's IIT in manufacturing supply chain with the six ASEAN countries, with significant variations in the observed patterns and determinants. The structural variations in manufacturing sectors and levels of economic development of these countries explain the idiosyncratic nature of the results.

In a more recent study, Aggarwal and Chkraborty (2017) examined bilateral IIT between India and 25 major trading partners during 2001–2015 using a panel data framework. The study found an upward trend in bilateral IIT indices and vertical IIT as the dominant form of India's IIT with these partners. The study concluded that trade facilitation among trading members may increase bilateral IIT level with India's high-income partners whereas it might not have any similar impact in case of the country's IIT with low-income partners. Bagchi (2018) observed that the liberalization process in India has induced IIT to play an increasingly dominant role in the country's total merchandise trade while estimating the share of IIT in India's total trade during 1990–2013. They also found that technologically inferior quality products (low vertical IIT) have been dominant over the study period in India's export basket reflecting deterioration in terms of trade. Further, in order to examine whether India's overall IIT adheres to the comparative advantage hypothesis, they computed revealed comparative advantage (RCA) for each commodity group engaged in such trade for the selected manufacturing industries and observed that across all forms of IIT, the share of RCA has been low but has improved over the years.

We proceed to discuss the literature on trade and environment subjugated predominantly by traditional theory of trade, i.e. inter-industry trade. Grossman and Krueger (1991, 1993), Antweiler et al. (2001) and other investigated the detrimental effects of trade on environment. Mixed evidences and concluding remarks are attributed to the nature of pollutants studied (Shafik 1994; Harbaugh et al. 2002; Antweiler et al. 2001; Cole and Elliot 2003a, b; Broda and Weinstein 2006; Mukhopadhyay and Chakraborty 2005, 2006; Dietzenbacher and Mukhopadhyay 2007; Mukhopadhyay 2006; 2009). Most of these studies found a strong correlation between pollution intensities and capital intensities. Copeland and Taylor (2003) also lent support in favour of this argument. They argued that the countries with abundant supply of capital are expected to enjoy a comparative advantage in those goods which are highly pollution-intensive and therefore would export them according to the HO theory. Dietzenbacher and Mukhopadhyay (2007) and Mukhopadhyay (2006; 2009) which studied the environmental impact of trade focusing on India also provided evidences in favour of factor endowment hypothesis and not for pollution haven hypothesis.

In a study, McAusland and Millimet (2013) used data across USA and Canadian provinces to identify a beneficial (harmful) causal effect of international (intra-national) trade on the environment, providing hypothesis of trade in favour of environment. Research has been diversified by focusing on issues like deforestation rate (Tsurumi and Managi 2014) and energy usage (Cole 2006; Chintrakarn and Millimet 2006).

Gürtzgen and Rauscher (2000), Aralus and Hoehn (2010), Cole et al. (2006, 2010) are a few of the studies which discussed the environmental aspects using a framework based on New Trade Theory. Gürtzgen and Rauscher (2000) using a Dixit-Stiglitz type model of monopolistic competition investigated the effects of domestic environmental policy and observed that the policy has an impact on market structure at home and abroad through spillover effects. Cole et al. (2010) found environmental and industrial regulations were the important determinants of net imports of Japan from the rest of the world, from the non-OECD countries and from China. By developing a neo-Chamberlinian-Krugman type model of monopolistic competition and trade including pollution, Sarma and Hoehn (2010) estimated the effect of trade in differentiated goods on environment for the countries engaging in both IIT and inter-industry trade. They showed that the impact on environment can be decomposed into three effects, such as scale, technique and selection effects. Leitao et al. (2011) found a negative correlation between carbon dioxide emissions and agricultural IIT in the USA. In another study, Roy (2015) assessed the impact of IIT on the environment. Using a data set with eight environmental indicators for 200 countries for the period 2000–2005, they showed IIT is more environmental friendly as compared to total trade, primarily due to lower adjustment costs and easier technology absorption.

Very recently, Dasgupta and Mukhopadhyay (2018) estimated the pollution content of trade by differentiating total trade into inter-industry and intra-industry trades for India's bilateral trade with the USA and EU (27) during the period 2001–02 and 2011–12. The study finds that India's IIT with trade partners has been rising over the study period. Regarding environmental impact, India is found to be a pollution haven for all three forms of trade that is total trade, inter-industry trade and intra-industry trade.

As mentioned earlier, a few studies have attempted to assess the environmental impact of IIT and none of them except Dasgupta and Mukhopadhyay (2018) has used the input–output framework as an analytical tool. In the Indian context, a number of studies have conducted estimating India's IIT but very few of them have tried to analyse IIT by decomposing it into horizontally and vertically differentiated goods. Also, a few studies are conducted to assess the environmental impact of IIT focusing on India's case. The present paper has attempted to fill this gap by conducting an in-depth study on India's IIT during reform period by decomposing IIT into horizontal and vertical IITs and also investigating separately environmental impact of IIT along with inter-industry trade. While there are a number of papers which investigated the impact of overall trade on the labour market, there are no such studies which focus on the impact of IIT on creation of job opportunities, especially when IIT is mostly taking place in the form of vertically differentiated goods which this paper presupposes to entitle with also.

3 Methodology

The input–output technique developed by Leontief (1953) provides the analytical framework of the present study. The basic equation of the input–output model is

$$X = AX + Y \tag{1}$$

or,

$$X = (I - A)^{-1} Y \tag{1a}$$

Here, X and Y represent the vectors of total output and total final demand, respectively. The input–output coefficient matrix 'A' gives the direct intermediate input requirements per unit of output, and the Leontief inverse matrix $(I - \mathrm{A})^{-1}$ provides the total requirements, that is, the direct and indirect intermediate input requirements per unit of output. Using this basic framework, we have developed three models, trade model, emission model and employment model to study India's specialization in vertically differentiated goods and to assess the impact of India's IIT on environment and employment.

3.1 Trade Model

The final demand vector Y can be decomposed into domestic demand (D) vector and net exports vector ($E - M$),

$$Y = D + E + M \tag{2}$$

In an attempt to measure the inter-industry and IIT components of exports and imports, we have decomposed the export vector (E) into export in inter-industry (E_{inter}) and export in intra-industry (E_{intra}) and the import vector (M) into import in inter-industry (M_{inter}) and import in intra-industry (M_{intra}).

$$E = E_{\text{inter}} + E_{\text{intra}} \tag{2a}$$

$$M = M_{\text{inter}} + M_{\text{intra}} \tag{2b}$$

So, we write the following equation

$$(E - M) = (E_{\text{inter}} - M_{\text{inter}}) + (E_{\text{intra}} - M_{\text{intra}}) \tag{2c}$$

The share of IIT in total trade can be estimated in various ways (Verdoorn 1960; Balassa 1966; Grubel and Lloyd 1971, 1975). In the present paper, we have applied the most widely used method proposed by Grubel and Lloyd (1971, 1975) which is commonly known as Grubel–Lloyd index.

The Grubel–Lloyd index (GLI) which measures the share of IIT in total trade of a particular industry q is as follows

$$I_q = \frac{\left\{\left(E_q + M_q\right) - \left|E_q - M_q\right|\right\}}{\left(E_q + M_q\right)} \times 100 \tag{3}$$

Here, I_q denotes the GL index of the industry q, and E_q and M_q denote export and import of the industry q, respectively. The numerator of the ratio is actually the IIT in industry q (which includes both export and import in IIT) which is estimated as the difference between total trade (i.e. $E_q + M_q$) and the absolute value of the net trade (i.e. $\left|E_q - M_q\right|$). Thus, the index I_q gives the share of IIT of industry q in its total trade. The value of I_q ranges from 0 to 100. I_q becomes 0 when there is no IIT, and it becomes exactly equal to 100 when the entire trade is in the form of intra-industry. Using the relative share of trade in a particular industry in aggregated trade of all industries as weight w_q, we can calculate the share of IIT in a country's total trade, which is nothing but a weighted average of I_q,

$$\text{GLI} = \sum_{q=1}^{t} I_q w_q \tag{4}$$

Therefore, the GL index (GLI) for the entire economy can also be written as

$$\mathrm{GLI} = \frac{\sum_{q=1}^{t}\left\{\left(E_q + M_q\right) - \left|E_q - M_q\right|\right\}}{\sum_{q=1}^{t}\left(E_q + M_q\right)} \times 100 \tag{5}$$

IIT can be decomposed into IIT in horizontally differentiated goods (HIIT) and IIT in vertically differentiated goods (VIIT). Among the various measures to isolate different forms of IIT, we have applied the most widely used method first proposed by Abd-el Rahman (1991) and later developed by Greenaway, Hine and Milner (1994, 1995). This method is famously known as unit value dispersion method. In this method, the IIT of each industry is divided into horizontal (HIIT) and vertical (VIIT) components using relative unit values of exports and imports. Let UV_q^m and UV_q^e denote the unit value of export and unit value of import of industry q, respectively. For industry q, the IIT will be considered as HIIT if the following condition is satisfied

$$1 - \alpha \leq \frac{\mathrm{UV}_q^e}{\mathrm{UV}_q^m} \leq 1 + \alpha \tag{6}$$

and the IIT will be considered as VIIT if the following condition is satisfied

$$\text{either} \quad \frac{\mathrm{UV}_q^e}{\mathrm{UV}_q^m} \prec 1 - \alpha \;\; \text{or} \;\; \frac{\mathrm{UV}_q^e}{\mathrm{UV}_q^m} \succ 1 + \alpha \tag{7}$$

Here, α is the dispersion factor which is assumed to be 0.15.[2] Thus, HIIT is defined as the simultaneous export and import where the UV of export relative to UV of import lies within a range of 0.85–1.15. If relative UVs lie outside this range, the IIT will be defined as the VIIT.

Vertically IIT can be further subdivided into low-quality vertical IIT (LVIIT) and high-quality vertical IIT (HVIIT). When the relative unit values of export to import of industry q are less than $(1 - \alpha)$, the VIIT is treated as low-quality type and if ratio is greater than $1 + \alpha$, the VIIT is considered as high-quality type[3].

The numerator of the GL index given in Eq. (3) shows the total volume of IIT of industry q which includes both exports and imports. In order to measure the pollution embodied in IIT, it is required to separate the export in IIT and import in IIT for each industry q. As the IIT is defined as the two-way matched trade where the value of export is exactly equal to the imports, we separate the export and import components of IIT using the following equation

[2]α can be also assumed as 0.25. However, both Abd-el-Rahman (1991) and Greenway et al. (1994, 1995) showed that changing the range from 15 to 25% has impact on the result.

[3]If $\mathrm{UV}_q^e/\mathrm{UV}_q^m < 0.85$, it is considered as a low-quality export, and if $\mathrm{UV}_q^e/\mathrm{UV}_q^m > 1.15$ it is considered as a high-quality export.

$$\mathrm{E}_{q\,\mathrm{intra}} = M_{q\,\mathrm{intra}} = \frac{\left\{ \left(E_q + M_q \right) - \left| E_q - M_q \right| \right\}}{2} \tag{8}$$

Let us now develop the emission model which will establish a link between trade and environment.

3.2 Emission Model

Total emission from fossil fuel combustion can be measured with the following equation

$$F_p = CX = C(I - A)^{-1}Y \tag{9}$$

The pollutant (p) considered in the present study is carbon dioxide; therefore, F_p which is a scalar gives the total (both direct and indirect) amount of CO_2 emitted to produce total output, X. Here, C is a vector showing direct pollution generated per unit of output (i.e. the direct pollution coefficients) whereas direct $C\,(\mathrm{I} - \mathrm{A})^{-1}$ gives the direct and indirect generation of pollution per unit of output (total pollution coefficients). Let us now consider the equations to measure the pollution content of various forms of trade.

Pollution embodied in inter-industry and intra-industry components of trade could be estimated by rewriting Eq. (4) in the following way

$$F_p = C(I - A)^{-1}[(E_{\mathrm{inter}} - M_{\mathrm{inter}}) + (E_{\mathrm{intra}} - M_{\mathrm{intra}})] \tag{10}$$

IIT is defined as two-way matched trade where the value of exports is exactly equal to the value of imports ($E_{\mathrm{qintra}} = M_{\mathrm{qintra}}$). So, we have to assume different technologies to obtain a feasible value of the pollution content of intra-industry trade. For this purpose, we have considered producers’ technology where India’s technology matrix along with India’s pollution coefficients is used to measure the pollution generated by domestic production of India’s exportables to different trade partners. On the other hand, to estimate the pollution content of India’s import sourced from these partners, we have applied the respective countries’ technology matrices and pollution coefficients.

Therefore, the pollution content of country i’s exports to country j is measured as

$$F^i_{p(\mathrm{exportto}\,j)} = C^i\left(I - A^i\right)^{-1}E$$

$$\mathrm{Or,}\, F^i_{p(\mathrm{exportto}\,j)} = C^i\left(I - A^i\right)^{-1}(E_{\mathrm{inter}} + E_{\mathrm{intra}}) \tag{11}$$

and the pollution content of country i's imports sourced from country j is estimated as $F^j_{p(\text{importfrom}\,j)} = C^j(I - A^j)^{-1}M$

$$\text{Or}, F^j_{p(\text{importfrom}\,j)} = C^j\left(I - A^j\right)^{-1}(M_{\text{inter}} + M_{\text{intra}}) \tag{12}$$

Equations (11) and (12) are scalar, giving different pollution contents of exports and imports. Using these equations, an index known as the pollution terms of trade (PTOT), which shows the pollution embodied in exports relative to that in imports, can be measured in the following way

$$\text{PTOT}_p = \frac{F^i_{p(\text{exportto}\,j)}}{F^j_{p(\text{importfrom}\,j)}} = \frac{C^i(I - A^i)^{-1}E}{C^j(I - A^j)^{-1}M} \tag{13}$$

Equation (13) is the PTOT for total export and total import only. The same ratio can also be estimated separately for inter-industry and IIT with Eqs. (13a) and (13b), respectively.

$$\text{PTOT}_p = \frac{F^i_{p(\text{exportto}\,j)}}{F^j_{p(\text{importfrom}\,j)}} = \frac{C^i(I - A^i)^{-1}E_{\text{inter}}}{C^j(I - A^j)^{-1}M_{\text{inter}}} \tag{13a}$$

$$\text{PTOT}_p = \frac{F^i_{p(\text{exportto}\,j)}}{F^j_{p(\text{importfrom}\,j)}} = \frac{C^i(I - A^i)^{-1}E_{\text{intra}}}{C^j(I - A^j)^{-1}M_{\text{intra}}} \tag{13b}$$

A value of PTOT greater than unity means the pollution content of one unit export is higher than that of an equivalent import, implying the country is losing environmentally from trade. Therefore, it is a case of pollution haven. On the other hand, PTOT less than one implies the country's export contains less pollution than it is received through imports and thus the country gains environmentally from trade.

3.3 Employment Model

Let l denote the labour coefficient vector where each element shows the domestic labour use in each sector per unit of output. l_{us} and l_s denote the unskilled labour coefficient vector and skilled labour coefficient vector, where each element of these vectors gives per unit requirement of skilled labour and unskilled labour in each sector, respectively.

To estimate the total labour requirement to produce total export, we use the following equation

$$L = l'(I - A)^{-1}E \tag{14}$$

l′ is the transpose of the labour coefficient vector, and $l'(I - A)^{-1}$ gives the total (direct and indirect) requirement of labour per unit of output.

Using Eq. (2a), we get

$$L = l'(I - A)^{-1}[E_{\text{inter}} + E_{\text{intra}}] \tag{15}$$

$$\text{Or, } L = l'(I - A)^{-1}E_{\text{inter}} + l'(I - A)^{-1}E_{\text{intra}} \tag{15a}$$

The first and second components in the right-hand side of the equation give the total labour requirements to produce inter-industry export and intra-industry export, respectively.

Similarly, we can get the following equations

$$L_{us} = l'_{us}(I - A)^{-1}E_{\text{inter}} + l'_{us}(I - A)^{-1}E_{\text{intra}} \tag{16}$$

$$L_{s} = l'_{s}(I - A)^{-1}E_{\text{inter}} + l'_{s}(I - A)^{-1}E_{\text{intra}} \tag{17}$$

where L_{us} and L_s show unskilled and skilled labour requirements to produce export. The first components of each of the equations give the unskilled/skilled labour content in inter-industry export, whereas the second components show the unskilled/skilled labour content in IIT export.

Let us now apply these models developed in this section to assess India's IIT.

4 Results and Discussions

The results obtained by applying the models developed above to assess the role of India's intra-industry trade (IIT) and its various components in its bilateral trade with the USA, EU (27) and China in the years 2001–02 and 2015–16 are discussed in this section. The impact on environment and employment is also analysed here.

4.1 India's IIT in Trade with Different Trade Partners

As discussed in Sect. 3, the shares of IIT in India's total trade with EU (27), the USA and China are measured with Grubel-Lloyd index (GLI). Table 1 reports the Grubel-Lloyd indices, i.e. the shares of IIT in India's total trade with these partners along with the shares of inter-industry trade. It is observed from Table 1 that the shares of IIT in India's total trade with all three trade partners have increased between 2001–02 and 2015–16.

Table 1 Inter-industry trade and IIT in India's trade

Trade partners	2001–02[a]		2015–16	
	Inter-industry	IIT	Inter-industry	IIT
USA	82.5	17.5	75.7	24.3
EU (27)	68.8	31.2	64.2	35.8
China	87.7	12.3	80.6	19.4

The figures are the percentage shares

Source Authors' calculation; [a]Dasgupta and Mukhopadhyay (2018)

In case of India's trade with the USA, the share of IIT has increased by a modest rate, from 17.5% in 2001–02 to 24.3% in 2015–16. For India's trade with EU (27), the corresponding share has moved up from 31.2% in 2001–02 to 35.8% in 2015–16. The share of IIT in trade with EU (27) is relatively higher than that with the USA; however, the share over the study period has increased at a slightly faster rate in case of trade with the USA as compared to EU (27). Rising share of IIT in India's trade with the countries from the developed block further indicates that the traditional form of trade, that is, the inter-industry trade, is gradually declining in importance. In case of trade with the USA and EU (27), the inter-industry trade accounted for 82.5 and 68.8%, respectively, in 2001–02, which declined to 75.7 and 64.2% in 2015–16 (Table 1). However, inter-industry trade continues to dominate over IIT in terms of share in total trade with these partners.

In case of China too, the inter-industry trade is the dominant form of trade, though its share is gradually declining. The share of IIT has consistently increased from 12.3% in 2001–02 to 19.4% in 2015–16.

Given the ongoing directional changes in India's foreign trade during the reform period, where more emphasis has been given by the government of India on building up greater trade relations with the countries in Latin America, Africa and Asia, the importance of India's traditional partners EU (27) and the USA in terms of trade share has reduced to a significant extent. In this scenario, an increasing share of IIT with these partners during the reform period indicates that a structural change has gradually been taking place in India's trade with the developed partners, which might not be entirely explained by the traditional theories of inter-industry trade (Dasgupta and Mukhopadhyay 2018). With the intensification of reform process, India's foreign trade with China has expanded rapidly and along with the share of IIT has also increased. Thus, the trade reform policies have brought about some interesting changes in India's pattern of trade with these trade partners.

For further analysis, we have differentiated the total IIT with different trade partners between horizontal IIT (HIIT) and vertical IIT (VIIT); vertical IIT is again decomposed into high-quality VIIT (HVIIT) and low-quality VIIT (LVIIT). This analysis could throw some light on degree of vertical specialization in India's trade. The results are presented in Table 2.

Table 2 reveals that India is specializing mostly in vertically differentiated goods, which are basically the goods differentiated by the quality. In 2001–02 and 2015–16, the shares of VIIT in total IIT between India and the USA were 92.8 and

Table 2 Horizontal IIT and vertical IIT in India's trade

Trade partners	2001–02[a]				2015–16			
	HIIT	VIIT	HVIIT	LVIIT	HIIT	VIIT	HVIIT	LVIIT
USA	7.2	92.8	25.6	74.4	8.1	91.9	28.0	72.0
EU (27)	6.6	93.4	21.8	78.2	7.2	92.8	23.0	77.0
China	13.2	86.8	46.4	53.6	9.9	90.1	42.7	57.3

HIIT + VIIT = IIT, HVIIT + LVIIT = VIIT
Source Authors' calculation; [a]Dasgupta and Mukhopadhyay (2018)

91.9%, respectively. Given the rising share of IIT between India and the USA, this almost stagnant share of VIIT in total IIT implies the share of VIIT in India's total bilateral trade with the USA has been rising. The share of vertically differentiated goods in India's total trade with the USA has increased from 16.2% in 2001–02 to 22.3% in 2015–16. However, it should also be noted that the share stands only at around one-fifth of total bilateral trade volume between India and the USA. In case of trade with EU (27) too, VIIT accounts for a larger share of total bilateral IIT. In 2001–02, the share of VIIT is found to be at 93.4% which has marginally declined to 92.8% in 2015–16. In this case too, the share of VIIT in total bilateral trade with EU (27) has gone up from 29.1% in 2001–02 to 33.2% in 2015–16, as the share of IIT with EU (27) is rising. So, an increase in trade in vertically specialized goods over the study period has been witnessed. Compared to the USA and EU, share of VIIT in total bilateral IIT with China is relatively lower; however, the share has increased over the study period from 86.8% in 2001–02 to 90.1% in 2015–16. This means, in India's total bilateral trade with China, trade in vertically differentiated goods occupied 10.7 and 17.5% in 2001–02 and 2015–16, respectively. Rising share of VIIT in India's trade with some of major trade partners could be an indication for its increasing participation in global production network.

It is also observed from Table 2 that India is basically specializing in vertically differentiated products which are mostly at the lower end in the quality ladder, particularly in case of trade with the USA and EU (27). In India's VIIT with the USA, the low-quality products account for 74.4 and 72.0% in 2001–02 and 2015–16, respectively. In case of trade with EU (27), the corresponding shares are slightly higher at 78.2 and 77%, respectively. Trade theory says that IIT in vertically differentiated goods may take place between developed and developing countries where the developing labour-abundant countries mostly specialize in low-quality low-price varieties of goods (Falvey and Kierzkowski 1987). The results of the study seem to be in tune with the theory, given the dissimilarity in per capita income and the level of development between India and its developed trade partners considered in this study (Dasgupta and Mukhopadhyay 2018).

In contrast, the shares of VIIT in high-quality products over the study period are significantly high in India's bilateral trade with China. India and China are more or less at the similar levels of development ladder, and this could explain the result. More striking fact is that the share of VIIT in low-quality products is gradually rising over the study period, the share being increased from 53.6% in 2001–02 to 57.3% in 2015–16.

Let us now analyse the commodity composition of IIT over the study period. In case of trade with the USA, the top five sectors in terms of IIT shares are miscellaneous manufacturing, machinery equipments, chemical, rubber and plastic, electronic equipments and metal products. The sectors accounted for almost 63–78% of total IIT with the USA over the study period. The major two sectors which have contributed largely in increasing the shares are miscellaneous manufacturing and chemicals, rubber and plastics (Dasgupta and Mukhopadhyay 2018). These top five sectors also account for a large share in terms of VIIT, and India's exports take place mostly in low-quality varieties.

Miscellaneous manufacturing, chemical, rubber and plastic, machinery equipments, electronic equipments, transport equipments are the top five sectors having the higher shares in IIT with EU (27), and most of the IIT of these sectors has occurred in vertically differentiated goods. Except for miscellaneous manufacturing, India has exported low-quality varieties of products of these sectors to EU (27).

In case of India's trade with China, the top sectors in terms of IIT are chemical, rubber and plastic, machinery equipments, ferrous metals, electronic equipments and textiles and they take place mostly in vertically differentiated products. Unlike the advanced trade partners considered in this study, India exports relatively higher-quality varieties of products to China. For chemical, rubber and plastic, electronic equipments and textiles, India's VIIT is of high-quality type whereas for machinery equipments and ferrous metals India exports low-quality varieties.

Thus, considering India's bilateral trade with some important trade partners, it is observed that the country's trade in vertically differentiated goods is on rise with the reform process. Vertical specialization and consequently India's role in global production network are gradually taking place, though the pace seems to be slow as India had already completed 25 years of its economic reforms (Table 3).

Let us now assess the impact on environment of India's IIT with different trade partners over the study period.

4.2 India's IIT and Environment

The environmental impact of inter-industry and IIT is analysed in this section. Table 4 presents the pollution embodied in a million dollar worth of India's bilateral export and an equivalent worth of bilateral import with different trade partners. The table also captures the pollution content of inter-industry and IIT components of exports and imports separately. Finally, Table 4 shows the PTOT estimated for three different forms of trade over the period 2001–02 to 2015–16. We considered CO_2 as the pollutant.

It is observed that CO_2 embodied in a million dollars of India's total export to the USA in 2001–02 is 836.8 tons which has increased to 941.5 tons in 2015–16. On the import side, the corresponding figures are 332.7 tons and 396.3 tons,

Table 3 Top sectors in India's IIT with the USA, EU (27) and China

USA			EU (27)			China		
IIT	HIIT	VIIT	IIT	HIIT	VIIT	IIT	HIIT	VIIT
Miscellaneous manufacturing	Chemicals, rubber and plastic	Miscellaneous manufacturing (LQ)	Miscellaneous manufacturing	Chemicals, rubber and plastic	Miscellaneous manufacturing (HQ)	Chemicals, rubber and plastic	Chemicals, rubber and plastic	Chemicals, rubber and plastic (HQ)
Machinery equipments	Electronic equipments	Machinery equipments (LQ)	Chemicals, rubber and plastic	Metal products	Chemicals, rubber and plastic (LQ)	Machinery equipments	Non-metallic minerals	Machinery equipments (LQ)
Chemicals, rubber and plastic	Miscellaneous manufacturing	Chemicals, rubber and plastic (LQ)	Machinery equipments	Electronic equipments	Machinery equipments (LQ)	Ferrous metals	Machinery equipments	Ferrous metals (LQ)
Electronic equipments	Ferrous metals	Electronic equipments (LQ)	Electronic equipments	Ferrous metals	Electronic equipments (LQ)	Electronic equipments	Ferrous metals	Textiles (HQ)
Metal products	Textiles	Metal products (LQ)	Transport equipment	Non-metallic minerals	Transport equipment (LQ)	Textiles	Miscellaneous manufacturing	Electronic equipments (HQ)

Source Authors' calculation

Table 4 Pollution embodied (in tons) in one million dollar worth of exports and imports of different forms of India's trade

			USA				EU				China			
			2001–02[a]		2015–16		2001–02[a]		2015–16		2001–02		2015–16	
			Trade volume	Pollution	Trade volume	Pollution	Tilde volume	Pollution	Trade volume	Pollution	Trade volume	Pollution	Trade volume	Pollution
Export	(1)	Total trade	1000000	836.8	1000000	941.5	1000000	851.3	1000000	936.5	1000000	993	1000000	1427.1
	(2)	Inter-industry trade	813885 (81-4)	658.5 (78.7)	757475 (73.7)	6894 (732)	669934 (67.0)	534.5 (62.8)	644589 (64.8)	555.2 (59.3)	827279 (82.7)	811.3 (81.7)	765873 (766)	1111.5 (77.9)
	(3)	IIT	186115 (18.6)	178.3 (21.3)	242525 (24.3)	252.1 (26.8)	330066 (33.0)	316.8 (37.2)	355411 (35.5)	381.3 (407)	172721 (17.3)	181.7 (183)	234127 (334)	315.6 (221)
Import	(4)	Total trade	1000000	332.7	1000000	396.3	1000000	120.4	1000000	140	1000000	1901.8	1000000	1486.2
	(5)	Inter-industry trade	836692 (83.7)	271.2 (81.5)	746573 (74.7)	298.8 (75.4)	703546 (70.4)	83 (68 9)	640032 (64.0)	90.6 (64.7)	9004420 (90.4)	1723.3 (90.6)	861547 (862)	1249.7 (84.1)
	(6)	IIT	163303 (16.3)	61.5 (18.5)	253427 (23.3)	97.6 (25.3)	296454 (29.6)	37.4 (31.1)	359968 (36.0)	49.4 (35.3)	995580 (9.6)	178.3 (9.4)	138453 (13.8)	236.5 (15.9)
PTOT	(7)	Total trade[(1) (4)]	2.5		2.4		7.1		6.7		0.5		1.0	
	(8)	Inter-industry trade [(2) (5)]	2.4		2.3		6.4		6.1		0.5		0.9	
		IIT [(3) (6)]	2.9		2.6		8.5		7.7		1.0		1.3	

Figures in the parenthesis show the percentage shares of the total. Trade volume is in US$. Total trade = inter-industry trade + IIT
Source Authors' calculation. [a]Dasgupta and Mukhopadhyay (2018)

respectively. The PTOT in case of India's total trade with the USA was 2.5 in 2001–02 and found to remain stagnant at 2.4 in 2015–16, which indicates India is a pollution haven in its bilateral trade with the USA.

Coming next to the inter-industry and intra-industry components, we observe that 78.7% of total CO_2 generated for India's export production to the USA is due to inter-industry trade whereas the remaining is resulting from intra-industry trade in 2001–02. In 2015–16, inter-industry trade accounts for a lesser share of 73.2% of total pollution generated due to export to the USA while intra-industry component accounts for a rising share of 26.8%. Table 4 also reveals that the PTOT for inter-industry trade is 2.4 and 2.3 in 2001–02 and 2015–16, respectively, while the corresponding share for IIT is marginally higher at 2.9 and 2.6. Over the years, the PTOT for IIT has changed very marginally, even when the share of pollutant generated by the IIT component of export has increased between 2001–02 and 2015–16. This is primarily due to the IIT component of import which has also increased during this period.

In case of bilateral trade with EU (27), a million dollar worth of India's export has generated 851.3 tons and 936.5 tons of CO_2 in 2001–02 and 2015–16, respectively, of which IIT component of export accounts for 37.2 and 40.7%, respectively. Unlike the case with the USA, the share of pollution generated by the IIT component of export with EU (27) has increased at a slower pace between 2001–02 and 2015–16. Consequently, the PTOT for IIT between India and EU (27) has declined from 8.5 to 7.7 over the study period. In case of total trade and inter-industry trade too, this ratio has declined over time but the reduction is found to be highest in case of IIT. However, India is revealed as a pollution haven for all form of trade with EU (27).

In case of India's trade with the USA and EU (27), pollution content of export is observed to be significantly higher than that of imports for all three forms of trade, resulting in a value of PTOT greater than unity. This could be explained by comparing the sectoral pollution coefficients which is nothing but the pollution generation per unit of output of each sector. India's coefficients are significantly higher than those of the USA and EU (27) as these developed countries follow a far better and effective pollution control mechanism than India.

Comparing the PTOT in case of the USA and EU (27), it may appear that India's trade with the USA is more beneficial than with EU (27) from the environmental perspective as in latter case the value of PTOT is considerably higher than the former. So far as commodity composition of trade is concerned, there is no major difference between India's trade with the USA and that with EU (27), but the factor which makes the difference is the sectoral pollution coefficients of the USA and EU (27). As compared to the USA, the pollution coefficients of EU (27) are observed to be significantly lower as the EU countries follow a more stringent environmental regulation.

The environmental impact of trade between India and China is quite interesting. The results show that PTOT has increased from 0.5 in 2001–02 to 1.0 in 2015–16, indicating India's pollution content of export is becoming higher than that of import. India's growing trade with this partner during the reform period might be affecting the environment adversely. In the earlier years of economic reform, India was not a case of pollution haven in its trade with China but as the result reveals the country is gradually moving towards becoming a pollution haven. It is also observed that PTOT in IIT is comparatively higher than that of inter-industry trade over the study period. While the PTOT of inter-industry trade is 0.5 and 0.9 in 2001–02 and 2015–14, the corresponding ratios for IIT are 1.0 and 1.3, respectively. Looking particularly at the trade pattern of India's trade with China where the share of IIT is rising consistently, a rising PTOT could be alarming.

The commodity composition of India's IIT with its trade partners (as shown in Table 3) could explain why the PTOT for IIT is comparatively higher than the other forms of trade [particularly for trade with EU (27) and China]. It is noticed that India's IIT mostly consists of pollution-intensive sectors like chemicals, rubber and plastic, machine equipments, electronic equipments and ferrous metal (in case of its trade with China in particular) and the country's vertical specialization has taken place mostly in low-quality products, which could be highly pollution-intensive.

4.3 India's IIT and Employment

This section primarily analyses the impact of IIT component of export along with the other forms of export, that is, total export and inter-industry component of export on the labour employment in India. For an intensive analysis, impact on labour employment is separately studied for skilled labour and unskilled labour. This investigation is conducted here for 1 year, that is, 2015–16.[4] The results of this experiment are given in Table 5.

Table 5 shows that given the commodity composition of India's bilateral export to the USA in 2011, one million dollar worth of export would embody 150.5 labours of which 147.1 are unskilled labours and 3.4 are skilled labours. This result is quite expected in an unskilled labour-abundant country like India. Since the inter-industry form of export dominates India's trade pattern with the USA, the labour embodied in inter-industry export (136.6 in number) greater than that in IIT export (13.9 in number). Inter-industry export accounts for 90.8% of total labour requirement, whereas IIT export accounts for only 9.2%. For unskilled labour requirement, 90.9% of labour comes from the inter-industry component and the remaining comes from the IIT.

One million dollar worth of bilateral export to EU (27) in 2015–16 requires 146.1 labours, out of which 142.7 are the unskilled labour requirement and 3.3 are the skilled labour. Labour embodied in same worth of bilateral export to China is 121.6, of which 118.3 and 3.4 are unskilled and skilled labour requirements,

[4]This is primarily due to limitation of data. Labour data are sourced from ImpactECON (2016) data set where data are given for 2011 only. Between the 2 years 2001–02 and 2015–16 considered in this study, the latter year is nearer to 2011. So, we have calculated the labour content only for 2015–16.

Table 5 Labour requirements in India's various forms of trade with different partners in 2015–16

	Total labour[a]			Unskilled labour[a]			Skilled labour[a]		
	Total export[b]	Inter-industry	IIT	Total export	Inter-industry	IIT	Total export	Inter-industry	IIT
USA	150.5	136.6 (90.8)	13.9 (9.2)	147.1	133.7 (90.9)	13.4 (9.1)	3.4	2.9 (86.6)	0.5 (13.4)
EU (27)	146.1	113.2 (77.5)	32.9 (22.5)	142.7	111.0 (77.8)	31.7 (22.2)	3.3	2.1 (64.9)	1.2 (35.1)
China	121.6	88.2 (72.5)	33.4 (27.5)	118.3	85.9 (72.6)	32.4 (27.4)	3.4	2.3 (68.8)	1.1 (31.2)

Figures in parenthesis give the percentage shares
[a]Labour in numbers; [b]total labour required in per million dollar worth of total export
Source Authors' calculation

respectively. Like the USA, unskilled labour requirements are quite high as compared to skilled labour in India's bilateral export to EU (27) and China too. Comparing the labour requirements between inter-industry and IIT components, it is, however, observed that, unlike the USA, the share of IIT in total labour requirement [22.5% for EU (27) and 27.5% for China] is quite high in these two cases. The reasons for this result, however, are different for EU (27) and China. As compared to the USA, the share of IIT in India's total trade with the EU (27) is higher (given in Table 1), which might lead to a higher share of labour embodied in IIT in case of trade with the EU (27). In case of trade with China, the two highly labour-intensive sectors, textiles and miscellaneous manufacturing[5], occupy a significant share in IIT, which might result in comparatively higher share of labour embodied in IIT component of export.

The study also observes that bilateral IIT with EU (27) requires 22.2% of unskilled labour and 35.1% of skilled labour. The corresponding shares for India's bilateral IIT with China are 27.4 and 31.2%, respectively. Thus, in these two cases, IIT component of export absorbs a significant number of labours, both unskilled and skilled. Comparing among these three partners, IIT with China absorbs comparatively more unskilled labour, implying that growing IIT with China could have a positive impact on the large unskilled labour market in India.

5 Conclusion

India's intra-industry trade (IIT) has expanded considerably in the last 25 years since the adoption of trade liberalization measures in 1991. The present paper has tried to assess India's IIT by considering different aspects like vertical specialization associated with IIT as well as the impact of IIT on environment and employment. The analysis focuses mainly on India's bilateral IIT with two traditional trade partners the USA and EU (27) and emerging trade partner China during the study period between 2001–02 and 2015–16.

The study concluded that the level of IIT between India and its trade partners is rising accruing to the trade liberalization measures adopted since 1991, which is similar to the experience of the other countries. The traditional inter-industry trade, however, remains to be the dominant form of trade. Comparing among the three trade partners, IIT with China is growing at a relatively faster pace than that with others. The results also reflect that India's IIT with the trade partners is mostly taking place in goods which are differentiated vertically. The share of VIIT in India's bilateral trade overall has also shown a consistent upward trend over the study period. Between 2001–12 and 2015–16, the share of VIIT has increased from 16.2 to 22.3% in total trade with the USA, from 29.1 to 33.2% in total trade with

[5]In Table 3 Textiles are included in the top five sectors, whereas both textiles and miscellaneous manufacturing would be included if top seven sectors are considered.

EU (27) and 10.7 to 17.5% in total trade with China. So, increasing vertical specialization might indicate increasing participation in global production network during the reform period. However, it could also be said that the pace of integration with the GVC is not up to the mark as India has been walking on the path of industrial and trade policy reforms since 1991. The study also reveals that in case of trade with the USA and EU (27), the share of VIIT in total IIT is stagnant at around 90%, while rising consistently in trade with China.

India's specialization in vertically differentiated goods may result in a higher adjustment cost. Economists have argued that with expansion of intra-industry trade, the resources are reallocated within the industry involving lower adjustment costs (Balassa 1966; Greenaway and Milner 1986; Brulhart and Elliott 2002). However, another strand of thought says that IIT in vertically differentiated goods may lead to higher adjustment costs (Fontagné et al. 2005). Thus, India's IIT dominated by VIIT suggests greater economic adjustment costs than it would be in the case with horizontal IIT. The study also shows that low-quality VIIT dominates in trade with the USA and EU (27). In case of trade with China, both low-quality and high-quality VIITs are found to be equally important, though the share of low-quality varieties has upward rising trends.

Regarding the environmental impact of IIT, PTOT is found to be greater than unity in case of trade with the USA and EU (27) over the entire study period, reflecting India as a case of pollution haven hypothesis. A value of PTOT greater than one implies India's export in IIT embodies relatively more CO_2 than the country's equivalent worth of import in IIT. Thus, having a PTOT greater than one India provides another evidence of pollution haven. In case of trade with China too, this ratio is found to be hovering around unity over the study period.

Given the growing share of IIT in India's trade with these three trade partners, the value of PTOT exceeding one seems to be an alarming fact. However, it should also be noticed that the PTOT has not shown any major upward shift in values, not even in case of China. On the contrary, between 2001–02 and 2015–16, the values of PTOT in IIT with the USA and EU (27) have marginally declined. In case of trade with China, PTOT has marginally increased from 1.0 to 1.3 during 2001–02 to 2015–16 and the corresponding ratio for inter-industry trade has risen from 0.5 to 0.9 during the same period. Overall consequential impact on environment given the growing importance of IIT in India's trade with major partners has shown some positive outlook towards future (Dasgupta and Mukhopadhyay 2018).

Regarding the impact on employment, the study finds that IIT has a positive impact on the employment expansion, particularly trade with EU (27) and China. Trade specialization in vertically differentiated sectors may also be associated with net factor content affecting the factor markets in the same way as inter-industry trade. The low-quality variety of goods usually absorbs larger amounts of unskilled labour than the high-quality varieties which are expected to absorb more capital and skilled labour (Falvey 1981; Falvey and Kierzkowski 1987; Gabszewicz and Turrini 1997). As India is specializing mostly in the varieties of lower quality with high unskilled labour content, expansion of IIT could have a positive impact on employment generation. Thus, promotion of IIT could lead to an inclusive growth in an unskilled labour-surplus economy like India.

A number of policies could be suggested in this regard. Firstly, industrial and trade policies should be made more oriented towards developing a domestic production structure which would help in increasing India's participation in GVC and consequent vertical specialization. Secondly, an integrated policy considering trade and environment is the need of hour. In the last 20 years, most Asian nations like India have introduced pollution control system similar to those in developed countries. However, India faces numerous ongoing challenges in enforcement. Moreover, there is an urgent need for better understanding of pollution control mechanisms in order to implement effective pollution control policies in India. Even though IIT in India is not the most environmentally suitable, the government has to promote intra-industry trade and insist on better environmental quality of exported goods for sustainable trade in the future. India's trade policy also needs to complement the country's trade targets with environmental priorities such as its commitments as per the Agenda 21 of United Nations Framework Convention on Climate Change (Mukhopadhyay and Chakraborty 2005). Its importance lies in the potential of IIT on employment enhancement as well as the prospect of inclusive growth.

Appendix: Data Sources

The data used in this paper are obtained from following sources:

1. Input–output tables:
   For India, the USA, EU (27) and China, the IO tables are taken from GTAP. For the year 2001–02 and 2015–16, we have used GTAP version 6 (Dimaranan 2006) with base year 2001 and GTAP version 9 (Narayanan et al. 2015) with base year 2011, respectively. Since version 9 with base year 2011 is the latest data set provided by the GTAP, we have to use this version to do our calculations for the year 2015–16.
2. Data on bilateral trade:
   Trade data for 2001–02 and 2015–16 are obtained from UN Comtrade, United Nations (available at http://comtrade.un.org/). The data applied in this study are categorized by the Standard International Trade Classification (SITC, Rev 3) System at the five-digit level. First, we have estimated the shares of IIT at the five-digit level using Grubel–Lloyd index and then the shares are aggregated for 18 sectors. The shares of IIT (and inter-industry trade) in total trade are then applied to the GTAP trade data aggregated for the 18 sectors. Concordances to assist in mapping data to the GTAP sectors are available in the GTAP Technical Paper (Aguiar et al. 2016).
3. Data on CO_2 emission:

Total CO_2 emission in India, the USA, EU (27) and China at the sectoral level is obtained from GTAP version 6 (Lee 2002) and GTAP version 9 (Narayanan et al. 2015). Total sectoral output required to estimate the pollution coefficients is also collected from the same source.

4. Data on labour:
   Requirements of various categories of labour at the sectoral level are sourced from ImpactECON (2016), GTAP. Sectoral output data are taken from GTAP to calculate the labour coefficients for different categories of labour.

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Part VII
Regional IO Modelling

The Regionalization of National Input–Output Tables: A Review of the Performance of Two Key Non-survey Methods

Anthony T. Flegg and Timo Tohmo

Abstract This chapter reviews the available empirical evidence on the performance of Flegg's location quotient (FLQ) and Kronenberg's Cross-Hauling Adjusted Regionalization Method (CHARM), a relatively new non-survey technique that accounts explicitly for cross-hauling when constructing regional input–output tables. The performance of the FLQ and related formulae is evaluated using official data for 20 Finnish and 16 South Korean regions. The results confirm previous findings that the FLQ can produce far more accurate estimates of regional output multipliers than can simpler LQ-based formulae such as the SLQ and CILQ. We also explore possible ways of determining suitable values for the unknown parameter δ in the FLQ formula. Finally, we carry out a detailed investigation into an innovative new approach, Kowalewski's sector-specific FLQ (SFLQ), but find that further work is required before the SFLQ can be recommended for routine use. Our assessment of CHARM employs official data for two contrasting regions: Uusimaa, the largest Finnish province, and the central Chinese province of Hubei. In the case of Uusimaa, detailed data for 26 regional sectors in 2002 are examined. CHARM is found to perform relatively well in terms of estimating exports, imports, the volume and balance of trade, and supply multipliers. The results are particularly encouraging for manufacturing sectors, which typically produce heterogeneous commodities and where cross-hauling is rife. As regards Hubei, CHARM is used to construct a detailed regional input–output table with 42 sectors, including 17 diverse types of manufacturing. The analysis makes use of official published national and regional data for 2007. However, in this instance, CHARM does not generate realistic estimates of Hubei's sectoral exports, imports, volume of trade, and supply multipliers. This outcome is attributed to the difficulty of estimating regional technical coefficients, the heterogeneity of commodities and final demand

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for this data set. This problem is linked to the relatively small size of Hubei, which generates around 4% of China's GDP. By contrast, Uusimaa produced 34.6% of Finland's national output in 2002. These findings highlight the crucial importance, especially in relatively small regions, of adjusting for any known divergence between regional and national technologies, heterogeneity and final demand.

1 Introduction

Regional input–output tables are an invaluable aid to regional planning, yet building a survey-based regional table is invariably complex, expensive and time consuming. As a result, regional analysts attempt to adjust the national table, so that it mirrors a region's economic structure. However, classical regionalization procedures—particularly those employing the commodity balance (CB) method or simple location quotients (SLQs)—tend to underestimate interregional trade. This problem arises because these methods fail to recognize the existence of *cross-hauling* (where a sector simultaneously exports and imports a specific product) and do not take explicit account of the relative size of regions.

In this chapter, we examine two more modern approaches to regionalization: Flegg's location quotient (FLQ) and Kronenberg's Cross-Hauling Adjusted Regionalization Method (CHARM). Both are classified as pure non-survey techniques, whereby a very limited amount of regional data (such as sectoral employment) is used to regionalize the national input–output table. This initial process is entirely mechanical, but analysts can subsequently incorporate superior data in an attempt to enhance accuracy.

The key idea underlying the FLQ is that a region's propensity to import from other domestic regions is inversely and nonlinearly related to its relative size. By incorporating explicit adjustments for interregional trade, analysts should be able to gain more accurate estimates of regional input coefficients and hence multipliers. As with other non-survey techniques, the principal aim of the FLQ is to provide a means whereby regional analysts can construct regional tables that reflect a region's economic structure as far as possible.

CHARM is an innovative new non-survey routine for constructing regional tables. It incorporates a systematic procedure for adjusting imports and exports to allow for cross-hauling, which is posited to vary directly with the heterogeneity of products, regional output and demand (Flegg et al. 2015). CHARM is suitable for environmental and other applications where the focus is on the overall supply of goods and services, irrespective of their source (Kronenberg 2009). It can only be employed in conjunction with type A national tables, those where imports have been included in the inter-industry matrix (Kronenberg 2012). In contrast, where the concern is with regional output and employment, the FLQ can be used to compute an initial set of regional input coefficients. However, the FLQ requires national transactions matrices that exclude imports (type B tables), which are unavailable for many countries including China.[1]

The rest of this chapter is structured as follows. The theoretical properties of the FLQ and related formulae are examined next. This is followed, in Sect. 3, by a discussion of empirical evidence drawn from case studies of 20 Finnish and 16 South Korean regions. In addition to testing the FLQ, we also evaluate a proposed new variant of the FLQ, namely the sector-specific FLQ (SFLQ). The theoretical foundations of CHARM and the role of cross-hauling are examined in Sect. 4. This is followed by case studies of the regions of Uusimaa in Finland and Hubei in China. In each case, we explain how CHARM was used to estimate sectoral exports, imports and the volume of trade. We also assess how well CHARM can simulate interregional trade and sectoral supply multipliers. Section 7 concludes.

2 The FLQ and Related Formulae[2]

Using LQs is a straightforward and inexpensive means of regionalizing national input–output tables. Earlier studies have frequently employed the SLQ or the *cross-industry* LQ (CILQ) to make suitable adjustments to national data, yet both are known to understate interregional trade. A key reason for this understatement is that the SLQ precludes cross-hauling, whereas the CILQ seriously underestimates its extent (Flegg and Tohmo 2013b, p. 239).

We can define an output-based SLQ as

$$\mathrm{SLQ}_i \equiv \frac{Q_i^r / \sum_i Q_i^r}{Q_i^n / \sum_i Q_i^n} \equiv \frac{Q_i^r}{Q_i^n} \times \frac{\sum_i Q_i^n}{\sum_i Q_i^r}, \tag{1}$$

where Q_i^r is regional output in sector i and Q_i^n is the corresponding national figure. $\sum_i Q_i^r$ and $\sum_i Q_i^n$ are the respective regional and national totals. Similarly, we can define a CILQ as

$$\mathrm{CILQ}_{ij} \equiv \frac{\mathrm{SLQ}_i}{\mathrm{SLQ}_j} \equiv \frac{Q_i^r / Q_i^n}{Q_j^r / Q_j^n}, \tag{2}$$

where the subscripts i and j denote, respectively, the supplying and purchasing industries.

[1]This taxonomy of tables into types A and B follows Kronenberg (2012) and the United Nations (1973). It is possible, however, to make some crude adjustments for “competitive” imports and thereby convert a type A national transactions table into an approximation of a type B table; see Miller and Blair (2009, pp. 149–157).

[2]For a more detailed discussion of the material in this section, see Bonfiglio and Chelli (2008), Flegg and Tohmo (2013a, 2016, 2018), Flegg et al. (2016) and Kowalewski (2015).

Defining LQs in terms of output is preferable to using a proxy such as employment since employment shares are affected by interregional variations in productivity. Fortunately, regional sectoral output data were readily available for both Finland and South Korea, the two empirical examples considered in Sect. 3.

The first step in applying LQs is to transform the national transactions matrix into a matrix of input coefficients, **A** = [a_{ij}], which can then be "regionalized" via the formula

$$r_{ij} = \beta_{ij} \times a_{ij}, \tag{3}$$

where r_{ij} is the regional input coefficient, β_{ij} is an adjustment coefficient and a_{ij} is the national input coefficient (Flegg and Tohmo 2016, p. 311). r_{ij} measures the amount of regional input i needed to create one unit of regional gross output j; it thus excludes any inputs obtained from other domestic regions or from other countries. Likewise, a_{ij} excludes any foreign inputs. The role of β_{ij} is to take account of a region's purchases of input i from other domestic regions.

We can estimate the r_{ij} by inserting, for example, the SLQ into Eq. (3), so that:

$$\hat{r}_{ij} = \mathrm{SLQ}_i \times a_{ij}. \tag{4}$$

No scaling is applied to a_{ij} if $\mathrm{SLQ}_i \geq 1$ and likewise for CILQ_{ij}. When $i = j$, $\mathrm{CILQ}_{ij} = 1$, so it is customary to use SLQ_i rather than unity along the principal diagonal of the scaling matrix.

An advantage of the CILQ is that a different scaling can be applied to each cell in a given row of the matrix **A,** which means that cross-hauling can occur. By contrast, the SLQ presupposes that an industry is either an exporter or an importer of a specific commodity but never both, so that cross-hauling is ruled out a priori. Nonetheless, empirical studies show that the CILQ still greatly underestimates interregional trade. Flegg et al. (1995) sought to remedy this shortcoming of the CILQ via their FLQ formula, which was subsequently refined by Flegg and Webber (1997). Following Flegg et al. (2016, pp. 26–27), the FLQ is defined here as

$$\mathrm{FLQ}_{ij} \equiv \mathrm{CILQ}_{ij} \times \lambda^*, \quad \text{for } i \neq j, \tag{5}$$

$$\mathrm{FLQ}_{ij} \equiv \mathrm{SLQ}_i \times \lambda^*, \quad \text{for } i = j, \tag{6}$$

where

$$\lambda^* \equiv \left[\log_2\left(1 + \sum\nolimits_i Q_i^r / \sum\nolimits_i Q_i^n\right)\right]^\delta. \tag{7}$$

Flegg et al. assume that $0 \leq \delta < 1$; as δ increases, so too does the adjustment for imports from other domestic regions. $\delta = 0$ represents a special case whereby $\mathrm{FLQ}_{ij} = \mathrm{CILQ}_{ij}$ for $i \neq j$ and $\mathrm{FLQ}_{ij} = \mathrm{SLQ}_i$ for $i = j$. As with other LQ-based formulae, the constraint $\mathrm{FLQ}_{ij} \leq 1$ is imposed.

Flegg et al. (2016, p. 27) highlight two key features of the FLQ formula: its cross-industry foundations and the explicit role attributed to regional size. With the FLQ, the relative size of the regional buying and selling industries is considered when making an allocation for imports from other regions. This is a feature that the CILQ and FLQ share. However, by also taking explicit account of the relative size of regions, Flegg and Tohmo (2016, p. 312) argue that the FLQ should help to resolve the problem of cross-hauling, which tends to be most serious in smaller regions, which are more likely than larger regions to trade with surrounding regions.

A substantial body of empirical evidence now demonstrates that the FLQ can produce more accurate estimates of regional input coefficients and hence multipliers than the SLQ and CILQ. This evidence includes case studies using regional data for Scotland (Flegg and Webber 2000), Finland (Tohmo 2004; Flegg and Tohmo 2013a, 2016), Germany (Kowalewski 2015), Argentina (Flegg et al. 2016), Ireland (Morrissey 2016) and South Korea (Flegg and Tohmo 2017).

Furthermore, Bonfiglio and Chelli (2008) used Monte Carlo methods to generate 400,000 type I regional output multipliers. These simulations revealed that the FLQ and a variant, the augmented FLQ (AFLQ), gave by far the most accurate estimates of these multipliers. This Monte Carlo study is examined in detail by Flegg and Tohmo (2013a). Nevertheless, Lamonica and Chelli (2017) demonstrate that, in some circumstances, the SLQ can produce slightly more precise results than the FLQ.

The AFLQ formula (Flegg and Webber 2000) recognizes that regional specialization may produce regional input coefficients that exceed the corresponding national coefficients, so that $r_{ij} > a_{ij}$ in Eq. (3). The effect of regional specialization is captured through SLQ_j. The AFLQ is defined as

$$\mathrm{AFLQ}_{ij} \equiv \mathrm{FLQ}_{ij} \times \log_2(1 + \mathrm{SLQ}_j). \tag{8}$$

The specialization term, $\log_2(1 + SLQ_j)$, is only applicable if $SLQ_j > 1$. As before, the restriction $FLQ_{ij} \leq 1$ is imposed.

However, even though the AFLQ has some theoretical advantages *vis-à-vis* the FLQ, its empirical performance is usually much the same (Bonfiglio and Chelli 2008; Flegg and Webber 2000; Flegg et al. 2016; Kowalewski 2015). One might argue, therefore, that the greater complexity of the AFLQ formula is not warranted by any enhancement in accuracy. Consequently, the AFLQ will not be considered further in this chapter.

Another variant of the FLQ is proposed by Kowalewski (2015), whose industry-specific FLQ, the SFLQ, is defined as

$$\mathrm{SFLQ}_{ij} \equiv \mathrm{CILQ}_{ij} \times [\log_2(1 + E^r/E^n)]^{\delta j}, \tag{9}$$

where E^r/E^n is regional size measured in terms of employment. The innovation here is in relaxing the assumption that δ is invariant across sectors. As usual, the restriction $SFLQ_{ij} \leq 1$ is imposed. Also, for $i = j$, SLQ_i is used in place of $CILQ_{ij}$. To estimate the δ_j, Kowalewski postulates the regression model

$$\delta_j = \alpha + \beta_1 \mathrm{CL}_j + \beta_2 \mathrm{SLQ}_j + \beta_3 \mathrm{IM}_j + \beta_4 \mathrm{VA}_j + \varepsilon_j, \tag{10}$$

where CL_j is the coefficient of localization, which measures the degree of concentration of national industry j, IM_j is the share of foreign imports in total national intermediate inputs, VA_j is the share of value added in total national output, and ε_j is an error term. While only national data are required for CL_j, IM_j and VA_j, regional data are needed for SLQ_j. CL_j is computed using the formula

$$\mathrm{CL}_j \equiv 0.5 \sum_r \left| \frac{E_j^r}{E_j^n} - \frac{E^r}{E^n} \right|. \tag{11}$$

3 Assessing the FLQ's Performance

Two empirical investigations are discussed in this section: an analysis of data for 20 Finnish regions by Flegg and Tohmo (2013a) and a comparable study of 16 South Korean regions by Flegg and Tohmo (2017). These studies are especially suitable for evaluating the performance of alternative LQ-based methods since several regions of varying size in each country are examined simultaneously. Consequently, the findings should be more robust than those based on a single region in one country alone. Furthermore, the data were compiled consistently by official bodies (Statistics Finland and the Bank of Korea).

Although these studies evaluated performance in terms of both type I sectoral output multipliers and input coefficients, the ranking of methods was very similar. Thus, for simplicity, only multipliers will be discussed here. The following statistical criteria were used in both studies to evaluate the estimated multipliers:

$$\mathrm{MPE} = (100/n) \sum_j (\hat{m}_j - m_j)/m_j, \tag{12}$$

$$\mathrm{WMPE} = 100 \sum_j w_j (\hat{m}_j - m_j)/m_j, \tag{13}$$

$$\mathrm{MAPE} = (100/n) \sum_j |\hat{m}_j - m_j|/m_j, \tag{14}$$

$$U = 100 \sqrt{\frac{\sum_j (\hat{m}_j - m_j)^2}{\sum_j m_j^2}}, \tag{15}$$

where m_j is the type I output multiplier for sector j and n is the number of sectors.

The mean percentage error, MPE, offers a handy means of assessing the extent of bias, yet it does not take any account of the relative importance of each sector. WMPE, the weighted mean percentage error, aims to overcome this limitation. The weight, w_j, is the proportion of total regional output produced in sector j. However, a drawback of the first two formulae is that a seemingly good result could be due to some large, but offsetting, positive and negative errors. MAPE and U are alternative ways of overcoming this problem. MAPE is the mean absolute percentage error, whereas U is Theil's inequality index, which has the advantage that it encompasses both bias and variance (Theil et al. 1966). A disadvantage of U is, however, that the use of squared deviations has the effect of accentuating any large positive or negative errors and thereby skewing the outcomes.

Both studies also endeavoured to capture the variability of the estimates, albeit in different ways. In the Finnish study, the standard deviation, V_1, of the absolute proportional differences was used to measure variability. By contrast, in the South Korean study, the squared difference in standard deviations, $V_2 = \{\text{sd}(\hat{m}_j) - \text{sd}(m_j)\}^2$, was employed to assess how far each method was able to replicate the dispersion in the benchmark distribution of multipliers.

Table 1 reveals that the FLQ yields much more accurate results than the SLQ and CILQ in the case of Finland, irrespective of which criterion or value of δ is used. When $\delta = 0.25$, for instance, the FLQ overstates the sectoral multipliers by a minimal 0.4% on average, whereas the SLQ and CILQ do so by 14.7 and 15.0%, respectively. The most obvious explanation of this outcome is that the SLQ and CILQ make inadequate adjustments for interregional trade. The fact that MPE and MAPE are both positive and of similar size in each case shows that these methods almost invariably overstate the regional input coefficients and hence multipliers.

Table 1 Estimating output multipliers for Finnish regions in 1995 via different methods and criteria (20 regions and 37 sectors)

Method	Criterion				
	MPE	WMPE	MAPE	U	V_1
SLQ	14.7	14.2	15.7	20.4	0.1167
CILQ	15.0	12.3	16.4	19.9	0.1061
FLQ ($\delta = 0.15$)	5.7	3.4	9.9	13.1	0.0763
FLQ ($\delta = 0.2$)	2.6	**0.5**	8.5	**11.9**	0.0682
FLQ ($\delta = 0.25$)	**0.4**	−1.7	8.2	**11.9**	**0.0673**
FLQ ($\delta = 0.3$)	−1.9	−3.7	**8.1**	12.3	0.0680

Source Flegg and Tohmo (2013a, Table 4), based on the unweighted mean of results for 20 regions. The best values are shown in bold type

Table 2 Estimating output multipliers for South Korean regions in 2005 via different methods and criteria (16 regions and 28 sectors)

Method	Criterion				
	MPE	WMPE	MAPE	U	$V_2 \times 10^3$
SLQ	21.210	24.374	22.224	26.529	20.822
CILQ	22.386	19.136	23.541	26.706	15.386
FLQ (δ = 0.2)	8.767	5.780	11.411	13.911	2.403
FLQ (δ = 0.25)	5.998	3.007	9.836	12.114	1.346
FLQ (δ = 0.3)	3.463	**0.500**	8.768	10.903	0.727
FLQ (δ = 0.325)	2.297	−0.642	8.424	10.538	0.573
FLQ (δ = 0.35)	1.190	−1.710	8.164	10.322	0.479
FLQ (δ = 0.375)	**−0.143**	−2.699	8.022	**10.237**	**0.444**
FLQ (δ = 0.4)	−0.848	−3.615	**7.984**	10.256	0.451
FLQ (δ = 0.425)	−1.788	−4.471	8.038	10.370	0.501
SFLQ (optimal δ_j)	1.399	−2.001	2.628	4.213	0.044
SFLQ (regression)	2.438	−4.780	7.346	9.423	0.315

Source Flegg and Tohmo (2017, Table 11), based on the unweighted mean of results for 16 regions, plus supplementary calculations for the SFLQ. The best values for the FLQ are shown in bold type

Although it is desirable to avoid bias in the estimated multipliers, MPE $\approx$ 0 could still mask some large, but offsetting, positive and negative errors. One should, therefore, also consider measures such as MAPE and U when assessing accuracy. Whilst these statistics indicate fairly similar optimal values of δ, they differ noticeably regarding the FLQ's accuracy; for instance, for δ = 0.25, they yield average errors of 8.2 and 11.9%, respectively. The higher error for U is due to the fact that simulation errors are squared, which puts more emphasis on larger errors. U is especially sensitive to the presence of outliers in the data.

Table 1 also reveals that the FLQ gives by far the best outcome for V_1, which measures dispersion in the estimated multipliers in terms of absolute proportional differences. The minima for V_1 and MPE occur when $\delta \approx 0.25$, which signifies that the FLQ is able to minimize bias and variance simultaneously. This inference is bolstered by the fact that U, which takes both bias and variance into account via a squared measure, is also minimized where $\delta \approx 0.25$.

The four criteria examined so far have exhibited a remarkable degree of consistency in pointing to an optimal $\delta \approx 0.25$. However, we should note that WMPE suggests that the larger sectors may need a value a little lower than that.

Let us now consider some findings from a study of 16 South Korean regions by Flegg and Tohmo (2017). Table 2 reveals that the outcomes for the different measures exhibit a high degree of consistency. Irrespective of which criterion is used, the SLQ and CILQ produce similar results, which are also much less accurate than those from the FLQ. MPE shows, for instance, that the SLQ overestimates the sectoral multipliers by 21.2% on average across the 16 regions, whereas the FLQ with $\delta = 0.375$ displays negligible bias. Moreover, with $\delta = 0.375$, MAPE = 8.0%, which is well below the corresponding figures for the SLQ and CILQ.

What is more, MPE, V_2 and U all point to a $\delta \approx 0.375$, so it is evident that there is no conflict between minimizing bias and variance in this data set. Even so, since WMPE gives an optimum of $\delta \approx 0.3$, the larger sectors may require a $\delta < 0.375$.

The findings for the two countries show a remarkable degree of correspondence in both the performance of the FLQ and the behaviour of the different statistical criteria. There is, however, one striking difference: whereas $\delta \approx 0.25$ appears to be the best single value for Finnish regions, $\delta \approx 0.375$ seems more appropriate for South Korea. A possible explanation of this phenomenon is that South Korean regions typically imported a substantially higher proportion of their inputs from other domestic regions than did Finnish regions.[3] Consequently, in order to adjust for this disparity in import propensities, a higher value of δ is required in South Korea than in Finland.

3.1 Deriving Region-Specific Values of δ

The discussion so far has focused on finding the best single value of δ in Finland and South Korea. However, optimal values may well vary across regions within each country. To explore this issue, let us consider the regression models reported in Table 3, which Flegg and Tohmo (2013a, 2017) fitted using region-specific data for each country.

Observations on $\ln \delta$, the dependent variable, were derived by finding the value of δ that minimized MPE for each Finnish region or MAPE for each South Korean region. The explanatory variables are defined as follows:

- R is regional size measured in terms of output and expressed as a percentage;
- P is the proportion of each region's gross output imported from other regions, averaged over all sectors and divided by the mean for all regions;
- I is each region's average use of intermediate inputs (including inputs from other regions), divided by the corresponding national average;
- F is the average proportion of each region's gross output imported from abroad, divided by the mean for all regions;
- B_{15} is a binary variable for South Korean region 15, which was found to be an outlier.

In terms of conventional statistical criteria, both regressions appear to be well specified. To illustrate their possible use, let us consider two contrasting South Korean regions, Seoul and Ulsan. For Seoul, $R = 18.2$, $P = 0.669$ and $F = 0.514$.

[3]South Korean regions imported, on average, 25.9% of gross output from other domestic regions in 2005 (Flegg and Tohmo 2017, Table 9). By contrast, the domestic import propensity for Finnish regions in 1995 was 18.7%. See Flegg and Tohmo (2013a, Fig. 2) for an illustration.

Table 3 Regression models to estimate δ using data for 20 Finnish regions in 1995 and 16 South Korean regions in 2005

	Finland	South Korea
Intercept	−1.838	−1.226
ln *R*	0.332 (11.66)	0.168 (4.80)
ln *P*	1.583 (6.25)	0.325 (2.37)
ln *I*	−2.881 (−3.33)	–
ln *F*	–	0.317 (6.64)
B_{15}	–	0.577 (6.12)
R^2	0.915	0.934
χ^2 (1) functional form	0.447	0.123
χ^2 (2) normality	0.559	0.002
χ^2 (1) heteroscedasticity	0.591	0.006

Note: *t* statistics are in brackets. The critical values of χ^2 (1) and χ^2 (2) at the 5% level are 3.841 and 5.991, respectively
Source Flegg and Tohmo (2013a, p. 713, 2017, Table 13)

Therefore, Seoul imported 33.1% less than average of its intermediate inputs from other South Korean regions and 48.6% less than average from abroad. The regression gives a predicted $\delta = 0.339$, which is extremely close to the $\delta = 0.337$ that minimizes MAPE. By contrast, $R = 7.1$, $P = 0.925$ and $F = 2.405$ for Ulsan. Hence, this region imported only 7.5% less than average of its intermediate inputs from other South Korean regions, yet imported 140.5% more than average from abroad. In this case, the predicted value is $\delta = 0.525$, which is fairly close to the $\delta = 0.542$ that minimizes MAPE.

The results manifest a tendency for the optimal δ to rise with regional size *R*. It is hard to explain this positive relationship theoretically but it is interesting that it occurs in both countries, albeit more strongly in Finland than in South Korea. As expected, there is a positive relationship between the optimal δ and the regional propensity to import from other regions. Consequently, regions exhibiting an above-average propensity would need a higher value of δ and vice versa. This relationship is demonstrably stronger in Finland than in South Korea.

The variable ln *I* exhibits the anticipated relationship in Finland but was redundant in South Korea (Flegg and Tohmo 2017, Table 13). As for ln *F*, this variable was not statistically significant in Finland but is highly so in South Korea, where it shows that a greater use of foreign intermediate inputs is associated with a higher optimal δ. This high significance is to be expected because South Korean regions vary greatly in terms of their proportion of foreign inputs; for instance, Seoul imported 6.0% of intermediate inputs from abroad in 2005, whereas Ulsan imported 28.3% (Flegg and Tohmo 2017, Table 9).

To sum up, the regressions suggest that, rather than using the same δ for all regions, analysts should consider using a higher value for regions known to use, say, an above-average proportion of either foreign inputs or inputs from other regions. To illustrate, suppose that a region produces 5.5% of national output; furthermore, its use of intermediate inputs from other regions is thought to be 10% above average, whereas its use of foreign inputs is believed to be 20% below average. Using the Korean model, with $R = 5.5$, $P = 1.1$ and $F = 0.8$, $\delta = 0.354$. By contrast, $P = F = 1$ would yield $\delta = 0.391$.

3.2 The Sector-Specific FLQ

Thus far, we have examined the FLQ's performance on the assumption that δ is invariant across sectors. This is clearly a strong assumption, so it is important to establish whether more precise results could be achieved by permitting this parameter to vary across sectors, as it does in the SFLQ formula (9). To evaluate this approach, Kowalewski (2015) analysed official survey-based data for the German state of Baden-Wuerttemberg (B-W).

At the outset, we need to assess whether, in principle, the SFLQ can give more precise estimates of the sectoral type I output multipliers. This first step involves using the available data for B-W to compute an "optimal" δ_j for each sector. Kowalewski used the mean absolute deviation of the estimated multipliers to find such values. She then evaluated the outcomes for multipliers using a similar set of statistics to those employed by Flegg and Tohmo (2017). The results were rather mixed: when judged in terms of MAPE, U and V_1, the SFLQ clearly outperformed the FLQ, whereas MPE and WMPE recorded superior outcomes for the FLQ (Kowalewski 2015, Table 3). Indeed, the SFLQ's estimates of multipliers were noticeably biased, whereas the FLQ's estimates displayed negligible bias. Even so, it is worth mentioning that Kowalewski also examined performance in terms of input coefficients and here the SFLQ invariably outperformed the FLQ.

Nevertheless, for the SFLQ to be a useful addition to the regional analyst's toolkit, we need to have a practical way of determining values of δ_j. With this aim in mind, Kowalewski fitted model (10) to data for B-W. Her results are reproduced here in Table 4.

It is noticeable that CL_j is highly statistically significant, whereas the other regressors have low t statistics. The fact that three of the four regressors in Kowalewski's model are not significant, even at the 20% level, means that it does not offer a reliable way of estimating the δ_j. Flegg and Tohmo (2017) attempted to address this issue by fitting a new model to data for all 16 South Korean regions. In doing so, they attempted to avoid the peculiarities of individual regions and thereby gain more robust results. Their findings are reported in Table 4.

Before considering Flegg and Tohmo's results, we should note that they modified Kowalewski's regression model (10) by imposing the restriction $\beta_2 = 0$ and

Table 4 Regression results based on the SFLQ model (10)

	State of Baden-Wurttemberg	16 South Korean regions
Intercept	−0.009	0.669
CL_j	1.266 (4.49)	0.269 (1.77)
SLQ_j	−0.025 (−0.38)	–
IM_j	−0.230 (−0.64)	−0.403 (−3.54)
VA_j	0.124 (1.12)	−0.628 (−4.57)
n	21	27
R^2	0.67	0.589

Note: t statistics are in brackets
Source Kowalewski (2015, Table 8) for B-W; Flegg and Tohmo (2017, Eq. 15) for South Korea

re-expressing the regressand as the unweighted mean of δ_j across all regions. SLQ_j was omitted because it is a region-specific variable.

Table 4 reveals that CL_j has a positive coefficient, which is consistent with Kowalewski's hypothesis that "the more an industry is concentrated in space, the higher the regional propensity to import goods or services of this industry" (Kowalewski 2015, p. 248). Such industries would need a bigger δ to adjust for this higher propensity. However, since the role of CL_j is to capture any regional imbalances in employment in sector j, its modest level of significance (p = 0.090) is rather surprising. By contrast, IM_j is highly significant (p = 0.002), as is VA_j (p = 0.000). R^2 = 0.589, a value that reflects the exclusion of relevant regressors, along with random variation in the δ_j.

The results displayed in Table 2 enable us to evaluate the performance of Flegg and Tohmo's model in terms of five different criteria. The outcomes for MAPE, U and V_2 demonstrate that this regression, notwithstanding its modest R^2, can outperform the FLQ. For instance, MAPE is almost 0.7% points lower for the regression-based estimates than for the FLQ (with δ = 0.375). However, the MPE shows that the SFLQ generates upwardly biased estimates of multipliers. Indeed, this bias is 2.4% on average.

We now need to consider whether, in the light of these results, the SFLQ offers a practical alternative to the FLQ. There are two main arguments against recommending this approach. The first is that a regression fitted using South Korean data may not be transferable to regions in other countries. Secondly, one could argue that the enhanced accuracy exhibited by MAPE, U and V_2 is insufficient to compensate for the bias that might be introduced by using the SFLQ rather than the FLQ. A riposte might be that there is much scope for greater accuracy in the regression-based estimates, as is evident from a comparison of the last two rows in Table 2. Nonetheless, in order to build a suitably refined model, one would need to find some extra regressors for which the necessary data were readily available.

3.3 Self-sufficient Sectors

Flegg et al. (2016) initiated a new line of enquiry by proposing that analysts should use the national input coefficients for sectors held to be self-sufficient or approximately so, i.e. to set $r_{ij} = a_{ij}$ for such sectors but use the FLQ-based estimates otherwise. Flegg et al. tested this approach with data for the Argentinian province of Córdoba and found that it gave much better results than simply using FLQ-based estimates for all sectors. For instance, by setting $r_{ij} = a_{ij}$ for 12 of the 28 sectors, the value of U was cut from 10.885 to 7.930; what is more, the optimal δ for the remaining sectors was raised from 0.104 to 0.402 (Flegg et al. 2016, Tables 3 and 5). Whilst it would be interesting to test this approach with the much larger data sets for Finland and South Korea, that would be beyond the scope of this chapter.

4 Cross-Hauling and CHARM[4]

Since CHARM is a refinement of the classical CB approach to constructing a regional input–output table (Isard 1953), it is appropriate to begin by considering the key concepts underlying the CB method. At the outset, the analyst would need to use the following formula to estimate the demand for each regional sector:

$$dt_i^r = \sum_j a_{ij}^n x_j^r + df_i^r, \tag{16}$$

where dt_i^r is total regional demand for commodity i in region r, a_{ij}^n is the national technical coefficient (the number of units of commodity i, irrespective of source, needed to produce one unit of gross output of national industry j), x_j^r is output of regional industry j, $\sum_j a_{ij}^n x_j^r$ is intermediate demand, and df_i^r is final demand. A key assumption here is that the region and the nation share the same technology. This postulate reflects the fact that data on regional technology are rarely available. Where regional sectoral output is unknown, as is often the case, employment can be used as a proxy.

If $dt_i^r < x_i^r$, the entire surplus is assumed to be exported; conversely, if $dt_i^r > x_i^r$, it is presumed that sufficient imports will be available to make up for the shortfall in regional output. Cross-hauling is ruled out. The CB method operates on the principle of maximum local trade, i.e. “if commodity i is available from a local source, it will be purchased from that source” (Harrigan et al. 1981, p. 71). One problem with this principle is that it “ignores the fact that any industry commodity in practice will be an aggregation of a number of quite distinct commodities” (ibid.), so that cross-hauling is almost bound to occur. Moreover, Richardson (1985,

[4]This section closely follows Flegg et al. (2015, Sect. 3).

p. 613) remarks that "[a]lthough industrial disaggregation helps to relieve the cross [-]hauling problem, it does not solve it." Consequently, other explanations of cross-hauling need to be explored.

Cross-hauling is ubiquitous in small regions that do not represent a functional economic area (Robison and Miller 1988) but it is also a serious concern in larger regions (Kronenberg 2009). It is apt to be encountered in densely populated and highly urbanized countries, especially those where commuting across regional boundaries is important (Boomsma and Oosterhaven 1992). Kronenberg identifies the *heterogeneity* of commodities as the main cause of cross-hauling and CHARM represents a novel way of dealing with this problem.

The interregional trade in automobiles between Hubei and other Chinese provinces is a good example of cross-hauling due to product differentiation. For instance, Dongfeng-Citroën cars are shipped from Wuhan, where this company's headquarters is situated, to Shanghai and Beijing, where Shanghai-Volkswagen and Beijing-Hyundai have their headquarters, while Shanghai-Volkswagen and Beijing-Hyundai cars are shipped to Wuhan.

Although product differentiation may well be the primary cause of cross-hauling, we should also recognize that, in reality, many input–output sectors represent an aggregation of several distinct commodities, so that cross-hauling is very likely to occur. The Chinese sector entitled "Paper, printing, stationery and sporting goods" exemplifies this point. Suppose that a region imports sporting goods but exports paper, printing and stationery; this would create an illusion of cross-hauling, which would vanish if sporting goods were reallocated into a separate sector.

Let us now compare and contrast CHARM with the CB method. A key similarity is that both methods employ national transaction tables that incorporate imports; this is because they aim to capture the underlying technology of production (Kronenberg 2012). Also, both employ the concept of a *commodity balance*; for commodity i, this balance, b_i, is defined as:

$$b_i \equiv e_i - m_i, \tag{17}$$

where e_i and m_i denote exports and imports, respectively, and b_i represents net exports. The value of b_i is computed as the estimated output of commodity i minus the estimated sum of intermediate and domestic final use (Kronenberg 2009, p. 46).

However, while CHARM and the CB method yield identical values for b_i, they give different values, in general, for the volume of trade, $e_i + m_i$. This is because CHARM takes cross-hauling, q_i, explicitly into account via the following equation (ibid., p. 47):

$$q_i = (e_i + m_i) - |(e_i - m_i)|. \tag{18}$$

Thus, q_i will be greater, the larger the volume of trade and the smaller the absolute trade balance. In the CB method, $q_i = 0$ as $e_i > 0$ and $m_i > 0$ cannot, by assumption, occur together. By contrast, with CHARM, $q_i > 0$ is possible and, indeed, probable in most cases.

For purposes of estimation, Kronenberg posits that q_i is proportional to the sum of domestic production, x_i, intermediate use, z_i, and domestic final use, f_i. The factor of proportionality, h_i, captures the heterogeneity of commodities, as shown in the equation:

$$q_i = h_i(x_i + z_i + f_i), \tag{19}$$

where $0 \leq h_i < \infty$ (ibid., p. 51). Consequently, $h_i = q_i/(x_i + z_i + f_i)$. Kronenberg assumes that h_i is invariant across regions and depends solely on the characteristics of products; it can, therefore, be estimated using national data. We would get $h_i = 0$ if $q_i = 0$, which would occur if $e_i = 0$ with $m_i > 0$ or $m_i = 0$ with $e_i > 0$ or $e_i = m_i = 0$.

5 Case Study of Uusimaa[5]

In order to assess CHARM's performance, benchmark regional data for imports, exports and multipliers are required. These figures can be derived for all Finnish regions in 2002, using data from Statistics Finland, but we opted instead to focus on Uusimaa, Finland's largest region, which produced 34.6% of national output in 2002 and accounted for 31.4% of aggregate employment. Its diversified industrial structure is illustrated in Table 5. Unfortunately, a lack of regional data meant that the 59 national sectors had to be reduced to 26, so there is some unavoidable loss of information and consequential aggregation bias.

As expected, Table 6 shows that the CB method substantially underestimates Uusimaa's total exports and imports and, consequently, its volume of trade. CHARM performs markedly better, although it too understates the overall amount of trade. This superior relative performance is primarily due to the fact that CHARM takes cross-hauling into account, whereas the CB method rules out the possibility of a sector's being both an exporter and an importer of a given commodity.

Table 7 reveals that CHARM almost invariably produces the best estimates of the *volume* of trade in individual sectors. This pattern is especially noticeable for manufacturing (sectors 5–15), where it can be explained by the heterogeneity of many manufactured products and the concomitant cross-hauling. Sector 13 is a good example: whereas CHARM captures 83.2% of the volume of trade, the CB method accounts for only 30.2%. Furthermore, the more detailed results in Table 6 reveal that CHARM captures almost all of the exports in sector 13 and two-thirds of the imports; by contrast, the CB method accounts for half of the exports but none of the imports.

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[5]This section closely follows Flegg and Tohmo (2013b, pp. 249–254).

Table 5 Employees in Uusimaa and Finland by regional sector

Sector	Description	Uusimaa: employees	Finland: employees	Regional share (%)	National share (%)	SLQ_i
1	Agriculture and hunting (1)	3,409	104,000	0.5	4.4	0.104
2	Forestry and logging (2)	1,105	20,000	0.1	0.9	0.176
3	Fishing (3)	37	2,000	0.0	0.1	0.059
4	Mining and extraction (4–8)	635	6,000	0.1	0.3	0.336
5	Manufacture of food products, beverages and tobacco products (9–10)	9,462	41,000	1.3	1.7	0.733
6	Manufacture of textiles and clothes; dressing and dyeing of fur; tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (11–13)	1,754	19,000	0.2	0.8	0.293
7	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (14)	1,576	31,000	0.2	1.3	0.162
8	Manufacture of pulp, paper and paper products; publishing, printing and reproduction of recorded media (15–16)	18,009	72,000	2.4	3.1	0.795
9	Manufacture of coke, refined petroleum products, nuclear fuels, chemicals and chemical products, rubber and plastic products (17–19)	9,127	40,000	1.2	1.7	0.725
10	Manufacture of other non-metallic mineral products (20)	2,964	16,000	0.4	0.7	0.589
11	Manufacture of basic metals and fabricated metal products, other than machinery and equipment (21–22)	8,191	62,000	1.1	2.6	0.420
12	Manufacture of machinery and equipment not classified elsewhere (23)	10,460	63,000	1.4	2.7	0.527
13	Manufacture of office machinery and computers; electrical machinery and apparatus; radio, television and communication equipment and apparatus; medical, precision and optical instruments, watches and clocks (24–27)	26,823	66,000	3.6	2.8	1.291

(continued)

Table 5 (continued)

Sector	Description	Uusimaa: employees	Finland: employees	Regional share (%)	National share (%)	SLQ_i
14	Manufacture of motor vehicles, trailers, semi-trailers and other transport equipment (28–29)	5,986	25,000	0.8	1.1	0.761
15	Manufacture of furniture; manufacturing not classified elsewhere; recycling (30–31)	2,924	19,000	0.4	0.8	0.489
16	Electricity, gas, steam and hot water supply; collection, purification and distribution of water (32–33)	4,915	16,000	0.7	0.7	0.976
17	Construction (34)	42,555	155,000	5.8	6.6	0.872
18	Sale, maintenance and repair of motor vehicles and motorcycles; retail of automotive fuel; wholesale, retail and commission trade, excluding motor vehicles and motorcycles; repair of personal and household goods (35–37)	122,176	300,000	16.5	12.8	1.294
19	Hotels and restaurants (38)	27,228	77,000	3.7	3.3	1.123
20	Land, water and air transport; travel agencies; post and telecommunications (39–43)	66,325	174,000	9.0	7.4	1.211
21	Financial intermediation; insurance and pension funding, except for compulsory social security (44–46)	20,733	41,000	2.8	1.7	1.606
22	Real estate and other business activities; rental of machinery and equipment and of personal and household goods; research and development (47–51)	114,585	236,000	15.5	10.0	1.542
23	Public administration and defence; compulsory social security (52)	52,838	173,000	7.1	7.4	0.970
24	Education (53)	50,405	157,000	6.8	6.7	1.020
25	Health and social work (54)	88,539	321,000	12.0	13.7	0.876
26	Sewage and refuse disposal, sanitation and similar activities; recreational, cultural, sporting and other service activities; private households with employed persons (55–59)	46,665	113,000	6.3	4.8	1.312
Sum		739,426	2,349,000	100.0	100.0	

Note The corresponding 59 national sectors are shown in brackets
Source Flegg and Tohmo (2013b, Table 3)

Table 6 Estimation of Uusimaa trade (millions of euros)

Sector	CHARM				Commodity balance				Benchmark				
	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Output
1	50.1	889.2	−839.1	939.3	0.0	839.1	−839.1	839.1	146	838	−692	984	182
2	4.9	358.3	−353.4	363.1	0.0	353.4	−353.4	353.4	43	165	−122	208	131
3	0.4	48.7	−48.3	49.1	0.0	48.3	−48.3	48.3	1	47	−46	48	13
4	22.9	979.8	−956.9	1,002.7	0.0	956.9	−956.9	956.9	26	888	−862	914	138
5	279.3	984.9	−705.6	1,264.2	0.0	705.6	−705.6	705.6	1,826	2,131	−305	3,957	2,134
6	173.4	775.5	−602.1	948.9	0.0	602.1	−602.1	602.1	122	730	−608	852	144
7	35.8	458.8	−423.0	494.6	0.0	423.0	−423.0	423.0	148	515	−367	663	208
8	2,190.9	216.4	1,974.5	2,407.4	1,974.5	0.0	1,974.5	1,974.5	2,140	1,682	458	3,822	3,329
9	1,434.4	2,069.4	−635.0	3,503.8	0.0	635.0	−635.0	635.0	1,856	2,371	−515	4,227	2,424
10	95.3	216.5	−121.2	311.8	0.0	121.2	−121.2	121.2	247	417	−170	664	471
11	451.2	889.6	−438.4	1,340.8	0.0	438.4	−438.4	438.4	808	1,411	−603	2,219	1,106
12	749.6	1,132.8	−383.2	1,882.4	0.0	383.2	−383.2	383.2	1,392	1,764	−372	3,156	1,938
13	6,944.5	3,250.1	3,694.4	10,194.6	3,694.4	0.0	3,694.4	3,694.4	7,367	4,883	2,484	12,250	8,979
14	832.5	1,234.3	−401.9	2,066.8	0.0	401.9	−401.9	401.9	941	1,260	−319	2,201	894
15	115.1	424.4	−309.3	539.5	0.0	309.3	−309.3	309.3	234	566	−332	800	305
16	63.7	124.5	−60.8	188.2	0.0	60.8	−60.8	60.8	188	88	100	276	1,593
17	0.0	1,175.5	−1,175.5	1,175.5	0.0	1,175.5	−1,175.5	1,175.5	387	224	163	611	6,311
18	2,562.5	159.1	2,403.4	2,721.6	2,403.4	0.0	2,403.4	2,403.4	4,441	140	4,301	4,581	12,906
19	28.9	61.5	−32.6	90.3	0.0	32.6	−32.6	32.6	170	206	−36	376	1,759
20	2,239.5	602.9	1,636.5	2,842.4	1,636.5	0.0	1,636.5	1,636.5	4,441	2,108	2,333	6,549	10,808
21	1,104.9	50.6	1,054.3	1,155.5	1,054.3	0.0	1,054.3	1,054.3	1,229	177	1,052	1,406	3,845
22	4,838.0	586.8	4,251.2	5,424.8	4,251.2	0.0	4,251.2	4,251.2	4,780	1,601	3,179	6,381	16,476

(continued)

Table 6 (continued)

Sector	CHARM				Commodity balance				Benchmark				
	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Output
23	34.9	184.2	−149.3	219.2	0.0	149.3	−149.3	149.3	213	169	44	382	3,889
24	7.0	1.3	5.7	8.3	5.7	0.0	5.7	5.7	32	47	−15	79	2,410
25	0.4	538.7	−538.3	539.1	0.0	538.3	−538.3	538.3	107	44	63	151	4,115
26	662.3	40.1	622.2	702.5	622.2	0.0	622.2	622.2	790	145	645	935	3,843
Sum	24,922.4	17,454.0	7,468.4	42,376.4	15,642.3	8,174.0	7,468.4	23,816.3	34,075	24,617	9,458	58,692	90,351

Source Flegg and Tohmo (2013b, Table 4)

Table 7 Estimates of supply multipliers and trade volume for the CB method and CHARM (employment-based)

Sector	Description	Supply multipliers			Ratio of estimated to target trade volume	
		Survey	CHARM	CB	CHARM	CB
1	Agriculture and hunting	1.171	1.127	1.143	0.955	0.853
2	Forestry and logging	1.238	1.116	1.123	1.746	1.699
3	Fishing	1.025	1.030	1.032	1.024	1.006
4	Mining and extraction	1.153	1.100	1.110	1.097	1.047
5	Manufacture of food products, beverages and tobacco products	1.536	1.827	1.968	0.319	0.178
6	Manufacture of textiles and clothes; dressing and dyeing of fur; tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	1.139	1.130	1.173	1.114	0.707
7	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	1.262	1.392	1.432	0.746	0.638
8	Manufacture of pulp, paper and paper products; publishing, printing and reproduction of recorded media	1.657	2.045	2.176	0.630	0.517
9	Manufacture of coke, refined petroleum products, nuclear fuels, chemicals and chemical products, rubber and plastic products	1.478	1.575	1.917	0.829	0.150
10	Manufacture of other non-metallic mineral products	1.479	1.632	1.817	0.470	0.182
11	Manufacture of basic metals and fabricated metal products, other than machinery and equipment	1.404	1.691	1.968	0.604	0.198
12	Manufacture of machinery and equipment not classified elsewhere	1.581	1.710	2.115	0.596	0.121
13	Manufacture of office machinery and computers; electrical machinery and apparatus; radio, television and communication equipment and apparatus; medical, precision and optical instruments, watches and clocks	1.634	1.754	2.235	0.832	0.302
14	Manufacture of motor vehicles, trailers, semi-trailers and other transport equipment	1.442	1.531	2.003	0.939	0.183
15	Manufacture of furniture; manufacturing not classified elsewhere; recycling	1.307	1.389	1.509	0.674	0.387

(continued)

Table 7 (continued)

Sector	Description	Supply multipliers			Ratio of estimated to target trade volume	
		Survey	CHARM	CB	CHARM	CB
16	Electricity, gas, steam and hot water supply; collection, purification and distribution of water	1.612	1.619	1.692	0.682	0.220
17	Construction	2.001	1.842	1.925	1.924	1.924
18	Sale, maintenance and repair of motor vehicles and motorcycles; retail of automotive fuel; wholesale, retail and commission trade, excluding motor vehicles and motorcycles; repair of personal and household goods	1.735	1.773	1.839	0.594	0.525
19	Hotels and restaurants	1.816	1.850	1.917	0.240	0.087
20	Land, water and air transport; travel agencies; post and telecommunications	1.529	1.774	1.885	0.434	0.250
21	Financial intermediation; insurance and pension funding, except for compulsory social security	1.519	1.494	1.532	0.822	0.750
22	Real estate and other business activities; rental of machinery and equipment and of personal and household goods; research and development	1.630	1.591	1.649	0.850	0.666
23	Public administration and defence; compulsory social security	1.631	1.600	1.654	0.574	0.391
24	Education	1.439	1.435	1.460	0.105	0.072
25	Health and social work	1.404	1.374	1.399	3.570	3.565
26	Sewage and refuse disposal, sanitation and similar activities; recreational, cultural, sporting and other service activities; private households with employed persons	1.711	1.699	1.747	0.751	0.665
	Mean	1.482	1.542	1.670	0.889	0.665
	Mean (excluding sectors 2, 17 and 25)	1.473	1.555	1.694	0.691	0.439
	Mean proportional error (%)		3.958	12.360		

Source Flegg and Tohmo (2013b, Table 5)

The disparities between CHARM and the CB method are generally less striking for non-manufacturing sectors. We should not expect cross-hauling to be an issue for many service industries, so CHARM is unlikely to outperform the CB method. Indeed, both methods perform very poorly indeed in Hotels and Restaurants (19) and Education (24), although the amount of trade involved is modest.

Moreover, there are three sectors (2, 17 and 25) where both methods dramatically overstate the volume of trade and by comparable amounts. This problem can, in turn, be attributed to errors in estimating the *balance* of trade, b_i, which equals net exports. Table 6 records estimates for b_i of −353.4, −1,175.5 and −538.3 (×€1 million) for sectors 2, 17 and 25, respectively, which differ markedly from the corresponding target figures of −122, 163 and 63. For Construction (17), the error occurs because intermediate and final demands for construction were overestimated by 6.5 and 7.8%, respectively, while output was underestimated by 14.0%. For Health and Social Work (25), the error can be attributed to a 10.4% overstatement of final demand and a 4.9% understatement of output. Finally, for Forestry and Logging (2), output was overstated by 24.8%, yet this error was dwarfed by the fact that the intermediate and final demands for this sector's output were overestimated by 97.9 and 120.6%, respectively.

It should be noted that we followed Kronenberg (2009) in making certain assumptions in our calculations of sectoral output and demand. In particular, we used employment data as a proxy for output. This is likely to be problematic where there is a significant divergence between regional and national labour

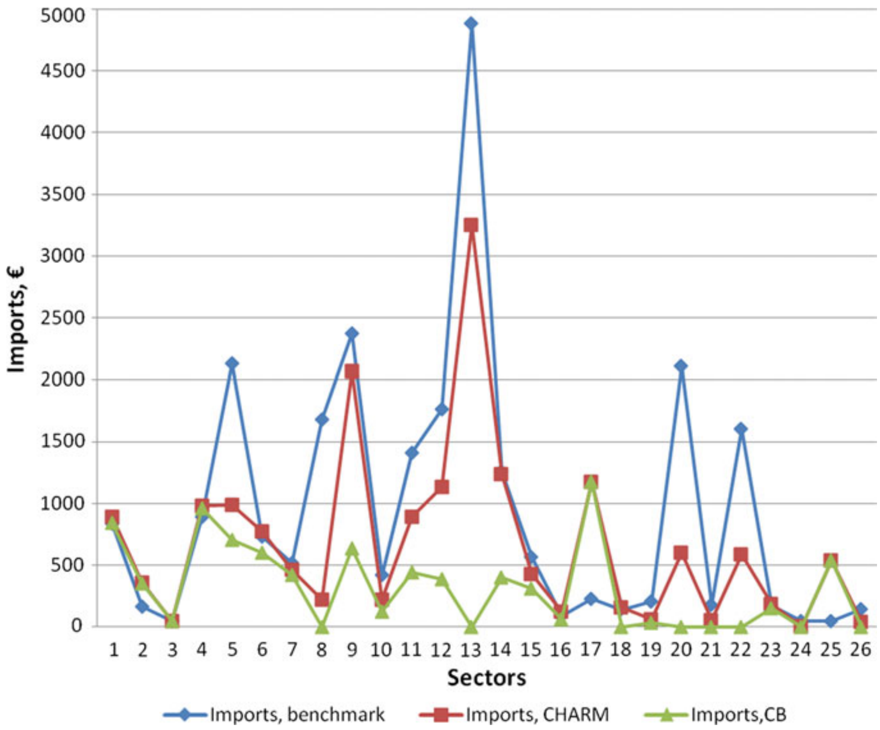

Fig. 1 Estimates of Uusimaa's Imports from CHARM and the CB method *Source* Flegg and Tohmo (2013b, Fig. 1)

productivities. We also assumed identical national and regional technologies. Finally, in calculating the regional final use of each commodity, we simply used the ratio of total regional to total national employment to scale down the national figures (cf. Kronenberg 2009, p. 46).

Figure 1 highlights the fact that, almost invariably, the CB method greatly underestimates the volume of Uusimaa's imports. CHARM generally performs much better, yet it does often still understate the volume of imports. This effect is especially noticeable for sectors 5, 8, 13, 20 and 22. However, both methods substantially overstate imports for sectors 17 and 25.

Table 7 reveals that both methods typically overstate the supply multipliers, although CHARM comes much closer to the target on average. CHARM is invariably the better method for manufacturing (sectors 5–15) but the pattern is less clear-cut for the non-manufacturing sectors. For instance, the CB method generates the closest estimates for Construction (17) and Health and Social Work (25). Nevertheless, the mean proportional error (MPE) confirms that CHARM is by far the more accurate method: an MPE of 4.0% versus 12.4% for the CB method.

To shed some light on the possible causes of these errors, we reworked our results using output rather than employment data. As expected, accuracy improved, yet most of the error remained. In particular, the MPE fell to 3.0% for CHARM and to 10.4% for the CB method. The improvement here is modest because labour productivity in Uusimaa is typically not very different from that in Finland. In other regions, especially those that are relatively small and located far from Helsinki, the divergence between national and regional labour productivities is apt to be more pronounced and the consequences more substantial.

The results obtained here for Uusimaa are certainly encouraging in terms of the effectiveness of CHARM as a regionalization method in situations where type A regional tables are most appropriate. Type A tables are those where imports are included in the regional and national transactions. However, one should always be cautious in generalizing from the findings of a case study of a single region. For this reason, we repeated our analysis for a further eleven Finnish regions, which varied in terms of their characteristics. We found that CHARM invariably outperformed the CB method in these regions as well, and by a wide margin. Even so, the estimates generated by CHARM for these other regions were substantially less accurate than those for Uusimaa. A possible explanation of this finding is that it is due to a greater divergence between regional and national labour productivities in these other regions. This hypothesis suggests that it might be fruitful to attempt to make some adjustment for differences in productivity when using CHARM to construct regional input–output tables. It is also worth pursuing the reasons why CHARM consistently overstated the size of the supply multipliers, both in Uusimaa and in the other regions we examined.

6 Case Study of Hubei[6]

The province of Hubei is located in central China. It produced around 4.0% of China's GDP in 2010 and employed about 2.8% of its urban labour force (National Bureau of Statistics of China 2011a). 44.3% of Hubei's population resided in urban areas in 2007, a figure that is almost identical to that for China (44.9%) (National Bureau of Statistics of China 2009). Hubei has a diversified economy. The main agricultural products include cotton, rice, wheat and tea, while important industries include automobiles, chemicals, construction, food and tobacco, iron and steel, machinery and equipment, power generation and textiles, along with high-technology products such as optical electronics and telecommunications. Hubei also has significant mineral and forestry resources.[7]

Hubei is traversed by two great rivers, the Yangtze and the Han, which meet in Wuhan, the provincial capital. The Three Gorges of the Yangtze, which lie to the west of the province, are an important tourist attraction. However, even though hydroelectricity is an important industry in Hubei, the electricity generated is mainly used to supply eastern provinces such as Shanghai, Zhejiang and Jiangsu. Therefore, many coal-fired electricity power stations and heat power plants have been built in several places in Hubei to meet the demand for electricity and heat. Hubei imports coal from Shanxi, Henan and Nei Menggu (Inner Mongolia) to supply these power stations and plants.

Wuhan, which is situated some 1,050 km south of Beijing, is one of China's largest cities (the 2010 census recorded a population of 6.4 million in its urban area and 9.8 million in its administrative area). Wuhan is a major transportation thoroughfare and the city is the economic hub of central China. It is a centre of higher education and research.

The published input–output tables for Hubei and China in 2007 have the same 42 sectors, which greatly simplifies the analysis. Even so, there are some noticeable differences in how far Hubei and China specialize in particular industries. This diversity is captured in the output-based SLQs displayed in Table 8. One can see, for example, that Hubei is highly specialized in sectors such as 1, 6 and 39, whereas sectors 2 and 3 are of negligible importance.

Table 8 shows that the values of h_i exhibit much diversity for both China and Hubei. These values were calculated by adapting Eq. (19) as follows:

$$h_i = q_i/(x_i + z_i + f_i + g_i), \qquad (20)$$

where q_i is cross-hauling and g_i is the residual error, which arises because output, x_i, is unequal to total domestic intermediate and final demand plus net exports, $z_i + f_i + (e_i - m_i)$. For Hubei in 2007, the official data show an overall residual error equal to 1.2% of total output.

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[6]This section closely follows Flegg et al. (2015, Sects. 2, 5 and 6).

[7]For more detail on Hubei's economy, see Hubei Bureau of Statistics (2011).

Eight regional sectors have $h_i = 0.0000$, indicating the absence of any cross-hauling (indeed, in most cases, any trade). These sectors include water production and supply, construction and real estate. In contrast, manufacturing sectors 16, 17, 19 and 20 have values of h_i well above average; this suggests that the commodities produced in these sectors are very heterogeneous and that there is much cross-hauling. Below-average values of h_i are found especially in the service sectors. Although the mean values of h_i for China and Hubei are very similar, there are many sectors where there are large disparities between h_i^n and h_i^r. Sectors 1, 6, 19 and 20 are cases in point.

6.1 Estimating Hubei's Imports and Exports

Table 9 highlights the differences between CHARM and the CB method. A key point is that, with the latter, a positive trade balance, $b_i > 0$, yields a corresponding volume of exports but no imports. Conversely, a negative trade balance, $b_i < 0$, generates an equivalent amount of imports but no exports. Cross-hauling is precluded by the CB procedure, whereas CHARM takes this common characteristic of regional trade explicitly into account, which is why it yields a greater volume of both exports and imports. This outcome, which is in accordance with the Finnish findings discussed earlier, can be verified from Table 9, where the column sums show that aggregate exports and imports are, respectively, 32 and 50% higher with CHARM. It is also worth noting that the CB method suggests that 25 of the 42 sectors did not import any of their inputs, whereas CHARM finds only five such cases. As regards exports, the CB method classifies 17 sectors as non-exporters, whereas CHARM identifies only one such case. By comparison, the official data record eight non-exporting and seven non-importing sectors.

Nevertheless, what is most intriguing about the results in Table 9 is that aggregate imports and exports from CHARM are well above the official figures (61% higher for exports and 23% higher for imports). In order to explain these discrepancies, it is helpful to decompose the overall error into three components:

- a *scaling* error due to the use of scaled national data to estimate regional final demand, f_i, and the residual error, g_i;
- a *technology* error introduced via the use of national data to estimate regional intermediate transactions, z_i;
- a *heterogeneity* error brought about by using national data to measure the degree of heterogeneity of products, h_i.

From the column sums in Table 10, we can separate out the contribution of each type of error to the overall error. For imports, this process gives:

- scaling error = 347,775 – 438,138 = −90,363
- technology error = 438,138 – 206,145 = 231,993

Table 8 Sectoral shares of output and heterogeneity of products in 2007: province of Hubei and China

Sector	Description	Share of output		SLQ_i	Degree of heterogeneity (h_i)	
		Hubei	China		China	Hubei
1	Agriculture, forestry, animal husbandry and fishing	0.104	0.060	1.740	0.0134	0.1603
2	Coal mining and washing	0.001	0.012	0.096	0.0200	0.0008
3	Oil and gas mining	0.001	0.012	0.068	0.0141	0.0120
4	Metal mining and selecting	0.004	0.008	0.534	0.0101	0.5963
5	Mining and selecting of non-metalliferous ore and other minerals	0.008	0.005	1.789	0.0383	0.0682
6	Food manufacturing and tobacco processing	0.081	0.051	1.580	0.0380	0.1723
7	Textile industry	0.036	0.031	1.168	0.0381	0.0908
8	Manufacturing of textile clothing, shoes, hats, leather and down	0.024	0.022	1.102	0.0392	0.0136
9	Wood processing and furniture manufacturing	0.011	0.013	0.798	0.0273	0.0377
10	Paper, printing, stationery and sporting goods	0.018	0.018	0.973	0.0583	0.0177
11	Oil processing, coking and nuclear fuel processing	0.013	0.026	0.488	0.0359	0.0055
12	Chemical industry	0.057	0.076	0.755	0.1150	0.0948
13	Manufacturing of non-metallic minerals	0.033	0.028	1.170	0.0170	0.0594
14	Metal smelting and press processing	0.045	0.075	0.600	0.0712	0.1452
15	Fabricated metal products	0.024	0.022	1.098	0.0361	0.0382
16	Manufacturing of general and special equipment	0.035	0.048	0.730	0.1429	0.1411
17	Manufacturing of transportation equipment	0.043	0.040	1.063	0.0915	0.2078
18	Manufacturing of electrical machinery and equipment	0.013	0.033	0.391	0.1349	0.0870
19	Manufacturing of communication equipment, computers and other electronic equipment	0.019	0.050	0.369	0.4217	0.1571
20	Manufacturing of instruments, equipment for cultural industries and office machinery	0.004	0.006	0.692	0.6195	0.2349
21	Arts, crafts and other manufacturing	0.005	0.008	0.650	0.0393	0.0126
22	Waste and scrap	0.001	0.005	0.237	0.0063	0.0282
23	Electric power, heat power production and supply	0.030	0.038	0.779	0.0006	0.1537
24	Gas production and supply	0.004	0.001	3.237	0.0000	0.0023
25	Water production and supply	0.003	0.001	2.322	0.0000	0.0000
26	Construction	0.089	0.077	1.157	0.0035	0.0000
27	Transport and storage	0.045	0.039	1.174	0.0352	0.0645
28	Post	0.001	0.001	1.380	0.0560	0.0227

(continued)

Table 8 (continued)

Sector	Description	Share of output		SLQ$_i$	Degree of heterogeneity (h_i)	
		Hubei	China		China	Hubei
29	Information transmission, computer services and software	0.013	0.012	1.071	0.0399	0.0480
30	Wholesale and retail trade	0.046	0.035	1.314	0.0000	0.0548
31	Hotels and catering services	0.025	0.018	1.359	0.0356	0.0128
32	Financial intermediation	0.023	0.024	0.981	0.0044	0.0236
33	Real estate	0.025	0.018	1.366	0.0000	0.0000
34	Leasing and business services	0.011	0.014	0.754	0.2118	0.0245
35	Research and development	0.002	0.002	1.118	0.0155	0.0230
36	Comprehensive technology services	0.004	0.005	0.783	0.0000	0.0000
37	Management of water conservancy, environment and public facilities	0.003	0.003	1.288	0.0000	0.0000
38	Services to households and other services	0.013	0.011	1.234	0.0232	0.0000
39	Education	0.031	0.016	1.912	0.0020	0.0118
40	Health, social security and social welfare	0.017	0.014	1.249	0.0018	0.0000
41	Culture, sports and entertainment	0.006	0.004	1.360	0.0860	0.0025
42	Public management and social organization	0.030	0.019	1.553	0.0027	0.0000
	Sum or mean	1.000	1.000		0.0606	0.0696

Source Flegg et al. (2015, Table 1), who used data from the official input–output tables for China and Hubei in 2007 (National Bureau of Statistics of China 2011b)

- heterogeneity error = 206,145 – 282,474 = −76,329
- overall error = 347,775 – 282,474 = 65,301

The corresponding figures for exports are:

- scaling error = 478,459 – 305,340 = 173,119
- technology error = 305,340 – 220,461 = 84,879
- heterogeneity error = 220,461 – 296,790 = −76,329
- overall error = 478,459 – 296,790 = 181,669

The first point to note is that the heterogeneity error is identical for exports and imports; this error depends solely on the extent to which h_i^r and h_i^n diverge. It is evident that the key reason for CHARM's better overall performance in terms of imports is that the scaling error partly offsets the technology error, whereas these two types of error reinforce each other for exports. It is also worth noting that, for imports, technology errors are more serious than scaling errors, whereas the converse is true for exports.

Let us now examine some specific results for imports. In many cases, CHARM's estimates of imported manufactured goods far exceed the official figures, although the massive shortfall in sector 6 is a striking exception to this pattern. There is also a

Table 9 Estimation of Hubei trade (millions of yuan) in 2007

Sector	CHARM				CB method				Official statistics				
	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Output
1	55,938	2,731	53,207	58,669	53,207	0	53,207	53,207	38,654	36,797	1,857	75,451	230,478
2	220	17,205	−16,985	17,424	0	16,985	−16,985	16,985	8	16,287	−16,279	16,295	2,520
3	198	24,776	−24,578	24,973	0	24,578	−24,578	24,578	111	15,134	−15,023	15,245	1,745
4	131	8,193	−8,062	8,324	0	8,062	−8,062	8,062	7,164	13,395	−6,230	20,559	8,901
5	7,634	580	7,054	8,214	7,054	0	7,054	7,054	1,790	1,255	535	3,045	18,667
6	46,355	6,029	40,326	52,383	40,326	0	40,326	40,326	40,245	29,921	10,325	70,166	178,833
7	28,551	2,539	26,012	31,090	26,012	0	26,012	26,012	21,545	6,555	14,990	28,099	79,711
8	19,090	1,774	17,315	20,864	17,315	0	17,315	17,315	8,460	683	7,777	9,143	53,953
9	736	647	89	1,383	89	0	89	89	913	1,892	−978	2,805	23,761
10	2,513	2,288	225	4,801	225	0	225	225	743	8,806	−8,063	9,549	39,367
11	1,483	28,522	−27,039	30,005	0	27,039	−27,039	27,039	204	19,140	−18,935	19,344	27,835
12	16,554	50,965	−34,411	67,518	0	34,411	−34,411	34,411	12,557	24,118	−11,561	36,675	126,726
13	9,820	1,152	8,669	10,972	8,669	0	8,669	8,669	11,501	4,069	7,432	15,569	72,267
14	7,924	32,013	−24,089	39,937	0	24,089	−24,089	24,089	17,098	14,198	2,900	31,296	99,239
15	19,165	1,581	17,584	20,746	17,584	0	17,584	17,584	12,873	1,799	11,074	14,672	52,654
16	12,646	33,332	−20,685	45,978	0	20,685	−20,685	20,685	11,236	14,201	−2,966	25,437	78,141
17	11,811	8,536	3,275	20,347	3,275	0	3,275	3,275	20,013	22,647	−2,635	42,660	94,972
18	5,568	30,714	−25,145	36,282	0	25,145	−25,145	25,145	2,581	4,510	−1,929	7,090	28,697
19	20,695	36,438	−15,743	57,133	0	15,743	−15,743	15,743	6,780	10,695	−3,915	17,475	41,205
20	7,154	11,963	−4,809	19,117	0	4,809	−4,809	4,809	2,508	5,571	−3,063	8,078	9,143
21	470	2,606	−2,136	3,077	0	2,136	−2,136	2,136	604	134	470	738	10,883
22	43	8,162	−8,118	8,205	0	8,118	−8,118	8,118	404	356	48	760	2,799

(continued)

Table 9 (continued)

Sector	CHARM				CB method				Official statistics				
	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Exports	Imports	Trade balance	Trade volume	Output
23	40	7,046	−7,006	7,086	0	7,006	−7,006	7,006	27,526	8,777	18,749	36,303	66,487
24	6,598	0	6,598	6,598	6,598	0	6,598	6,598	2,742	20	2,722	2,761	9,719
25	4,057	0	4,057	4,057	4,057	0	4,057	4,057	0	0	0	0	7,416
26	26,521	649	25,872	27,170	25,872	0	25,872	25,872	0	0	0	0	196,670
27	22,415	3,207	19,209	25,622	19,209	0	19,209	19,209	20,636	6,027	14,610	26,663	100,810
28	542	142	400	684	400	0	400	400	66	418	−352	484	2,733
29	2,428	1,135	1,294	3,563	1,294	0	1,294	1,294	1,410	1,995	−585	3,405	29,105
30	35,899	0	35,899	35,899	35,899	0	35,899	35,899	15,961	5,336	10,625	21,297	102,634
31	13,693	1,727	11,966	15,420	11,966	0	11,966	11,966	4,446	676	3,770	5,122	54,532
32	234	2,314	−2,081	2,548	0	2,081	−2,081	2,081	1,386	1,220	166	2,606	51,771
33	13,498	0	13,498	13,498	13,498	0	13,498	13,498	0	0	0	0	54,679
34	5,915	13,615	−7,700	19,530	0	7,700	−7,700	7,700	1,477	580	897	2,057	24,080
35	70	759	−689	829	0	689	−689	689	114	1,646	−1,532	1,759	4,176
36	0	2,481	−2,481	2,481	0	2,481	−2,481	2,481	0	2,702	−2,702	2,702	9,329
37	1,229	0	1,229	1,229	1,229	0	1,229	1,229	0	0	0	0	7,528
38	4,663	633	4,030	5,296	4,030	0	4,030	4,030	0	0	0	0	29,263
39	31,031	103	30,928	31,134	30,928	0	30,928	30,928	3,003	788	2,215	3,791	67,693
40	7,624	61	7,562	7,685	7,562	0	7,562	7,562	0	0	0	0	37,645
41	3,563	1,013	2,550	4,575	2,550	0	2,550	2,550	32	129	−97	162	13,048
42	23,741	145	23,596	23,886	23,596	0	23,596	23,596	0	0	0	0	66,554
Sum	478,459	347,775	130,685	826,234	362,444	231,759	130,685	594,203	296,790	282,474	14,316	579,264	2,218,368

Source Flegg et al. (2015, Table 2)

Table 10 Impact on the estimates from CHARM of using official Hubei data (millions of yuan) in 2007

Sector	Imports							Exports						
	Original CHARM estimates	Using official f_i and g_i	Using official f_i, g_i and z_i	Scaling error	Technology error	Heterogeneity error	Official data for imports	Original CHARM estimates	Using official f_i and g_i	Using official f_i, g_i and z_i	Scaling error	Technology error	Heterogeneity error	Official data for exports
1	2,731	2,943	3,074	−212	−132	−33,723	36,797	55,938	24,492	4,931	31,446	19,561	−33,723	38,654
2	17,205	17,748	16,492	−543	1,257	205	16,287	220	225	213	−5	12	205	8
3	24,776	24,887	15,153	−111	9,734	19	15,134	198	198	130	0	68	19	111
4	8,193	8,001	6,352	192	1,649	−7,043	13,395	131	130	121	1	8	−7,043	7,164
5	580	596	705	−16	−109	−550	1,255	7,634	6,828	1,240	806	5,588	−550	1,790
6	6,029	23,802	6,599	−17,773	17,204	−23,322	29,921	46,355	7,112	16,923	39,243	−9,812	−23,322	40,245
7	2,539	2,875	2,749	−336	126	−3,806	6,555	28,551	11,244	17,739	17,307	−6,495	−3,806	21,545
8	1,774	2,004	1,961	−230	43	1,278	683	19,090	7,606	9,738	11,484	−2,133	1,278	8,460
9	647	7,372	1,640	−6,725	5,733	−252	1,892	736	739	661	−3	77	−252	913
10	2,288	6,956	10,593	−4,668	3,637	1,787	8,806	2,513	2,427	2,530	86	−103	1,787	743
11	28,522	30,200	20,273	−1,678	9,928	1,133	19,140	1,483	1,512	1,337	−29	175	1,133	204
12	50,965	62,815	26,801	−11,850	36,015	2,683	24,118	16,554	17,198	15,240	−644	1,958	2,683	12,557
13	1,152	1,199	1,162	−47	37	−2,906	4,069	9,820	4,284	8,595	5,536	−4,311	−2,906	11,501
14	32,013	33,986	6,963	−1,973	27,023	−7,235	14,198	7,924	7,992	9,863	−68	−1,872	−7,235	17,098
15	1,581	1,626	1,699	−45	−72	−100	1,799	19,165	16,708	12,772	2,457	3,936	−100	12,873
16	33,332	38,569	14,346	−5,237	24,224	144	14,201	12,646	12,996	11,380	−350	1,616	144	11,236
17	8,536	39,327	11,441	−30,791	27,887	−11,207	22,647	11,811	10,025	8,806	1,786	1,219	−11,207	20,013
18	30,714	22,927	5,931	7,787	16,996	1,422	4,510	5,568	5,076	4,002	492	1,074	1,422	2,581
19	36,438	46,134	22,117	−9,696	24,017	11,421	10,695	20,695	22,383	18,201	−1,688	4,182	11,421	6,780
20	11,963	13,434	9,676	−1,471	3,758	4,105	5,571	7,154	7,502	6,613	−348	889	4,105	2,508
21	2,606	372	419	2,234	−47	285	134	470	3,232	889	−2,762	2,343	285	604
22	8,162	7,561	17	601	7,543	−338	356	43	41	66	2	−24	−338	404
23	7,046	9,912	33	−2,866	9,879	−8,744	8,777	40	41	18,781	−1	−18,740	−8,744	27,526

(continued)

Table 10 (continued)

Sector	Imports							Exports						
	Original CHARM estimates	Using official f_i and g_i	Using official f_i, g_i and z_i	Scaling error	Technology error	Heterogeneity error	Official data for imports	Original CHARM estimates	Using official f_i and g_i	Using official f_i, g_i and z_i	Scaling error	Technology error	Heterogeneity error	Official data for exports
24	0	0	0	0	0	−20	20	6,598	4,469	2,722	2,129	1,747	−20	2,742
25	0	0	0	0	0	0	0	4,057	2,758	0	1,299	2,758	0	0
26	649	662	695	−13	−32	695	0	26,521	18,981	695	7,540	18,286	695	0
27	3,207	3,380	3,287	−173	92	−2,739	6,027	22,415	12,744	17,897	9,671	−5,153	−2,739	20,636
28	142	141	515	1	−374	97	418	542	566	163	−24	404	97	66
29	1,135	6,448	1,757	−5,313	4,690	−238	1,995	2,428	1,264	1,172	1,164	92	−238	1,410
30	0	0	0	0	0	−5,336	5,336	35,899	22,039	10,625	13,860	11,414	−5,336	15,961
31	1,727	5,543	1,873	−3,816	3,670	1,197	676	13,693	2,003	5,643	11,690	−3,640	1,197	4,446
32	2,314	4,475	229	−2,161	4,246	−991	1,220	234	238	395	−4	−157	−991	1,386
33	0	0	0	0	0	0	0	13,498	27,834	0	−14,336	27,834	0	0
34	13,615	10,265	5,005	3,350	5,261	4,425	580	5,915	5,594	5,902	321	−308	4,425	1,477
35	759	59	1,609	700	−1,550	−37	1,646	70	795	77	−725	719	−37	114
36	2,481	0	2,702	2,481	−2,702	0	2,702	0	187	0	−187	187	0	0
37	0	0	0	0	0	0	0	1,229	741	0	488	741	0	0
38	633	565	680	68	−115	680	0	4,663	10,443	680	−5,780	9,763	680	0
39	103	126	132	−23	−6	−656	788	31,031	8,274	2,346	22,757	5,928	−656	3,003
40	61	58	68	3	−10	68	0	7,624	11,490	68	−3,866	11,422	68	0
41	1,013	993	1,223	20	−230	1,094	129	3,563	4,004	1,126	−441	2,877	1,094	32
42	145	176	177	−31	−1	177	0	23,741	925	177	22,816	749	177	0
Sum	347,775	438,138	206,145	−90,363	231,993	−76,329	282,474	478,459	305,340	220,461	173,119	84,879	−76,329	296,790

Source Flegg et al. (2015, Table 3)

very large shortfall in sector 17. Outside of manufacturing, we should note that CHARM yields absurdly low imports for sector 1, while the only anomalous services sector is 34, where CHARM greatly overstates regional imports.

Table 10 shows the impact of using the official regional figures for f_i and g_i in place of estimates derived via a simple scaling of the national data. The net effect is to raise estimated imports by 26%, from 347,775 to 438,138 million yuan. However, over half of this rise can be traced to sectors 6 and 17. The initial shortfall in imports is largely due to an understatement of final consumption in sector 6 and of gross fixed capital formation in both sectors. The use of official data has a substantial impact in sector 34, cutting its estimated imports by about 25%. Other sectors with pronounced scaling errors include 9, 10, 29 and 31. As anticipated, scaling errors are negligible for the primary sectors 1–5.

Regarding technology errors, Table 10 reveals that the use of official regional intermediate transactions data causes a marked fall in the estimated imports for most manufacturing sectors. Indeed, the upshot of switching from national to regional technology is that aggregate estimated imports fall by 53%, from 438,138 to 206,145 million yuan. This outcome reflects the fact that most sectors in Hubei are more efficient than those in China as a whole, in the sense that they have a lower ratio of intermediate inputs to output. This greater efficiency means that the typical Hubei industry has a lower propensity to import.

A unique feature of CHARM is its ability to show how the heterogeneity of commodities can affect regional trade. To illustrate this point, consider the anomalous sector 1. Table 10 shows that CHARM's estimate of imports, 2,731 million yuan, is way below the official figure of 36,797 million yuan; furthermore, this discrepancy is almost entirely due to the enormous heterogeneity error. That, in turn, is a consequence of CHARM's presumption of identical regional and national heterogeneities, which is way off the mark since $h_i^n = 0.0134$ but $h_i^r = 0.1603$ (see Table 8).

Sector 6 is another instance where Table 10 records a massive heterogeneity error. However, when a more realistic figure for h_i is used, namely $h_i^r = 0.1723$ rather than $h_i^n = 0.0380$, estimated imports rise sharply from 6,599 to 29,921 million yuan, the official value. This sector is unusual as Table 10 also reveals huge scaling and technology errors, yet these errors largely offset each other, so the heterogeneity error essentially determines the overall result. A similar outcome occurs in sector 1 but for a different reason: here the scaling and technology errors are negligible and hence hardly affect the overall error.

By contrast, for sector 19, CHARM's estimate of imports is 25,743 million yuan above the official figure. This huge gap is due to a scaling error of −9,696, a technology error of 24,017 and a heterogeneity error of 11,421. Unlike the previous two examples, however, the heterogeneity error is positive, which reflects the fact that $h_i^n = 0.4217$, while $h_i^r = 0.1571$.

Let us now consider CHARM's estimates of exports. Here, it is helpful to split the data into two broad groups: sectors 1–22 and 23–42. This dichotomy reflects the fact that, for the first group, CHARM yields smaller overall errors for exports than for imports for 17 of the 22 sectors. For instance, for sector 6, the overall error is 6,110 for exports but −23,892 for imports. By contrast, for the second group, the results are worse for exports in 16 cases out of 20. Table 10 shows that this second group spans sectors such as energy, construction, transport and storage, wholesale and retail, hotels, education and public management, whereas the first group is focused on agriculture and manufacturing.

It is striking that CHARM misses the large volume of exports officially recorded for sector 23. As noted earlier, Hubei exports much of its electricity to other provinces and CHARM signally fails to capture this aspect. Table 10 shows very big technology and heterogeneity errors for this sector. By contrast, CHARM greatly overstates the exports of sector 30, owing to large errors of all three types. Furthermore, the official statistics show zero or negligible exports for sectors 26, 33, 39 and 42, yet CHARM indicates substantial exports in each case. These are all regionally based sectors for which one would not expect significant exports. Table 10 records big scaling as well as technology errors for sectors 26, 33 and 39, whereas the problem for sector 42 is almost wholly a scaling issue.

From the above discussion, it is obvious that CHARM's estimates of exports and imports for individual sectors should be treated with the utmost caution. Its estimates of the exports of the energy, construction and services sectors are especially unreliable. The primary cause of the poor simulations is the difficulty of getting reliable regional data for final demand, intermediate transactions and the degree of heterogeneity of products.

6.2 *Estimating Supply Multipliers for Hubei*

A multiplier is an invaluable tool for evaluating the impact of fluctuations in the demand for the products of particular regional sectors. Indeed, regional analysts may be more interested in obtaining satisfactory estimates of sectoral multipliers than in estimating regional exports and imports. In this study, *supply* rather than *output* multipliers have been computed (Kronenberg 2012). Supply multipliers measure the impact of changes in final demand on the total supply of commodities rather than on regional output. They are, therefore, useful in environmental assessments, where the focus is on the total supply of a pollutant rather than on where it was produced. A good example is the coal imported by Hubei to supply its coal-fired power stations and power plants.

The supply multipliers were computed as follows. First, the supply of each industry j was calculated by summing the regional output of j, x_j, and the imports of this product, m_j. Secondly, a set of supply-based regional input coefficients was defined as:

$$r_{ij}^{s} = z_{ij}/(x_j + m_j), \tag{21}$$

where z_{ij} is the total value of intermediate inputs purchased by industry j from sector i, inclusive of goods sourced from within Hubei, from other provinces or from abroad. The coefficient matrix corresponding to Eq. (21) can be written as $\mathbf{R}^{\mathbf{s}} = [r_{ij}^{s}]$. Thirdly, the Leontief inverse of $\mathbf{R}^{\mathbf{s}}$ was derived. This can be expressed as $\mathbf{L}^{\mathbf{s}} = [b_{ij}^{s}]$. Lastly, each column of $\mathbf{L}^{\mathbf{s}}$ was summed to obtain the sectoral supply multiplier, k_j:

$$k_j = \sum_i b_{ij}^{s}. \tag{22}$$

The results from each method and the official data are displayed in Table 11.

The official data yield a mean supply multiplier of 1.919. This figure suggests that a rise in the final demand for Hubei's industries of 1 million yuan would raise the total supply of commodities (including products imported from other provinces or from abroad) by 1.919 million yuan on average. CHARM indicates a somewhat higher average rise of 2.078 million, whereas the CB method signals a rise of 2.218 million.

The fact that the CB method invariably produces bigger supply multipliers than CHARM can easily be explained in terms of Eq. (21): the two methods use identical values for z_{ij} and x_j but different values for m_j. CHARM produces higher imports because it encompasses heterogeneity and thus cross-hauling. Hence, the input coefficients and thus supply multipliers from CHARM are lower than those from the CB method.[8]

The disparity between the estimated multipliers from CHARM and the CB method varies across sectors. Deviations are small for sectors like 15 that produce relatively homogeneous products, where cross-hauling is minimal. Big differences occur in sectors like 19 and 20, which have very high values of h_i and hence exhibit much cross-hauling. The mining sectors 2 and 3 are atypical as both methods give multipliers close to the minimum of $k_j = 1$; this arises because each sector produces a mere 0.1% of Hubei's total output, so intermediate transactions are negligible, and a very high proportion of supply comes from elsewhere.[9]

Table 11 reveals that the mean multiplier based on official Hubei data is somewhat lower than CHARM's estimate. This finding can once again be explained in terms of scaling, technology and heterogeneity errors; on average, these errors cause the multipliers from CHARM to be overstated by 0.066, 0.072 and 0.022, respectively.

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[8]CHARM and the CB method would produce identical *output* multipliers because the term z_{ij} in Eq. (21) would be the same, while m_j would not be present.

[9]According to the official data, the ratio $\sum_i z_{ij}/(x_j + m_j)$ equalled 0.078 and 0.054, respectively, for sectors 2 and 3. CHARM gave figures of 0.069 and 0.026. Hence, it is unsurprising that the multipliers for these sectors are very low.

Table 11 Alternative estimates of supply multipliers in 2007: province of Hubei

Sector	CB method	CHARM	Scaling error	Technology error	Heterogeneity error	Official data
1	1.920	1.862	0.040	0.048	0.126	1.648
2	1.145	1.135	0.008	−0.011	0.002	1.137
3	1.059	1.055	0.002	−0.056	0.002	1.107
4	1.728	1.684	0.013	−0.215	0.302	1.583
5	2.366	2.243	0.045	−0.049	0.058	2.190
6	2.653	2.529	0.194	−0.037	0.233	2.138
7	3.117	2.928	0.062	0.204	0.135	2.527
8	3.175	2.976	0.064	0.285	0.018	2.609
9	2.912	2.756	0.520	−0.076	0.039	2.272
10	2.866	2.632	0.267	0.132	−0.040	2.274
11	1.548	1.521	0.022	−0.280	−0.009	1.788
12	2.394	2.172	0.122	−0.087	−0.013	2.150
13	2.643	2.532	0.050	0.122	0.080	2.280
14	2.347	2.200	0.044	−0.136	0.152	2.140
15	2.904	2.732	0.054	0.350	0.053	2.275
16	2.417	2.152	0.083	−0.034	0.030	2.073
17	3.142	2.771	0.555	−0.023	0.146	2.092
18	2.018	1.844	−0.110	−0.136	−0.023	2.113
19	2.434	1.868	0.139	0.007	−0.187	1.909
20	2.221	1.689	0.072	−0.027	−0.189	1.834
21	2.533	2.390	−0.223	0.039	−0.023	2.597
22	1.072	1.070	−0.003	−0.256	0.035	1.294
23	2.329	2.275	0.082	0.276	0.102	1.815
24	2.129	2.097	0.024	0.495	0.003	1.575
25	2.214	2.156	0.045	−0.115	0.005	2.221
26	2.834	2.723	0.045	0.028	0.043	2.607
27	2.106	2.010	0.060	−0.040	0.046	1.943
28	2.186	2.047	0.072	0.102	−0.015	1.888
29	1.871	1.751	0.133	0.092	−0.002	1.528
30	1.876	1.816	0.032	0.286	0.026	1.471
31	2.461	2.351	0.154	0.010	0.041	2.145
32	1.622	1.579	0.045	−0.127	0.005	1.656
33	1.367	1.341	0.010	−0.265	−0.006	1.602
34	2.207	1.926	−0.039	−0.039	−0.187	2.191
35	2.120	2.002	−0.126	0.532	0.009	1.588
36	1.802	1.725	−0.168	0.370	0.002	1.521
37	2.098	2.020	0.047	0.414	0.003	1.556
38	2.270	2.138	0.066	0.179	−0.021	1.914
39	2.016	1.942	0.052	0.302	0.000	1.588

(continued)

Table 11 (continued)

Sector	CB method	CHARM	Scaling error	Technology error	Heterogeneity error	Official data
40	2.561	2.434	0.071	0.169	0.000	2.194
41	2.388	2.200	0.066	0.297	−0.064	1.900
42	2.071	1.999	0.064	0.279	−0.005	1.661
Mean	2.218	2.078	0.066	0.072	0.022	1.919

Source Flegg et al. (2015, Table 4)

The multipliers from CHARM and those based on the official Hubei statistics use identical values for x_j but different values, in general, for both z_{ij} and m_j in Eq. (21). The scaling error operates via the term m_j. This error is positive for all but six Hubei sectors, so it tends to lower m_j for the typical sector and thereby boost k_j. The technology error operates in a more complex way, as it affects both z_{ij} and m_j. As regards z_{ij}, it is helpful to examine the ratio $\sum_i z_{ij}/x_j$, which represents the degree of intermediation. With CHARM, the z_{ij} were calculated using the national technical coefficients and hence reflect the national technology, whereas the official tables for Hubei reflect technology specific to this province. In fact, for 34 of the 42 sectors, CHARM gives higher values for $\sum_i z_{ij}/x_j$. On average, this ratio is 0.619 for CHARM but 0.553 for the official data. This disparity is a key reason why the multipliers from CHARM exceed those based on the official data.

Finally, we should explore the effects of employing regional rather than national data to capture the heterogeneity of commodities. Using h_i^r rather than h_i^n when estimating cross-hauling marginally boosts imports and hence supply for the average sector; this, in turn, slightly lowers the mean multiplier from 1.941 to 1.919, the expected value when all three sources of error are removed. Since 19 sectors have $h_i^n > h_i^r$, 19 have $h_i^n < h_i^r$, and four have $h_i^n = h_i^r = 0$ (see Table 8), heterogeneity has little overall impact. Hence, the means are very close, 0.0696 for h_i^r and 0.0606 for h_i^n, while the mean heterogeneity error is only 0.022. However, this unremarkable overall outcome masks some fairly big differences in particular sectors, which reflect divergent values of h_i^n and h_i^r. For instance, for sector 20, $h_i^n = 0.6195$ gives $k_j = 1.645$, whereas $h_i^r = 0.2349$ yields $k_j = 1.834$. When absolute values are taken, the mean heterogeneity error rises from 0.022 to 0.059, although this is still well below the mean absolute technology error of 0.167.

Flegg et al. (2015, pp. 408–410) explore several ways in which more accurate results from CHARM might be gained. These strategies include (i) adjusting for intersectoral differences in the share of value added in gross output, (ii) using a more refined way of scaling national final demand, and (iii) adjusting for any known differences between the regional and national sectoral product mixes. They also recommend pursuing a hybrid approach, whereby "judicious use [is] made of superior data gleaned from official sources and from partial surveys of key regional sectors and important cells in the regional input–output table" (ibid., p. 411).

Furthermore, Többen and Kronenberg (2015) demonstrate that the original CHARM formula, as discussed in this chapter, requires modification if it is to (i) capture cross-hauling in interregional trade and (ii) yield estimates that are consistent with accounting balances. They then specify an appropriately modified formula.

7 Conclusion

This chapter has examined the performance of two pure non-survey methods for constructing regional input–output tables: Flegg's location quotient (FLQ) and Kronenberg's Cross-Hauling Adjusted Regionalization Method (CHARM). With these methods, a very limited amount of regional data (such as sectoral employment or output) is used to regionalize the national input–output table. This initial process is entirely mechanical but analysts can subsequently incorporate superior data in an effort to enhance accuracy. The principal aim of both methods is to enable analysts to construct regional tables that reflect a region's economic structure.

CHARM is suitable for environmental and other applications where the concern is with the overall supply of goods and services, regardless of their source. CHARM can only be used in conjunction with type A national tables, those where intermediate transactions include imports. In contrast, where the emphasis is on regional output and employment, the FLQ may be used to generate an initial set of regional input coefficients. It requires national transactions matrices that exclude imports (type B tables). It should also be noted that this chapter has focused on individual regions, so the analysis would need to be adapted to deal with multiple regions.[10]

The performance of the FLQ and related formulae was evaluated using official data for 20 Finnish and 16 South Korean regions. In both cases, the FLQ gave far more accurate results than did simpler LQ-based formulae. For instance, the SLQ overstated the type I sectoral output multipliers by an average of 14.7% in Finland and 21.2% in South Korea, whereas the FLQ produced estimates with negligible bias. Moreover, for the FLQ, the mean absolute percentage error (MAPE) was around 8%, on average, in both countries, compared with 15.7% for the SLQ in Finland and 22.2% in South Korea.

Analysts face a dilemma when choosing a value for the unknown parameter δ in the FLQ formula: if too low a value is chosen, the regional input coefficients and hence multipliers will be overestimated and vice versa. Unfortunately, δ appears to vary across both regions and countries. For instance, $\delta \approx 0.25$ was identified as the best single value for Finnish regions, whereas $\delta \approx 0.375$ was found to be more appropriate for South Korea. This phenomenon was explained by the fact that the South Korean regions typically imported a noticeably higher proportion of their

[10]See Többen and Kronenberg (2015), Hermannsson (2016) and Jahn (2017).

inputs from other domestic regions than was true for the Finnish regions. Consequently, to adjust for this disparity in import propensities, a bigger δ was required in South Korea than in Finland. To assist in selecting a value of δ, we estimated a regression model that could be used by analysts to perform a sensitivity analysis.

We also evaluated a proposed new variant of the FLQ, namely Kowalewski's SFLQ, in which the strong assumption that δ is invariant across sectors is relaxed. We used data for the 16 South Korean regions to model the effects of three key determinants of the sector-specific values of δ. National data for these variables should readily be available in most cases. Using this model, we found that the SFLQ outperformed the FLQ in terms of MAPE and two other criteria. More specifically, MAPE was some 0.7% points lower for the SFLQ. However, two other criteria indicated that the SFLQ generated biased estimates of multipliers. Although the SFLQ is a promising new approach, a suitably refined regression model would need to be built before it could be recommended for general use. Even then, there would still be some doubt whether a model that performed well in one region would do likewise elsewhere.

We employed official data for the Finnish province of Uusimaa and the central Chinese province of Hubei to assess CHARM's performance. By adjusting the respective national tables, this method was used to simulate the input–output structure of each province.

The case study of Uusimaa produced encouraging results: CHARM performed relatively well in estimating exports, imports, the volume and balance of trade, and supply multipliers. For instance, on average across the 26 sectors, the unweighted mean supply multiplier from CHARM was 1.542, which is not far above the target figure of 1.482. The results were particularly encouraging for manufacturing sectors, which typically produce heterogeneous commodities and where cross-hauling is rife.

By contrast, CHARM gave very poor estimates of Hubei's sectoral exports and imports, although its estimates of supply multipliers were generally more realistic. Three sources of error in these estimates were identified via a decomposition analysis. These scaling, technology and heterogeneity errors refer to discrepancies introduced by (i) using scaled national data to estimate regional final demand; (ii) adopting national rather than regional technology; and (iii) using national rather than regional values for a parameter, h_i, which measures the heterogeneity of commodities.

The disappointing outcomes for Hubei can be explained by the difficulty of estimating regional technical coefficients, heterogeneity and final demand. This difficulty was linked to the relatively small size of Hubei, which generates around 4% of China's GDP. By contrast, Uusimaa produced 34.6% of Finland's national output in 2002. These contrasting findings highlight the crucial importance, especially in relatively small regions, of adjusting for any known divergence between regional and national technologies, heterogeneity and the pattern of final demand. As with any pure non-survey procedure, however, CHARM can only generate a preliminary set of results, which should then be reviewed by the analyst and appropriate refinements made.

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Impact of Key Infrastructure Sectors in Creating Formal and Informal Jobs in Two States: Indian Regional IO Analysis

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Abstract The states in India are investing in infrastructure, and a large share of investment is made in irrigation canal construction, building construction national highways/urban roads construction, rural roads construction and other construction. Given this, the major objective of this study is to develop a set of employment multipliers (direct, indirect, induced) for selected infrastructure sub-sectors in the two selected states of India, i.e. West Bengal and Gujarat. The methodology used was the input–output multiplier analysis. We have used the hybrid methods for developing the regional IO tables, combining a survey along with non-survey techniques, and we also used the NSSO (66th round, unit-level data) to get worker distribution by sectors and as formal and informal. Major findings show that employment multipliers in Gujarat are highest for rural roads construction (for formal, informal and total workers). The induced effects for both formal and informal employment are highest for buildings construction, reflecting that induced multiplicative effects are high for buildings in the Gujarat economy. In West Bengal, employment multipliers for irrigation canal construction (for formal, informal and total workers) are higher. But, induced effects for formal employment are highest in buildings and national highways/urban roads construction and for informal employment are highest in national highways/urban roads construction.

JEL Codes O18 (Urban, Rural, Regional, and Transportation Analysis; Infrastructure) · R11 (Regional Economic Activity: Growth, Development, and Changes) · J23 (Employment Determination; Job creation; Demand for Labour)

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1 Introduction

The infrastructure sector has vast potential to drive growth and developing countries, including India, are investing in this sector to achieve full growth potential (Federation of Indian Chamber of Commerce & Industry 2012). It is now widely recognized that high quality and efficient infrastructure services are necessary to provide the impetus for realizing the complete potential of the growth impulses in an economy. But in India, infrastructure development has slowed down as compared to the economy. As per the World Economic Forum's Global Competitive Report 2015–16, the India's overall infrastructure ranked 81st out of 141 economies. India is behind BRICS countries in overall infrastructure. The growth pattern of infrastructure investment indicates a downward trend over the years from its peak of nearly 42% in 2008 to only 3% in 2013. The recent growth figures are nearly 15% in 2014 and slightly more than 11% in 2015. However, to keep in perspective, the non-infrastructure sector growth has also been lower and was only 3.4%.

In more recent years, India has been advancing public investment in infrastructure and also been active in building up public–private partnerships in the infrastructure sector to meet growing demand. Total outlay for 2016–17 is to invest Rs. 2.21 trillion in creating and upgrading infrastructure. Within the infrastructure sector, transport services have the highest share of 71.4% followed by miscellaneous services at 12.7%, communication services at 4.8%, wholesale and retail trading at 4.6%, information technology at 4.3% and hotels and tourism at 2.1%. (ASSOCHAM study on "Analysis of Infrastructure Investment in India", May 2016).

On examining the situation of the two states of West Bengal and Gujarat, it has been observed that in West Bengal, total Infrastructure investment of Rs. 37,482 Crores has been made in the National Highways which includes (New Highways of 600 km—Rs. 6,000 Crores; ongoing 12,063 Crores; in the tender stage Rs. 3,728 Crores and new highways for 2015–16, 2016–17 Rs. 15,691 Crores) (Bengal Global Business Summit, 2016). In Gujarat, an investment of nearly Rs. 267 billion (USD4.5 billion) has been planned to develop road connectivity and to leverage the potential thrown up by the Dedicated Freight Corridor (DFC) by Delhi Mumbai Freight Corridor (DMIC). A total length of almost 3,300 km of road network has been planned to be developed by 2020.

Other sectors in Gujarat under new investments are captured through Gujarat's aim in the water sector "To ensure safe reliable and affordable drinking water for all, and provide stable water supply for agriculture through a pan Gujarat water grid and efficient irrigation systems". Total estimated investment of INR 1,364 billion (USD22.7 billion) is needed by 2020 to develop Gujarat's water projects. Development of Sardar Sarovar Project, along with small hydropower projects on PPP mode along the Narmada Branch Canal. Sujalam Sufalam Yojana intends to provide surplus water to arid areas across Gujarat via canals. Saurashtra Narmada Avtaran Irrigation Yojana (Sauni Yojana) aims to divert flood water of Narmada to Saurashtra region. Hydrology Project would use Hydrological Information System (HIS) in cost-effective allocation, planning, management and development of water resources. (Source: Roads and Buildings Department, Government of Gujarat; and BIG 2020).

Given this background, the major objective of this study is to develop a set of employment multipliers (direct, indirect, induced) for selected infrastructure sub-sectors in two selected states of India, i.e., West Bengal and Gujarat. These multipliers are developed by using input–output models that are derived after developing input–output tables of the two states. Naturally, this growth in infrastructure would have an impact on employment growth. In this paper, we attempt to examine the impact of investment in the infrastructural sector on both formal and informal employment in West Bengal and Gujarat.

It is now well known that in a developing country like India, informal economy provides a means of livelihood to many, who might otherwise be without any means of livelihood. Studies conducted since the late 1990s have indicated that contrary to classical trade theories, liberalization of trade have neither really helped in raising worker welfare, nor in the automatic upgradation of technology and the impact of such across the board opening up have instead led to informalization of work, increased wage differentials across formal and informal manufacturing and led to market segmentation rather than a greater degree of economic integration. Authors such as Stallings and Peres (2000), Sinha and Adam (2000, 2007), Unni (2001), Carr and Chan (2002), Harriss-White (2003), Jhabvala et al. (2003), Sinha et al. (2003a, b), Harriss-White and Sinha (2007a, b), have described the rapid expansion of this informal economy in direct contradiction to assumptions of neo-classical economic theories of international trade. Certain studies have explored the role of the informal economy that is positive in the process of development. However, though the informal sector has been viewed in terms of inherent dynamism, this sector is very closely related to poverty with very low working and living conditions for most people involved in it (Meagher and Yunusa 1996). Sinha (2014) further shows using unit-level data from NSSO Rounds 66th and 68th, that for working population (aged 15–65 years), social security is not available to nearly 89% of unorganized sector workforce, which has marginally improved since 2009–10.

2 Methodology

To examine the impact of changes in the infrastructural sectors on employment generation due to the policy drives as noted above, we use the input–output models. The use of input–output structure to describe informality (with a focus on gender) was discussed in an earlier paper by Duchin and Sinha (1999). To derive the models the regional tables are developed. The input–output (IO) sectors for Gujarat and West Bengal are constructed based on the latest All-India IO Table for the year 2007–08 and updated by the NCAER to 2009–10. The characteristics of workers are taken from the NSSO data on employment and unemployment (NSSO 66th Round, 2009-10) to set the base information by employment types (formal and informal).

The methods of constructing a regional input–output table can be roughly divided into two categories including survey-based method and non-survey-based method. One of the key problems of input–output tables is that the survey-based method is extremely time consuming and therefore expensive. There are lots of data gaps at the state level, which are however easily resolved at the national level. These techniques can be classified according to the degree of incorporation of direct regional information. Most of the researchers use hybrid methods, combining some survey information with non-survey techniques, in which specific regional indicators are applied to convert national values into regional ones. In fact, according to Jensen (1980), errors in survey tables can result from errors in the process of gathering the data (e.g., errors arising from incorrect definition of the sample, hiding of information or lack of concern in answering the questionnaires by the respondents or errors in compilation procedures). Besides, other problems may arise whenever the questions included in the questionnaires require very detailed information to which some respondents may not be able to answer. In this context, Jensen (1980) argues that the concept of holistic accuracy must be privileged, meaning that the assembly of direct information should be directed only towards the larger or most important elements of the economy being studied, thus ensuring a correct representation of the structure of the economy, in general terms (Hewings 1982). In other words, hybrid methods assure the best compromise between accuracy and required resources.

There are certain basic steps that are generally accepted for generating regional-/state-level IO tables. These are described below:

1. Identifying and adjusting a "parent" or "mother" table. Generally, this "mother" table would be a national table from time $(t - i)$ for the country in which the region of interest is located. This may be a transactions table or a coefficients table. This parent table needs to be updated to the period for which the regional/state table is to be made. One could use RAS or some alternative technique to update the table.
2. Using some allocation or quotient method to convert national to regional/state coefficients.
3. Inserting data from surveys, expert opinion, etc.
4. Defining the appropriate regional/state sectors, usually through (weighted) aggregation of the national sectors. Inserting additional superior data again, after the

Table 1 Data sources for developing regional-level input–output tables

Sectors IO components	Agriculture	Manufacturing	Services
Intermediate flow	Use of SDP accounts and national-level IO coefficients	Use of ASI, NSSO and SDP data for input and output flow	Use of national-level IO coefficients
Private final consumption expenditure (PFCE)	Consumption structure from NSSO 55th round	Consumption structure from NSSO 55th round	Consumption structure from NSSO latest
Government final consumption expenditure (GFCE)	Use of national-level coefficients applied on total GFCE (from budget documents)	Use of national-level coefficients applied on total GFCE (from budget documents)	Use of national-level coefficients applied on total GFCE (from budget documents)

(continued)

Table 1 (continued)

Sectors IO components	Agriculture	Manufacturing	Services
Gross fixed capital formation (GFCF)	Use of national-level IO coefficients	GFCF (organized) from ASI and GFCF (unorganized) using org/unorganized ratio in GVA	Use of national-level IO coefficients
Change in stocks (CIS)	Use of national-level IO coefficients	GFCF (organized) from ASI and GFCF (unorganized) using org/unorganized ratio in GVA	Use of national-level IO coefficients
Exports (external)	DGCI&S	DGCI&S	DGCI&S
Exports (interstate)	Use of DGCI&S exports data by rail and river. Interstate exports by road to be taken from DGCI&S	Use of DGCI&S exports data by rail and river. Interstate exports by road to be taken from DGCI&S	Use of DGCI&S exports data by rail and river. Interstate exports by road to be taken from DGCI&S
Imports	Residual	Residual	Residual
Indirect taxes*	Handbook of statistics of state government finance, national coefficients	Handbook of statistics of state government finance, national coefficients	Handbook of statistics of state government finance, national coefficients
Gross value added	SDP accounts	SDP accounts and database for disaggregated manufacturing sectors	SDP accounts
Value of output	National-level VA to output ratio	Database for disaggregated manufacturing sectors	National-level VA to output ratio
New sector's primary survey	–	–	Survey of new infrastructural sectors

Source *Sinha (ed.) (2009)

aggregation, in those cases where such information is known only at this more aggregated level. This might be done especially for "critical" sectors or focus sectors.

5. Using superior data and opinion once again—for example, by comparing multipliers derived from "similar" and dissimilar regions—and deriving the final regional/state IO tables.

Data sources are described in Table 1.

To distribute workers of projected population of Gujarat and West Bengal by sector, using sector-wise ratios from NSSO (66th round, unit-level data) were generated and applied to the projected workers of the census. We have distinguished between formal and informal market workers by using information from various unit-level data sets and field discussions for target sectors. The major secondary state-level unit data sets are from the NSSO and ASI, processed at the NCAER. As per NSSO 66th round (Employment and Unemployment), the workers who have reported as regular workers are considered here as formal workers.

2.1 Distribution of Construction Sector Workers

Tables 2, 3 and 4 show the distribution of workers by type in the infrastructure sectors in the two states of Gujarat and West Bengal, which are "key" to this study.

Table 2 shows that within sub-sectors of construction in Gujarat, the share of informal workers is highest in buildings construction (45.6%) followed by the other construction sector (33.6%), irrigation canal construction sector (8.3%), rural roads construction (6.84%) and finally, national highways construction (5.6%).

Table 3 shows that within sub-sectors of the construction sector in West Bengal, the share of informal workers is highest in other construction (48.9%) followed by

Table 2 Sector-wise employment in infrastructure sectors by worker type: Gujarat

Sector	Formal workers	Informal workers	Total workers
Irrigation canal construction	7,664	196,872	204,536
Building construction	42,150	1,082,796	1,124,946
National highways/urban roads construction	5,173	132,889	138,062
Rural roads construction	6,323	162,419	168,742
Other construction	15,327	799,132	814,459
Total	76,637	2,374,108	2,450,745

Source Authors calculations based on NSSO and NCAER data

Table 3 Sector-wise employment in infrastructure sectors by worker type: West Bengal

Sector	Formal workers	Informal workers	Total workers
Irrigation canal construction	14,784	130,674	145,458
Building construction	147,840	1,306,742	1,454,583
National highways/urban roads construction	17,297	152,889	170,186
Rural roads construction	21,141	186,864	208,005
Other construction	94,618	1,702,956	1,797,574
Total	295,680	3,480,125	3,775,806

Source Authors calculations based on NSSO and NCAER data

Table 4 Percentage of workers by types in infrastructural sectors

Name of Sector	Type of employment	Gujarat	West Bengal
Irrigation canal	Formal	6.76	10.44
	Informal	93.24	89.56
Highways/urban roads	Formal	5.16	11.23
	Informal	94.84	88.77
Rural roads	Formal	4.33	10.45
	Informal	95.67	89.55
Buildings	Formal	8.79	11.60
	Informal	91.21	88.40

Source Authors calculations based on NSSO and NCAER data

the buildings construction sector (37.5%), rural roads construction (5.4%), national highways construction (4.4%) and lastly irrigation canal construction (3.8%).

2.2 Input Structures of New Infrastructure Sectors

In each of these "new" infrastructure sectors, two kinds of activities are involved: new construction and repairs and maintenance of existing construction. The GVA of each sector is estimated using GVA-Output ratio of the aggregate construction sector, and the total intermediate input of each sector is derived as the difference of output and GVA.

Irrigation Canals: Since all canals are owned by the state government, all of their expenditures are met by the state government. The information on the output of this sector has been collected from the state government budgets analysis. Data on the expenditures on repairs and maintenance of canals are taken from the budget analysis of current revenue expenditures, and the new construction expenditure is available in the budgets as capital outlay of the Department of Irrigation on canals. These two figures make-up the output of the sector.

Roads: The expenditures on construction of new roads has been estimated indirectly from km length of new urban and rural roads constructed, available from the "Basic Road Statistics of India", published by the Transport Research Wing of the Ministry of Road Transport and Highways. Information on per km cost of constructing urban and rural roads was obtained from the interviews with government engineers, contractors and other subject experts.

Buildings: Adding the output of new building construction (the fixed capital formation) and repairs and maintenance of building construction, we have obtained the gross output of the buildings construction sector. For the buildings sector row, the entries include the capital formation in the GFCF column, the public building repairs and maintenance in the GFCE and the private buildings repair and maintenance which would appear in the row in various producing sectors columns as the expenditure. Such expenditures are made by the sectors on repairs and maintenance of buildings owned by them. These data have been obtained for the state from the total expenditure on repairs and maintenance of buildings in the state in the proportion of national-level IO table construction row entries.

Other Construction: The column (row) of the other construction sector has been derived as the residual of the aggregated construction sector in the 16 sector IO table of the state removing the components relating all the new four infrastructure construction sectors described above.

3 Findings of the Study

3.1 Multipliers Analysis

Depending on the specific need, an input–output table can be formulated that allows the analyst to estimate different types of multiplier such as the output, income or employment multipliers (Miller and Blair 2009). We would like to state here upfront, that the magnitude of the multipliers are not uniquely determined but are governed by the degree of model closure (i.e., which segment of the input–output model in introduced within the endogenous part of the matrix and which remains outside, such as parts of final demand components). The objectives of this work are to show how alternative multipliers may be derived.

Open Model Employment Multipliers: For this analysis, we examine the change in number of workers due to change in output by Rs. one hundred thousand as additional demand in output of infrastructural sector. The highest labour-intensive infrastructure construction sector in Gujarat is rural road construction with an employment multiplier (Type I) of 2.677 (see Table 5). This means that to increase output of rural roads construction in Gujarat by Rs. one hundred thousand, three additional workers per day over one year are required out of which, 94% are informal workers.[1] The next highest multiplier (among the construction sectors) is for irrigation canal construction, followed by other construction,[2] then by highways/urban roads and lastly by building construction. This shows that buildings construction in Gujarat is more capital intensive compared to the other sectors of interest. Also, it is due to informal workers that higher labour intensity has been generated in these sectors, respectively. Except for public administration, the multiplier for informal workers is higher than the multiplier for formal workers in both the states. Incidentally, public administration also has the highest formal employment multiplier in Gujarat. For informal employment, in Gujarat, the highest informal employment multiplier is due to wooden furniture and

[1]The simulation results given below show the exact break-ups of the workers by type and gender.

[2]As per Sector Specifications for Input–Output Transactions, 2003–04, CSO, Other Construction includes: construction and maintenance of aerodromes, railways, bridges, pipelines, ports, harbours, runways communication systems, waterways, water reservoirs, hydroelectric projects, industrial plants and activities allied to construction.

Table 5 State-wise open model employment multipliers[a]

Sector names	Gujarat			West Bengal		
	Formal[b] workers	Informal[c] workers	Total workers	Formal workers	Informal workers	Total workers
Agriculture and allied activities	0.039	2.291	2.331	0.065	2.262	2.327
Mining	0.038	0.158	0.197	0.227	0.755	0.982
Furniture and fixtures: wooden	0.063	2.689	2.752	0.080	1.806	1.886
Petroleum products	0.037	0.149	0.187	0.213	0.703	0.917
Bricks, tiles (structural clay products)	0.139	0.370	0.508	0.118	1.981	2.100
Cement	0.125	0.197	0.322	0.230	0.609	0.839
Non-metallic mineral products	0.096	0.361	0.457	0.132	1.077	1.209
Iron and steel (ferro alloys and casting and forging)	0.069	0.245	0.314	0.132	0.630	0.762
Iron and steel foundries	0.086	0.326	0.411	0.132	0.690	0.822
Electrical machinery and tools	0.148	0.400	0.548	0.124	0.815	0.939
Other manufacturing	0.093	0.673	0.766	0.110	1.258	1.369
Irrigation canal construction	**0.106**	**0.797**	**0.903**	**0.421**	**3.300**	**3.721**
Buildings construction	**0.078**	**0.486**	**0.564**	**0.129**	**0.908**	**1.037**
Highways/urban roads construction	**0.068**	**0.663**	**0.731**	**0.171**	**1.218**	**1.389**
Rural roads construction	**0.159**	**2.518**	**2.677**	**0.314**	**2.559**	**2.873**
Other construction	0.072	0.784	0.857	0.131	1.486	1.617
Electricity and water supply	0.077	0.217	0.294	0.136	0.413	0.550
Transport services	0.156	0.560	0.716	0.175	0.871	1.046
Other services	0.207	0.394	0.600	0.167	0.599	0.767
Public administration	0.550	0.033	0.583	0.365	0.010	0.375

Source Authors calculations based on NSSO and NCAER data
[a]Change in workers due to a change in output worth Rs. hundred thousand
[b]Formal worker: "regular" worker
[c]Informal worker: "casual" worker

fixtures (2.69) followed closely by rural roads (2.52) and agriculture (2.29). The lowest informal employment multipliers are in public administration (0.03) and petroleum products (0.15). Hence, we see in Table 5 that out of the relevant infrastructure sectors in Gujarat, rural roads construction creates the most of employment and most of that again is by informal employment though formal employment in this sector also comparatively has higher job-creating possibility.

In West Bengal, among the sector's key to the study, (excluding other construction), the highest total employment multiplier is in irrigation canal construction (3.72), followed by rural roads construction (2.87) and highways and urban roads (1.38). The employment multipliers in these sectors are again driven by informal employment. Of all the sectors, the lowest informal employment multiplier is in public administration as expected. It is interesting that in West Bengal, most of the informal employment is created in irrigation canal construction (which is mainly due to maintenance and repair) followed by rural roads. On the other hand, the

Table 6 State-wise closed model employment multipliers[a]

Sector names	Gujarat			West Bengal		
	Formal workers	Informal workers	Total workers	Formal workers	Informal workers	Total workers
Agriculture and allied activities	0.417	4.454	4.871	0.662	6.975	7.638
Mining	0.399	2.224	2.623	0.797	5.255	6.053
Furniture and fixtures: wooden	0.425	4.761	5.186	0.641	6.233	6.874
Petroleum products	0.388	2.158	2.547	0.766	5.063	5.829
Bricks, tiles (structural clay products)	0.482	2.335	2.817	0.661	6.266	6.927
Cement	0.477	2.214	2.691	0.779	4.942	5.721
Non-metallic mineral products	0.439	2.329	2.768	0.679	5.390	6.069
Iron and steel (ferro alloys and casting and forging)	0.415	2.226	2.641	0.669	4.863	5.532
Iron and steel foundries	0.427	2.281	2.708	0.668	4.919	5.587
Electrical machinery and tools	0.490	2.361	2.851	0.663	5.070	5.733
Other manufacturing	0.449	2.710	3.159	0.672	5.693	6.366
Irrigation canal construction	**0.453**	**2.787**	**3.240**	**0.966**	**7.598**	**8.564**
Buildings construction	**0.430**	**2.501**	**2.930**	**0.681**	**5.270**	**5.952**
Highways/urban roads construction	**0.416**	**2.655**	**3.071**	**0.725**	**5.585**	**6.310**
Rural roads construction	**0.509**	**4.523**	**5.032**	**0.854**	**6.824**	**7.678**
Other construction	0.426	2.810	3.236	0.690	5.901	6.591
Electricity and water supply	0.429	2.237	2.666	0.694	4.812	5.505
Transport services	0.503	2.547	3.050	0.723	5.197	5.920
Other services	0.572	2.485	3.057	0.745	5.155	5.900
Public administration	0.923	2.169	3.091	0.954	4.664	5.619
Households	0.373	2.136	2.509	0.590	4.654	5.244

Source Authors calculations based on NSSO and NCAER data
[a]Change in workers due to a change in output worth Rs. hundred thousand

buildings construction sector has the lowest total employment multiplier (1.04), demonstrating again, the capital-intensive nature of this sector.

Closed Model Employment Multipliers: Rural road construction has the highest formal (0.51), informal (4.52) and total employment (5.03) multipliers in Gujarat, while in West Bengal irrigation canal construction has the highest multipliers (0.97, 7.60 and 8.56, respectively, as reflected in Table 6). Public administration has the highest formal employment multipliers in both the states. Wooden furniture and fixtures in Gujarat have the highest employment multiplier for informal workers followed by rural roads construction and then agriculture. In West Bengal, the highest multipliers for informal workers are for irrigation canal construction, followed by agriculture and bricks and tiles manufacturing (see Table 6).

Another insight is that so far, the share of informal employment is higher in all sectors except in public administration. The job creation shown in the household sector is the increase in employment as households plough back their income to the economy by purchase of goods. They also purchase goods which result in more informal employment. This is expected as they would purchase goods such as agriculture, and other products from informal labour intense sectors.

3.2 *Simulation Analysis*

For each construction sector, it is assumed that the capital investment or the Gross Fixed Capital Formation (GFCF) in the IO model increases by 10% due to an exogenous factor. This increase is incorporated into the IO model through changes in final demand and resultant output change are observed.

Among the infrastructure sectors, buildings construction forms the largest share of the output of the economies of Gujarat (3.64%) and West Bengal (3.85%) as shown in Fig. 1. The rest of the sectors form smaller shares. Other construction is

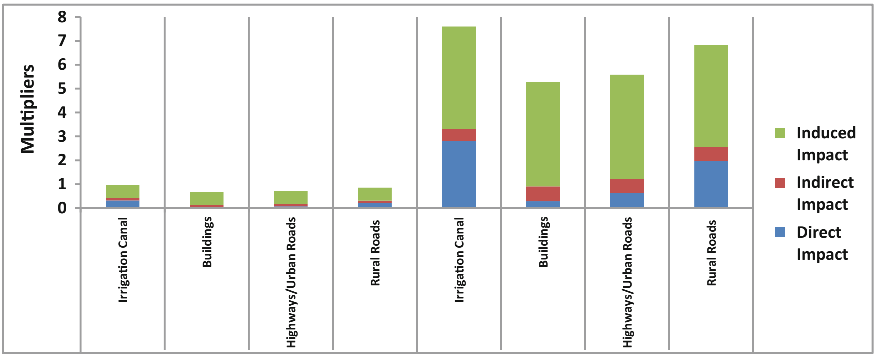

Fig. 1 Direct, indirect and induced employment multipliers by type: West Bengal. *Source* Authors' analysis

the second largest in both states (1.48% in Gujarat and 1.76% in West Bengal). Irrigation canal construction is third highest in Gujarat (it forms 0.22% of the total output) and highways/urban roads construction is third highest in West Bengal (forming 0.25% of total output).

3.2.1 Irrigation Canal Construction Sector

The first simulation, for irrigation canal construction, shows the changes in outputs and employment of all sectors in the economies of both the states to satisfy a 10% increase in GFCF or investments in irrigation canal construction and cost on repair.

In Gujarat, if investment in irrigation canal construction increases by about Rs. 2,294 million (reflecting a 10% increase) then final demand increases by 6.35%. In Gujarat, irrigation canal construction output also increases by Rs. 2,294 million. The sectors impacted most by this change in irrigation canal construction output, in order of highest impact, are other services and other manufacturing where outputs must increase by about Rs. 739 million and Rs. 666 million respectively. If we look at the closed model, other services must increase by Rs. 1,934 million and other manufacturing by Rs. 1,634 million.

The total output generated in the economy of Gujarat as a result of this investment in irrigation canals construction, taking also into account induced effects, is Rs. 8.9 billion. Figure 2 shows the gender and type wise employment

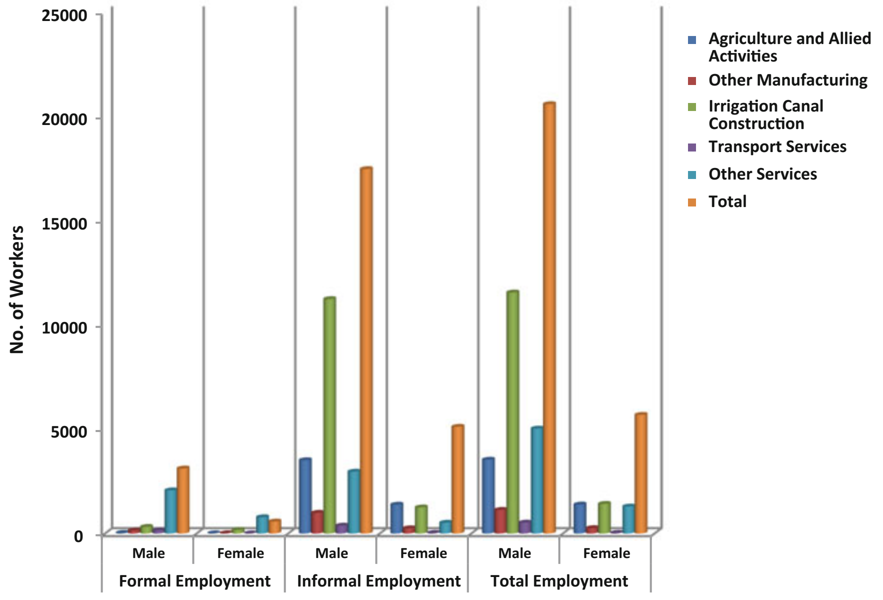

Fig. 2 Investment shock on investment in irrigation canal construction: Gujarat. *Source* Authors' analysis

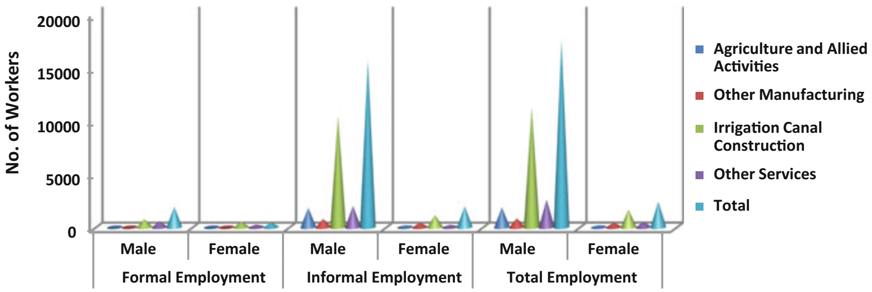

Fig. 3 Investment shock on irrigation canal construction: West Bengal. *Source* Authors' analysis

generation as a result of this simulation due to 10% increase in investment on irrigation canals construction (see Fig. 2).

Employment in the irrigation sector will increase by 12,996 workers of which 487 are formal comprising 317 male and 170 female, and 12,509 are informal comprising 11,258 male, 1,251 female. Taking induced effects into account, total employment generated in the closed model economy is 26,289 workers (3,692 formal: 3,120 male, 572 female and 22,597 informal: 17,473 male, 5,124 female). In other services, the resultant employment generation is of 6,332 workers of which 2,849 is formal employment (2,069 male, 780 female) and 3,483 is informal employment (2,969 male, 514 female).

In West Bengal, if investment in irrigation canal construction increases by Rs. 411 million (10% increase), output for irrigation canal construction also increases by the same. Final demand goes up by 8.83%. In the open model, total output increases by Rs. 899 million. Taking the induced effect of households into account, the total output in the West Bengal economy increases by Rs. 3,024 million. In the open model, the sectors impacted by the investment shock are other services and other manufacturing, where output increases by Rs. 143 million and Rs. 60 million, respectively. Total employment generated is 13,250 workers (1,398 formal and 11,852 informal).

Figure 3 shows the findings of this investment on the closed model of West Bengal.

In the closed model, output in other services goes up by Rs. 511 million and in other manufacturing is Rs. 358 million. The total employment generated in the economy (with induced effects) is 19,870 workers (2,361 formal: 1,928 male, 433 female and 17,509 informal: 15,525 male, 1,984 female). The employment generated in the irrigation sector is 12,846 workers (1,306 formal: 783 male, 522 female and 11,541 informal: 10,387 male, 1,154 female).

3.2.2 National Highways/Urban Roads and Rural Roads Construction

The simulations for roads construction bring out the differences between national highways/urban roads and rural roads, both in terms of impact as a whole on the entire economy as well as the sector-wise impacts on outputs.

In Gujarat, a 10% increase in investment in highways/urban roads amounts to Rs. 2,345 million. This leads to a 6.9% change in final demand (highways output changes by the same amount as investment). Without the households' induced effects, output in the economy increases by Rs. 5.53 billion in the open model. The sectors impacted most by the investment in highways/urban roads are mining (Rs. 570 million increases in output) and petroleum products (Rs. 529 million increase in output). Employment requirement in this model increases by 10,417 workers (537 formal and 9,880 informal) in total.

Figure 4 shows the sector-wise impacts on employment in the closed model.

Under the total multiplier analysis (closed model), it is seen that the induced effects of the households sector lead to an increase in total output in the economy of Rs. 9.34 billion. Change in highways output remains the same as in the open model. The sectors impacted the most in the closed model are other services and other manufacturing, reflecting a rise in output of Rs. 1,647 million and Rs. 1,438 million, respectively. Employment generation in the highways sector is 9,527 extra workers (357 formal: 214 male, 143 female and 9,170 informal: 8,253 male, 917 female). The sectors impacted most in terms of employment generation as a result of the shock on investment are agriculture [6,164 extra workers: 37 formal (29 male, 8 female), 6,127 informal (4,399 male, 1,728 female)] and other services [4,492 extra workers: 2,021 formal (1,468 male, 553 female), 2,471 informal (2,107 male, 365 female)]. The total employment generation in the Gujarat economy in the closed model is 21,804 workers (2,673 formal: 2,258 male, 414 female and 19,132 informal: 14,793 male, 4,339 female). In West Bengal, if investment in highways/ urban roads construction increases by Rs. 1,831 million (10% increase), final demand increases by 6.16%. In the open model output in the highways sector increases by the same amount (Rs. 1,831 million). The mining sector is impacted the most—output rises by Rs. 472 million. The second highest impact is on the petroleum products sector—output rises by Rs. 391 million. The total output in the

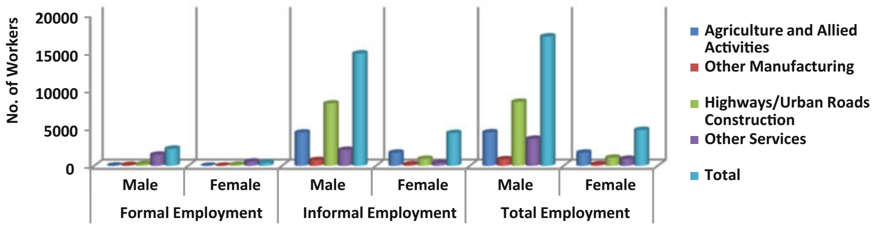

Fig. 4 Investment shock on national highways/urban roads construction: Gujarat. *Source* Authors' analysis

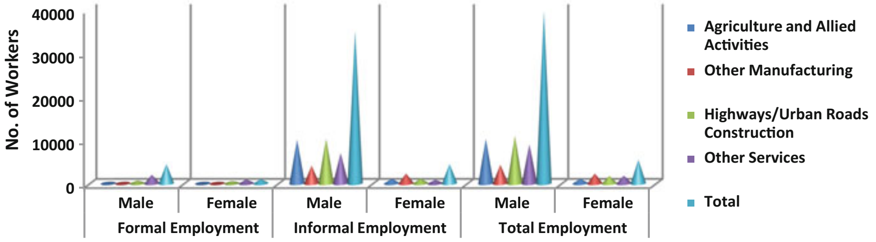

Fig. 5 Investment shock national highways/urban roads construction: West Bengal. *Source* Authors' analysis

economy increases by Rs. 4,422 million. Employment in the highways sector goes up by 12,814 workers (1,302 formal, 11,511 informal). The mining sector is again impacted the most and requires an additional 900 workers to satisfy the rise in demand for highways/urban roads output (234 formal, 666 informal). The total employment generated in the open model is 14,804 workers (1,667 formal and 13,137 informal). Figure 5 shows the employment impacts of this simulation on the closed model.

In the closed model, total output in the economy increases by Rs. 9.63 billion. We find that output in highways/urban roads construction increases by the same amount as in the open model. The sectors impacted most are other services (Rs. 2,014 million) and other manufacturing (Rs. 1,713 million). Output generated in the households sectors is Rs. 4,415 million. Employment in the highways sectors increases by the same amount as in the open model. The highest impact is on the agriculture sectors [11,459 extra workers: 200 formal (183 male, 17 female), 11,259 informal (10,174 male, 1,085 female)] and on other services [10,887 extra workers: 2,983 formal (2,039 male, 944 female), 7,904 informal (7,044 male, 861 female)]. The total worker requirement in the West Bengal economy in the closed model increases by 45,173 workers (5,509 formal: 4,498 male, 1,011 female, 39,664 informal: 35,170 male, 4,496 female).

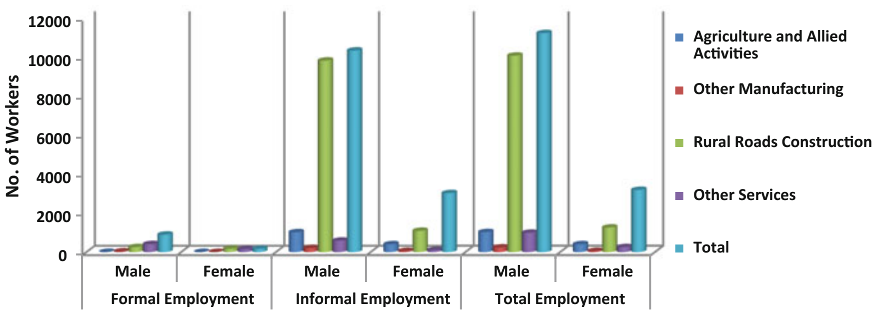

Fig. 6 Investment shock on rural roads construction: Gujarat. *Source* Authors' analysis

In Gujarat, an investment of Rs. 499 million (reflecting a 10% increase) in rural roads construction leads to an increase in final demand of 6.72%. Output rises by the same amount in the rural roads sector (Rs. 499 million) in both the open and closed models. In the open model, total output in the economy increases by Rs. 1.14 billion. The highest impact is on other services (Rs. 139 million worth of output generation) and other manufacturing (Rs. 139 million). Employment in rural roads increases by 11,345 workers (425 formal, 10,920 informal). Among the impacted sectors, the highest employment requirement is in other services (149 extra workers: 67 formal, 82 informal) and agriculture (101 extra workers, all informal). The total employment generation in the open model economy is 11,664 workers (505 formal and 11,159 informal).

Figure 6 shows the simulation impacts on employment by sectors most impacted in the closed model in Gujarat.

In the closed economy model, accounting for the induced effects of the household sector, we see that total output in the economy increases by Rs. 1.96 billion. Output generated in the households sector is Rs. 893 million. The highest impact on other services (Rs. 400 million) followed by other manufacturing (Rs. 348 million). Employment in rural roads changes by the same amount as in the open model: 11,345 workers (425 formal: 255 male, 170 female and 10,920 informal: 9,828 male, 1,092 female). Highest employment is generated in agriculture [1,428 workers: 9 formal (7 male, 2 female), 1,420 informal (1,020 male, 400 female)] followed by other services (1,248 workers: 562 formal (408 male, 154 female), 687 informal (585 male, 101 female). The total employment generated in the closed model is 14,438 workers (1,061 formal: 896 male, 164 female and 13,377 informal: 10,343 male, 3,034 female).

In West Bengal, an increase in investment by 10% reflects an investment of Rs. 479 million in the rural roads construction sector. Final demand changes by 6.16%. The output in rural roads construction changes by the same amount in both the open and closed models (Rs. 479 million). The total output generated in the economy of West Bengal in the open model is Rs. 1.14 billion. The mining sector gets the highest impact-output increases by Rs. 104 million. This is followed by other manufacturing where Rs. 92 million worth of output is generated. Employment of 10,484 workers is generated in the rural roads construction sector in both the open and the closed models, of which 1,066 are formal (586 male, 480 female) and 9,418 informal workers (8,477 male, 942 female). 167 workers (43 formal, 123 informal) are to be hired in the mining sector and 77 (21 formal, 56 informal) in other services to satisfy this increase in investment in rural roads construction. The total employment generated in the economy is 10,966 workers (1,143 formal and 9,823 informal).

Figure 7 shows the sector-wise employment impacts of this simulation in the closed model.

The closed model shows an increase in total output in the economy of Rs. 2.47 billion. The sectors impacted most are other services (Rs. 513 million) and other manufacturing (Rs. 436 million). Employment generation is highest in agriculture [2,867 workers: 50 formal (46 male, 4 female), 2,817 informal (2,545 male,

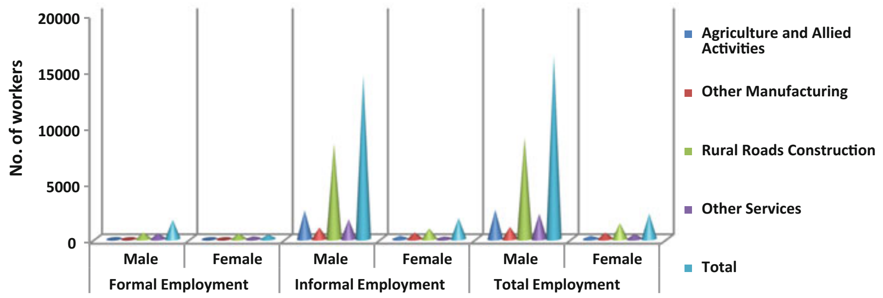

Fig. 7 Investment shock on rural roads construction: West Bengal. *Source* Authors' analysis

272 female)] and other services [2,698 workers: 739 formal (505 male, 234 female), 1,959 informal (1,745 male, 213 female)]. The total employment generated in the West Bengal economy in the closed model is 18,483 workers (2,086 formal: 1,703 male, 383 female and 16,397 informal: 14,539 male, 1,858 female).

3.2.3 Buildings Construction Sector

The buildings sector forms the highest share of total output in the economies of both Gujarat and West Bengal among the "newly carved out" construction sectors. The simulation for this sector shows this is a key growth sector.

In Gujarat, 10% investment in the buildings sector is equivalent to Rs. 51.1 billion increase in GFCF. This leads to increase in final demand by 9.92% (almost one to one with GFCF). In the open model, the output in the buildings sector increases by Rs. 52.52 billion. Total output in the economy goes up by Rs. 120 billion. The highest impact is on other services (rise in output by Rs. 13.34 billion) and on other manufacturing (Rs. 12.83 billion rise in output). Employment generated in the buildings construction sector in the open model is 102,404 workers (3,837 formal, 98,567 informal). 13,522 extra workers are to be hired in other services (6,084 formal, 7,438 informal). Total employment generated in the economy is 130,339 workers (11,153 formal and 119,185 informal).

Figure 8 shows the impacts on the sectors most impacted due to this change in the closed model for Gujarat.

In the closed model, output in the buildings sector increases by Rs. 53.3 billion. Total output in the economy increases by Rs. 204 billion. Output in other services increases by Rs. 40.3 billion which is the highest impacted sector, followed by other manufacturing (Rs. 34.66 billion increase in output). Employment in the buildings sector increases by 105,458 workers (3,951 formal: 2,371 male, 1,581 female, 101,507 informal: 91,356 male, 10,151 female). Employment in other services increases by 123,388 workers (55,515 formal: 40,321 male, 15,195 female and 67,873 informal: 57,857 male, 10,016 female). The total employment generated

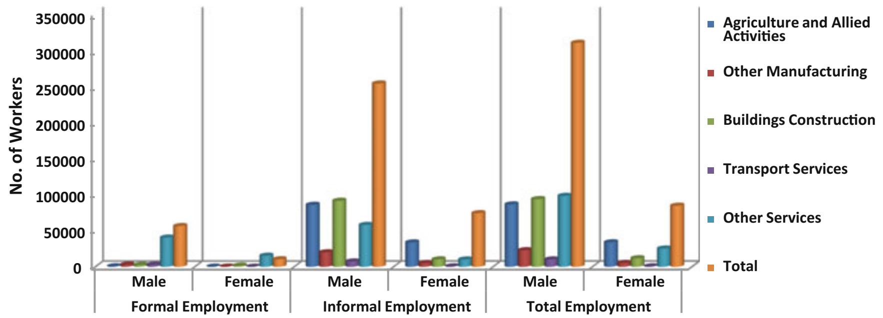

Fig. 8 Investment shock on buildings construction: Gujarat. *Source* Authors' analysis

in the economy is 393,900 workers (66,689 formal: 56,352 male, 10,337 female, 327,211 informal: 253,008 male, 74,203 female).

Investment of Rs. 38.78 billion in West Bengal (equivalent to 10% increase) leads to an increase in final demand by 9.87%. In the open model, buildings output increases by Rs. 39.87 million. The highest impact is on other services (Rs. 10.87 billion) and other manufacturing (Rs. 7.58 billion). Employment generated in buildings is 132,004 workers (13,417 formal, 118,587 informal). In total, the employment generation is of 171,890 workers (19,975 formal and 151,914 informal). Figure 9 shows the results of the simulation for the closed model.

For the closed model, the output generated in the buildings sector is Rs. 40.88 billion. The total output generated in the economy is Rs. 201 billion. Employment in the buildings sector increases by 138,786 workers (14,106 formal: 7,758 male, 6,348 female and 124,680 informal: 112,212 male, 12,468 female). Employment generated in other services is 269,733 (73,902 formal: 50,505 male, 23,396 female and 195,831 informal: 174,509 male, 21,322 female). Total employment generated in the economy is 817,731 workers (107,379 formal: 87,672 male, 19,707 female and 710,352 informal: 629,864 male, 80,488 female).

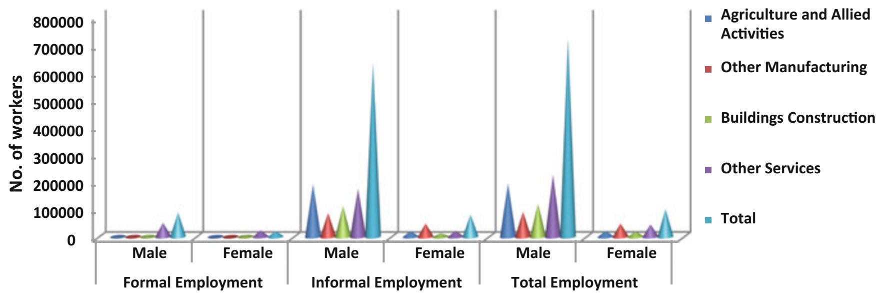

Fig. 9 Investment shock on buildings construction: West Bengal.

3.3 Employment Effects

The employment structure within the key infrastructure sectors under focus for this study shows that buildings construction takes most of the workers within these sectors in both the states. This share, as shown in Fig. 10, is as high as 69% in Gujarat and 74% in West Bengal.

When the output rises due to the demand shocks described above, the growth of employment fulfilling these additional outputs in the open model framework are given in Fig. 11.

It may be noted that the informal jobs created in the economy are much higher than the formal jobs created in both the states. This could point to the need for greater formalization of these sectors, perhaps at the national level.

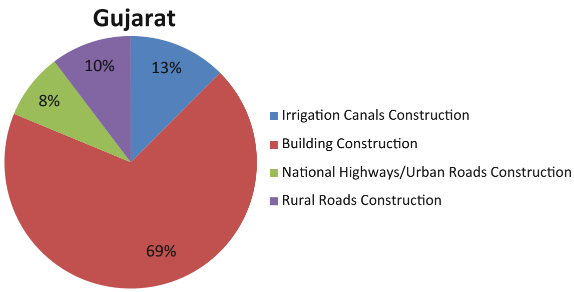

Fig. 10 State-wise shares of employment of key infrastructure sectors. *Source* Authors' analysis

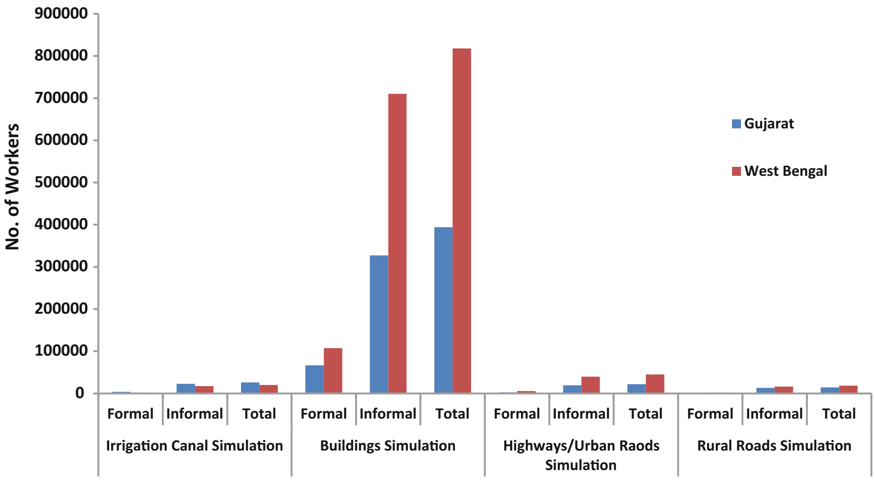

Fig. 11 Simulation results: state-wise employment generation by worker type (closed model results). *Source* Authors' analysis

We find that informal employment in overwhelmingly high in all the infrastructure sectors in both the states (see Table 7). We are presenting below the percentage share of workers in formal and informal works in the Building sector when the investment in the sector increases by 10%. As a net result share of informal workers in West Bengal is somewhat higher than Gujarat. However, though in terms of growth the two States are considered to be very different, the in the issue of informal employment growth the states are similar with certain sectoral variations.

Table 7 Simulation with 10% shock in investment in building sector

Simulation results	Buildings					
Change in employment	Gujarat			West Bengal		
	Formal	Informal	Total	Formal	Informal	Total
Agriculture and allied activities	0.60	99.40	100.00	0.60	99.40	100
Mining	16.41	83.59	100.00	10.74	89.26	100
Furniture and fixtures: wooden	1.09	98.91	100.00	0.69	99.31	100
Petroleum products	0.00	0.00	0.00	0.00	0.00	100
Bricks, tiles (structural clay products	37.16	62.84	100.00	24.12	75.88	100
Cement	92.83	7.17	100.00	87.99	12.01	100
Non-metallic mineral products	24.25	75.75	100.00	15.37	84.63	100
Iron and steel (ferro alloys and casting and forging)	91.85	8.15	100.00	91.35	8.65	100
Iron and steel foundries	99.59	0.41	100.00	99.59	0.41	100
Electrical machinery and tools	87.51	12.49	100.00	80.35	19.65	100
Other manufacturing	9.52	90.48	100.00	10.05	89.95	100
Irrigation canal construction (public)	0.00	0.00	0.00	0.00	0.00	0.00
Buildings construction	74.94	25.06	100.00	75.28	24.72	100
Highways/urban roads construction (public)	0.00	0.00	0.00	0.00	0.00	0.00
Rural roads construction (public)	0.00	0.00	0.00	0.00	0.00	0.00
Other construction	33.65	66.35	100.00	32.52	67.48	100
Electricity and water supply	37.63	62.37	100.00	26.47	73.53	100
Transport services	23.17	76.83	100.00	15.54	84.46	100
Other services	39.87	60.13	100.00	28.81	71.19	100
Public administration	0.00	0.00	0.00	0.00	0.00	0.00
Total	34.16	65.84	100.00	34.97	65.03	100

Source Authors calculations based on NSSO and NCAER data

4 Conclusions

The major objective of the study was to develop a set of employment multipliers (direct, indirect, and induced) for selected infrastructure sub-sectors in two selected states of India: Gujarat and West Bengal. The methodology used is the input–output multiplier analysis which operates through the multi-sectoral linkages that exist in an economy.

In the present study, we have examined the impact of a change in investment demand of the "new" infrastructure sectors (irrigation canals, buildings, highways/ urban roads and rural roads) on job creation and growth potential in the states of Gujarat and West Bengal.

Tables 8 and 9 show that output multipliers are generally similar for both the states when we use the open model. The output multiplier is perceptibly higher in the irrigation canal construction sector for Gujarat compared to West Bengal. On

Table 8 State-wise open model multipliers

Sector	Output multipliers		Employment multipliers	
	Gujarat	West Bengal	Gujarat	West Bengal
Irrigation canals	2.254	2.190	0.903	3.721
			(0.797)	(3.300)
Buildings	2.351	2.357	0.564	1.037
			(0.486)	(0.908)
Highways	2.360	2.415	0.731	1.389
			(0.663)	(1.218)
Rural roads	2.293	2.383	2.677	2.873
			(2.518)	(2.559)

Note The numbers given in parentheses under employment multipliers are of informal workers
Source Authors calculations based on NSSO and NCAER data

Table 9 State-wise closed model multipliers

Sector	Output multipliers		Employment multipliers	
	Gujarat	West Bengal	Gujarat	West Bengal
Irrigation canals	5.656	7.364	3.240	8.564
			(2.787)	(7.598)
Buildings	5.795	7.608	2.930	5.952
			(2.501)	(5.270)
Highways	5.765	7.672	3.071	6.310
			(2.655)	(5.585)
Rural roads	5.722	7.516	5.032	7.678
			(4.523)	(6.824)

Note The numbers given in parentheses under employment multipliers are of informal workers
Source Authors calculations based on NSSO and NCAER data

Table 9a Direct, indirect and induced employment multipliers by type of worker: Gujarat

Sector	Formal employment			Informal employment		
	Direct impact	Indirect impact	Induced impact	Direct impact	Indirect impact	Induced impact
Irrigation canal	0.021	0.084	0.348	0.545	0.252	1.990
Buildings	0.007	0.071	0.352	0.183	0.304	2.014
Highways/ urban roads	0.015	0.053	0.348	0.391	0.272	1.992
Rural roads	0.085	0.074	0.350	2.190	0.328	2.005
Other	0.006	0.066	0.354	0.330	0.454	2.026

Source Authors calculations based on NSSO and NCAER data

the other hand, the output multiplier is higher for highways in West Bengal. As we examine the employment multipliers, it is seen that the employment potential is higher in West Bengal. Moreover, the share of informal workers is also somewhat higher in West Bengal, being about 87% compared to that of 84% in Gujarat. The per capita SDP for Gujarat is Rs. 75,115 and is substantially lower for West Bengal at Rs. 55,222 in 2010–11 (Central Statistical Office, Government of India).

However, the population in West Bengal is higher than that of Gujarat being about 90 million compared to 59.5 million in Gujarat (Office of Registrar General of India). This has an implication on the impact when the models are closed (including the household income and consumption demand in the system). The impact of households is much higher in West Bengal as the total income of the economy gets occupied in building up demand and hence production. The induced effect drives up both output and employment to substantially higher degrees in West Bengal compared to Gujarat. However, the matter of concern still remains that the employment growth is driven by informal employment.

Also, Tables 9a and 9b show the break-up of the closed model employment multipliers as direct, indirect and induced: The formal and informal workers have

Table 9b Direct, indirect and induced employment multipliers by type of worker: West Bengal

Sector	Formal employment			Informal employment		
	Direct impact	Indirect impact	Induced impact	Direct impact	Indirect impact	Induced impact
Irrigation canal	0.318	0.103	0.545	2.810	0.490	4.298
Buildings	0.033	0.096	0.553	0.289	0.619	4.362
Highways/ urban roads	0.071	0.100	0.553	0.629	0.589	4.367
Rural Roads	0.222	0.092	0.540	1.966	0.594	4.264
Other	0.046	0.085	0.559	0.822	0.665	4.415

Source Authors calculations based on NSSO and NCAER data

different dynamics of employment as we see in these tables. The direct employment impacts of a change in investment demand in the new infrastructure sectors are lower for formal workers than for informal workers. Also, as the household consumption expenditure is endogenized, the impact on employment demand is higher due to the additional consumption originating from households (as total wage incomes increase in the economy).

It can be seen that the policymakers can use the multiplier analysis to determine in which sector of the economy to spend one additional unit of rupee, a comparison of output multipliers would show where this spending would have the greatest impact on output or employment generated throughout the economy. Note that when maximum total output effects are the exclusive goal of the planner's spending, it would always be rational to spend all the money in the sector whose output, income and employment multiplier is the largest.

Key Findings
Following are the key findings for the states of Gujarat and West Bengal.

Gujarat

(1) The open model and closed model employment multipliers in Gujarat are highest for rural roads construction (for formal, informal and total workers). Open model multipliers are 0.159, 2.518 and 2.677 for formal, informal and total workers, respectively. Closed model multipliers are 0.509, 4.523 and 5.032 for formal, informal and informal workers, respectively.
(2) The direct impact on formal and informal employment is highest for rural roads (0.085 and 2.19, respectively). The indirect impact on formal employment is highest in irrigation canals construction (0.084) while for informal employment it is highest for rural roads construction (0.328). The induced effects for both formal and informal employment are highest for buildings construction (0.352 and 2.014, respectively); showing that the effect of including households to take into account induced multiplicative effects is high for buildings in the Gujarat economy.

West Bengal

(1) The open model and closed model employment multipliers in West Bengal are highest for irrigation canal construction (for formal, informal and total workers). Open model multipliers are 0.421, 3.3 and 3.721 for formal, informal and total workers, respectively. Closed model multipliers are 0.966, 7.598 and 8.564 for formal, informal and informal workers, respectively.
(2) The direct impact on formal and informal employment is highest for irrigation canal construction (0.318 and 2.81, respectively). The indirect impact on formal employment is highest in irrigation canals construction (0.103) while for informal employment it is highest in buildings construction (0.619). The induced effects for formal employment are highest in buildings and national highways/urban roads construction (0.553 for both) and for informal employment are highest in national highways/urban roads construction (4.367) with

buildings not too far behind (0.362). This shows that buildings construction and national highways/urban roads construction generate employment in West Bengal.

Simulation Findings (Closed Model Results)

(1) A 10% increase (exogenous shock) in investment in irrigation canals construction sector leads to 86,446 extra workers being hired in Gujarat and 48,768 extra workers being hired in West Bengal. Also, this shock leads to a Rs. 12.98 billion growth in Gujarat's economy and a Rs. 3.02 billion growth in West Bengal's economy. As the irrigated area is higher in Gujarat to start with, the implication in numbers is higher for Gujarat, though the multipliers are noted to be higher in West Bengal.
(2) A 10% increase in the investment in highways/urban roads construction sectors leads to 83,401 extra workers being hired in Gujarat and 178,181 extra workers being hired in West Bengal. Also, this shock leads to a Rs. 13.52 billion growth in Gujarat and Rs. 14.05 billion growth in West Bengal.
(3) A 10% investment shock in rural roads causes 27,715 extra workers being hired in Gujarat and 51,666 extra workers being hired in West Bengal. Also, this shock leads to a Rs. 2.86 billion growth in Gujarat and Rs. 3.6 billion growth in West Bengal. A 10% shock to investment in the buildings construction sector results in 1,766,938 extra workers being hired in Gujarat and 36,28,008 extra workers being hired in West Bengal. Also, this shock leads to a Rs. 296 billion growth in Gujarat and Rs. 295 billion growth in West Bengal.
(4) Maximum employment is generated due to expansion of the buildings sector, as it uses inputs from most other sectors and is also used by both private and public (government) final users. So it is a key sector of the economy (reflecting strong linkages with other sectors and economic agents). Moreover, in both the states, its share in the pie of total construction is much higher than other infrastructure construction sectors (69% in Gujarat and 74% in West Bengal).
(5) It may also be noted that the informal jobs created in the economy are much higher than the formal jobs created in both the states. This could point to the need for greater formalization of these sectors, perhaps at the national level.
(6) The investment impact of the study sectors seems to have nearly similar impacts on the two states in terms of growth but generally has a much higher implications in employment for West Bengal. This reflects the labour-intensive nature of the West Bengal economy compared to Gujarat.

5 Way Forward

Given the findings and challenges we face while developing IO models, we note here some recommendations for future research:

(1) To understand interlinkages of sectors and the related employment generation by types of workers we need more intense data collection. This needs to be in two aspects. One is to have both source and use of goods from both the formal and informal sectors. Though, the DME and NDME provide data on output of unregistered sectors, data are not identified as originating from informal parts of a sector. For example, if we have input from textile sector, the data do not specify the nature of the input sector.
(2) Hence, extensive survey program is required to collect data on sectoral inputs. To understand the strength of the output multiplier, data collection needs to focus on tracing the origins of a sector's inputs which would span more than one state.
(3) Trade data for interstate movement of goods is very poor till date. This needs to be improved by recording movement of goods across states through various modes, including roads. It is urgent to have more uniform types of data across states for wages by various labour types. Also, data on more informally employed sections (vendors, home-based workers) have not been focused on substantially by the NSSO.

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Challenges in Construction of Regional Accounts in India

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Abstract India is a land of diversity. The disparity among the states in the country, attributable to historical difference in initial conditions, natural resource endowments, level of industrialization and differences in human capital indicators, viz. education, health, etc., not only has manifested in varying levels of growth and development, but are also likely to affect the returns on investment. Regional supply–use frameworks are a tool for planners to help analyse the effect of varying levels of investment and optimizing the use of available resources. But the regional supply–use framework needs to be 'regionalized' properly by using local-level information, without which it may lead to wrong inferences. Two important roadblocks, which are faced by the compilers of regional supply–use tables in India, are the vectors on capital formation and trade. Estimates of capital formation at the regional level are not compiled at the regional level due to the absence of state-level data sources as are available at the national level. The national-level estimates are allocated to the states using appropriate indicators. As regards trade, there is a lack of reliable, comprehensive data on the quantity and value of products exported from a state to other Indian states or to other countries. This paper reviews the methods used so far in the available literature and attempts to give some suggestions in this regard, with the help of new/unconventional data sources for the period of 2012–13 to 2014–15 for eight major states of India.

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1 Introduction

The Indian economy is markedly characterized by unequal distribution of natural resource endowments, varying levels and allocation of infrastructure and production factors across sectors and states, resulting in uneven growth across regions of India (Sachs et al. 2002). Even across the state, the rich states have had a higher degree of uniformity in growth and hence convergence, while the poor states suffer from inequality even within the state. Also, higher growth rates help develop a mechanism wherein the economic units are able to take advantage of scale, are in a position to bargain for better input and output prices and, hence, can attract labour and capital. This agglomeration aids the growth of certain regions at the cost of other regions leading to the persistence of cumulative causation.

In order to help decision-making, quantitative approaches have been developed for identifying and interpreting the structural changes in an economy. These approaches are based on statistical tools, econometric models and dynamic forecasts. One such approach is that of analysis of input–output structures of various industries and sectors. It has been recognised and illustrated, nationally and internationally, that Input–Output Transaction Tables (IOTTs) or supply–use Tables can be used as a tool for the states to plan for regional development by optimizing the sources available in the region. The analysis of input–output tables can help make an informed assessment on industries which can be promoted at the state level. These tables can help make projections for answering the following questions: (1) how to reduce regional disparity; (2) which sectors to be developed for maximizing the growth of the region, as also how to maximize the growth of a sector; (3) what are the corresponding requirements of labour and investment; and (4) what would be the effect on trade—both domestic and foreign. The multipliers emanating from the input–output analysis can be used to assess the effects of the exogenous changes of final demand (consumption, investment, exports) on outputs of the sectors in the economy, value added and income earned by the households, and employment that is expected to be generated by the new activity levels.

A principal use of the input–output tables is measuring the scale of production induced at each sector by generation of a certain final demand—private and government consumption expenditures, domestic capital formation and exports—as also to estimate import requirements induced by both intermediate import product requirements and final demand requirements. Therefore, it is essential that the vectors of capital formation, exports and imports are separately constructed.

However, the key issue here is that of an inadequate data required for the construction of these final demand vectors, including that on capital formation and on inter-state trade. The system of customs/import duties that are imposed on international trade has helped to record the international transactions attributable to a state to a great degree. On the other hand, in the case of inter-state trade, the commodities traded can be freely moved anywhere in the country as there is no restriction on the buying and selling of the goods/services. The absence of a 'barrier' is associated with the inadequate data on the inter-state trade, which could help in incorporating these in the input–output tables.

National/regional accounts are generally prepared from 'enterprise accounts' rather than 'establishment accounts', as these give expansive information on the production, expenditure and income required for the compilation of these accounts. Though these 'enterprise accounts' often give details of production and income by 'establishment' too, investment details at the 'establishment' level are lacking. This is important for the capital formation vector, which requires not just the location of asset formation but also its extent.

In a nutshell, compiling inter-regional input–output tables requires high-quality data (Eurostat 2013), but so far, apart from a small part of developed countries, the vast majority of countries cannot meet the basic data requirements for compiling inter-regional input–output tables in the existing statistical system, because the costs and time requirements of constructing RIOTs directly from surveys and primary data are often prohibitive. Some of these issues have been discussed in detail in Sargento (2009). So, the only option available for compiling inter-regional input–output tables when the data resources are relatively low is to formulate methodology which optimizes the use of available information.

The present study aims to address some of the issues in the construction of regional input–output tables, by looking at unexplored databases, especially for the final demand vectors, without which the utility of these tables is highly constrained. Section 2 gives the history of regional input–output tables in the Indian context, while Sect. 3 outlines the proposed methodology for the inter-state trade and capital formation vectors. The results are discussed in Sect. 4.

2 History of Regional Input–Output in India

The regional diversities in India have compelled policy-makers and researchers to study the regional economies especially to come up with answers to the growth 'what-ifs'. An abridged list of papers is given below:

S. No.	Year	Author	Remarks
1	1963	Ramachandran, M.	IO at national level; different plan scenarios
2	1970	Venkataramaiah, P., Kulkarni, A.R. and Argade, L.	IO matrices for 21 states; final demand vectors not attempted
3	1971	Alagh, Y.K. and Kashyap, S.P.	Inter-industry matrices only
4	1971	Alagh, Y.K., Subramanian, K.K. and Kashyap, S.P.	Inter-industry matrices only
5	1975	Bhalla, G.S.	Inter-industry matrices only
6	1977	Barua, S.	Inter-industry matrices only
7	1978	Prakash, S. and Patanker, P.K.	Inter-industry matrices only

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S. No.	Year	Author	Remarks
8	1988	Dholakia, B.H. and Dhalokia, R.H.	Input–output coefficients for Gujarat using survey and non-survey methods; final demand not mentioned
9	1988	Dholakia, B.H. and Dhalokia, R.H.	Input–output coefficients for Kerala using survey and non-survey methods; final demand not mentioned
10	1990	Bhalla, G.S., Chadha, G.K., Kashyap, S.P. and Sharma, R.K.	IO tables for Punjab for 1969–70 and 1979–80; analysis using the IO tables; capital formation based on state government publication for household and govt; ASI for others; trade vectors using a RITES survey
11	1990	Deman, S.	4Analysis of Gujarat and Haryana IO. Capital formation vector said to be a 'guess'. Inter-regional trade not included
12	1991	Saluja, M.R. and Atul Sharma	Comparison of Punjab and Assam using IO; no specific comment about GFCF; net trade taken as residuals
13	1992	Saluja, M.R. and Atul Sharma	IO not constructed; sector-wise details of sources/methods available; capital formation suggested using ASI and construction sector estimates
14	1992	Pratap Narain	Generic prescription of format/ methodology; no details; suggests residual approach for capital formation plus net trade
15	1992	Sharma, S.P. and Saxena, K.K.	Repetition of past work, methods available; no specific work/prescription
16	1992	Dhawan, Sangeeta and Saxena, K. K.	No mention of states. Limitations highlighted
17	1992	Thakur, P.D., and Singh, S.P.	Discusses the approach; input–output table not constructed
18	1992	Parasuram, Y.	Identifies the gaps in regional input–output tables using the example of sugar industry
19	1992	Dholakia, R.H.	Prescribes methods for regionalisation —RAS/generalized inverse—for different situations—when value added/ capital formation is or not available
20	1992	Dholakia, R.H. and Dholakia, B.H.	Input–output coefficients for Rajasthan using survey and non-survey methods
21	1992	Saluja, M.R. and Sharma, Anil	Sector-wise details of sources/methods available; capital formation using ASI and construction sector estimates
22	2007	Sharma, S.	Review of work done so far in IO by India; No specific method suggestion

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S. No.	Year	Author	Remarks
23	2008	Swaminathan, A.M.	IO for Maharashtra; capital formation from ASI
24	2011	Inderjeet Singh and Lakhvinder Singh	Compilation of IOs for Punjab using different methods; GFCF and CIS approximated from ASI
25	2013	Directorate of Economics and Statistics, Delhi	Abridged repetition of publication at the national level; many instances of use of national ratios; capital formation using ASI
26	2014	Sengupta, A.	IO for West Bengal using non-survey method; GFCF and CIS approximated from ASI
27	2015	Anushree Sinha, Avantika Prabhakar, Rajesh Jaiswal	Regional IO for Gujarat and West Bengal; CIS and net exports taken as residuals; GFCF of public from state; private GFCF methods not specified

A quick review of how these problems have been overcome in the construction of regional input–output tables in the past helps in assessing the merits of this proposed methodology. Kolli (2007) presents a list of the regional input–output matrices constructed in India. An advantage is that the issues faced in the construction of regional input–output tables in India are well-documented by researchers. When Venkataramaiah et al. (1970) compiled the input–output matrices of 21 states, the authors while recognizing the importance of the final demand vectors, i.e. the vectors on consumption, capital formation and external trade, did not include them as part of the study due to the lack of adequate data at the state level.

Subsequently, many attempts have been made to compile complete regional input–output matrices including the final demand vectors. In an attempt to make optimum use of the available databases, Bhalla et al. (1990) used a very detailed methodology for the construction of input–output tables for 1969/70 and 1979/80 for the state of Punjab. In these tables, data on exports and imports were taken from a survey and for items not covered in survey, taken as residual. As regards capital formation, data on investment, as collected through the Annual Survey of Industries, were used for the registered industries, along with certain publications of the state government on capital formation in rural and urban households, and investment by state government and local authorities. However, due to the absence of adequate information, private corporate sector and investment made by the Union Government in the state have been ignored. In another early work on regional input–output tables, Deman (1990), ‘the capital formation vector is (quoted to be) purely arbitrary and the result of guesswork’.

In a further effort, Saluja et al. (1991), while compiling the input–output matrices of Punjab and Assam, estimates of ‘net trade’ were obtained as ‘residuals’ between the production and demand sides. In the same paper as also in Singh and Singh (2011), ‘first approximation of other final demand categories like gross fixed capital and changes in stocks have been obtained from ASI and allocated to respective sectors'. The assumption here is that the proportions of capital formation in the manufacturing sector are synchronous with the overall capital formation. Now, post-liberalization, many states of India have seen growth not in the manufacturing sectors, but in the service sectors. In fact, state governments are looking for opportunities to develop the service sectors (like software services, tourism and health) in view of the low capital-output ratio and easy availability of domestic market for absorbing output, implying thereby faster returns and shorter lead times. In these circumstances, the assumption is not likely to hold good.

Due to the high data requirement for construction of input–output tables using traditional methods, IO matrices are now also compiled using location quotients. This has been done in Sengupta (2014), for the preparation of input–output table for West Bengal. But these methods also require an initial value to start with. For instance, in this case, 'net trade' obtained as 'residuals' was taken as the epoch values. It may be prudent to note that since iterations would be required to balance the primary matrices before arriving at the final tables, a wrong 'starting vector' may lead to an adjustment in the wrong direction. In the same paper, 'approximated values of other final demand categories like gross fixed capital and changes in stocks have been obtained from ASI and allocated to respective sectors'.

Even the input–output tables compiled by Directorate of Economics and Statistics, Delhi (2013), are an adaptation of the national table, not exploiting the state-level datasets, which may have been able to improve the robustness of these tables. In this table, only international trade has been considered, which is likely to be only an insignificant proportion of the trade vector at the state level, given the fact that the region has a pre-dominant service industry presence and lacks enterprises of both primary and secondary sectors. Further, the total final use, consisting of three components, (i) Private Final Consumption Expenditure (PFCE), (ii) Government Final Consumption Expenditure (GFCE) and (iii) Gross Fixed Capital Formation (GFCF), has been split by using national ratio and proportions, an assumption not likely to hold true, because of the divergence in the structure of the Indian economy and that of Delhi.

In a nutshell, most of the tables available can be classified into two categories—one, which gave only the inter-industry linkages, without some or all of the final demand vectors; and two, which assumed that the national-level ratios were applicable for the state also. Both of these can be viewed as tables with limited utility, which may be appropriate for certain purposes, but not suitable for other analyses. These may also lead to wrong conclusions regarding the inter-dependencies in the regional economy.

3 Methodology and Data

3.1 Sources of Data

Any study in India requires mammoth data so as to cover the regional differences and regional peculiarities. So instead of coming up with prescriptions that can resolve the issues of data requirement for regional input–output tables, a different approach of examining the existing datasets, which gives granular state-wise information to suit these requirements, was undertaken. Three such sets of data which were found suitable for the purpose are outlined below:

1. Inter-state trade data

Directorate General of Commercial Intelligence and Statistics (DGCIS) of the Government of India collects data on intra-Indian trade flows and presents these in the 'Inter-State Movements/Flows of Goods by Rail, River and Air', which provides data on the movement of goods by rail, river and air across 37 trade blocks in India for 99 categories of goods, classified by 2-digit ITCHS codes (Indian Trade Classification based on Harmonized System codes). These data are unique, as they provide insight into domestic trade flows, which are generally not available in developing countries. There are, however, two caveats that need to be noted when using the data. The first is that inter-state trade is measured in volumes and not in values, and the second caveat is that the inter-state trade data do not include trade via roads.

2. External trade data

DGCIS also releases foreign trade statistics for both export and import, giving both value and quantity of India's import/export, by commodity and port on a monthly basis. By concording the ports to states and commodities to ITCHS, prices of import/export can be derived at 2-digit level of ITCHS, by state.

3. CapEx database

CapEx database by the Centre for Monitoring Indian Economy (CMIE) give expenditure on government projects (centre, state and local) and on private corporate sector projects that are currently being implemented. However, the investment expenditure reported is not the expenditure by each project in a year, but the total expenditure for completing each project. The investment expenditure therefore captures investment made in previous years in all ongoing projects and also the expected investment in future years on these projects. The CapEx database captures projects that entail a capital expenditure of Rs. 10 million or more. It contains information on projects recorded by CMIE since 1995. The CMIE CapEx database gives aggregation and comparison of trends in investments by Industry and industry groups; by states and homogeneous regions; and by government and private sectors, separately.

3.2 Preparation of Data for Use

3.2.1 Trade Data

In the Indian context, the following three classifications are used in the datasets concerning trade:

1. National Product Classification for Manufacturing Sector, in line with CPC
2. Indian Trade Classification based on Harmonized System of Coding (ITCHS)
3. Codes for 169 principal commodities, in line with SITC—used in port-level information of imports/exports

So, firstly the data had to be 'prepared' for merging by concording the different classifications. In this study, the different classifications were concorded with 2-digit ITCHS for the purpose of merging the datasets.

Next issue was to convert the 'quantities' of the inter-state trade data to 'values'. Assuming that the import–export prices are applicable to the items shipped out of the state and shipped into the state, respectively, the prices derived from international trade were used to convert the quantities of the 'inter-state movement' database at 2-digit ITCHS into values. For items which were not available in the foreign trade data, prices were taken from the input prices as available from the Annual Survey of Industries data for the particular year.

These datasets were then merged to arrive at estimates for value of total outflow/inflow of goods for the study states.

3.2.2 Capital Formation Data

Capital formation was estimated separately for each of the institutional sectors by apportioning the national estimates to each of the states. This ensured capturing capital formation across industries and also comparability of estimates across states. The methodology was adapted from that described in Rajeswari et al. (2009), (2015).

The CapEx database gives expenditure (cumulative as on date) for government and private corporate sector projects currently being implemented. Investments outstanding at the end of quarter, as available in the database for the projects 'under implementation' stage, have been used as an indicator for allocation across states. The inherent assumption is that the project mix across states is similar, as also that, similar projects will take similar time for completion, irrespective of the state. Quarterly data on four industry groups—'mining', 'manufacturing', 'electricity', 'services' and 'all', further classified as public and private—from March 2011 to March 2015 on the total cost of projects 'under implementation' have been used for the purpose of compiling the estimates of GFCF. Estimates for the industries —'agriculture, forestry and fishing' and 'construction'—have been allocated based on the GFCF of 'all industries'.

For the household sector, indicators were compiled from the different rounds of NSS, namely the Situation Assessment Survey (70th Round of NSS) and Enterprise Survey (67th Round of NSS). The method is outlined in the following paragraphs:

1. Agriculture, forestry and fishing—Estimates of 'net investment in productive asset' for the benchmark year as available from the Situation Assessment Survey of Agricultural Households have been moved using the GVA of 'agriculture, forestry and fishing', to form the state-wise proportions.

2. Manufacturing, trade, other services—Estimates of 'net addition to fixed asset' for the benchmark year as available from the NSS 67th Round Enterprise Survey for the specific industry group have been moved using the GVA of the respective industries, to form the state-wise proportions.
3. Mining, electricity, gas and water supply, construction—Estimates of 'net addition to fixed asset' for the benchmark year as available from the NSS 67th Round Enterprise Survey for 'all industries' have been moved using the GVA of the respective industries, to form the state-wise proportions.

The above methodology was used for GFCF. The other component of capital formation, changes in stock (CIS) has been allocated, industry-wise, in the same proportion as GSVA. It may be noted that the share of CIS is only around 5% in the total capital formation.

Splitting the capital formation vector by institution is also likely to improve the product classification of GCF. Since the three institutions—government, private corporate sectors and households—have distinct asset profiles, the product mix would also be different for these institutional sectors. While the government's major assets are likely to be infrastructural assets like roads, railways and bridges, that of the private corporate sector would be of factories and other non-residential buildings and its associated machinery and equipment. The assets of the household sector are likely to comprise mainly of residential buildings and those of farm sector and small unorganized enterprises.

This classification, by institution, is also likely to alleviate some of the imbalances in the supply and use sides, thereby improving the utility and validity of the input–output tables constructed at the regional level.

3.2.3 The supply–use/input–output Framework

The System of National Accounts contains a wide range of macroeconomic indicators. One of the most important indicators is Gross Domestic Product (GDP) which is estimated by different approaches, based on the different views of the economic system. In theory, the different approaches should produce the same result but in reality they may generate different results. These are often depicted as a 'statistical discrepancy' between the different approaches. Since the compilation of these macroeconomic indicators uses a multitude of data sources and models, the errors are difficult to detect, and hence, a definitive GDP estimation can only be accomplished after a process of balancing and adjustments. Supply and use tables are an effective statistical tool serving primarily as a balancing framework that reconciles the GDP estimation finding the most accurate result, while checking for consistency and completeness of statistical data.

The framework is based on the concept of 'product balance'. The amount of a product entering the economy must have been supplied either by domestic production or by imports. The same amount of the product entering an economy in an accounting period must be used for intermediate consumption, final consumption, capital formation (including changes in inventories) or exports. These two statements can be combined to give a statement of a product balance:

$$\begin{Bmatrix} \textbf{SUPPLY} \\ \text{Output} \\ + \text{Imports} \end{Bmatrix} = \begin{Bmatrix} \textbf{USE} \\ \text{intermediate consumption} + \text{final consumption} \\ + \text{capital formation} + \text{exports} \end{Bmatrix}$$

A full articulation of the product balance for any product, that forms the supply–use table, ensures that the balancing process tends an optimal use of the existing information in order to have an accurate estimation while assessing the quality of respective data sources used, to ensure that determine the sources and methods reliably in order to decide which one is the best estimation of GDP. In other words, the balancing process, by validating product-wise information, helps in eliminating the statistical discrepancy.

Supply and use tables are a powerful tool with which to compare and contrast data from various sources and improve the coherence of the economic information system (Eurostat 2008). These also help in optimizing the use of available information to compile the symmetric input–output tables, which are required for policy analysis. The compilation of input–output tables is, however, an analytical step. The supply–use tables are transformed into the symmetric input–output tables using certain 'product' or 'industry' assumptions.

In this background, in order to make appropriate use of the input–output/supply–use tables, not just for policy analysis but also to re-assess the validity of the 'GDP', it is essential that each of the matrices/vectors of the supply–use tables are constructed using all the available information.

4 Results

With a view to assess the validity of the proposed methodology, it was decided to compile the vectors of trade and capital formation for certain important states. Cue for the selection of states was taken from a cursory study of India, which reveals the spatial pattern of development for the Indian economy. The regions can be delineated on the basis of growth—the western region is industrialized and prosperous while the north-western region strives on agriculture and the eastern region is moderately prosperous; the southern and south-eastern regions are high on the technological front while the south-western region is characterized by high level of human and social development. In this paper, Odisha and West Bengal were chosen to represent the eastern region, a well-endowed region in terms of coal, minerals and water, but is, nevertheless, relatively less-developed, while Gujarat and Maharashtra were selected for the western region. Punjab and Haryana were selected from the northern region, both of which started out as agrarian states but have diversified into the manufacturing sector. Karnataka and Tamil Nadu were selected to represent the southern region.

The detailed results have been given in Tables 3, 4, 5, 6, 7 and 8. Table 3 in the Appendix gives the values of capital formation, GSDP, the share of the state in national GCF and its rate to GSDP for the eight states namely Gujarat, Maharashtra, Punjab, Haryana, Karnataka, Tamil Nadu, Odisha and West Bengal. Table 4 gives the share of GCF by institutional sectors.

Table 5 gives GSDP, total outward and total inward trade while Table 6 gives the corresponding rates to GSDPs. Tables 7 and 8 give the commodity group-wise estimates of outward and inward trade.

4.1 Investment

Of the states under study, Maharashtra alone has a share of about 11% in the national investment, while all these states put together account for more than half of the national GCF. Gujarat, Karnataka and Tamil Nadu are a close second, with a near 10% share. These seem to be following the trend in regional distribution of FDI inflows. However, a comparison with the incomes generated in the state, proxied by their respective GSDP, says a different story altogether. The states of Karnataka and Gujarat as also the states of Haryana and Odisha are investing a creditable 40% share of their GSDP. Haryana and Tamil Nadu also have 'better than national average' rates of investment.

The fact that numbers can be interpreted to suit the interests of the analyst could not get a better example than the set of estimates of institution-wise capital formation. The capital formation of public sector is relatively at around 30% for the states of Odisha and Maharashtra, but the estimate for Odisha is one-third of that Maharashtra. So, while the share of Odisha in public sector GCF is just about 5%, it is 14% for Maharashtra. Share of Karnataka in the public sector GCF is also a significant 10%.

With reference to the private sector, Gujarat, Maharashtra and Karnataka have a share of more than 10% each in the national GCF. But share of the private sector in the state's GCF is the highest in Haryana, followed by Gujarat and West Bengal. Another way of interpreting this would be to say that private sector investment is the dominant factor for the state's capital formation.

The seemingly 'capital-unintensive' household sector is the dominant sector in Tamil Nadu and Punjab. But though Tamil Nadu has a share of 14% in the national household GCF, Punjab has a share of just 4%. Maharashtra and Karnataka, each has a share of about 9% in the national household GCF.

These differences in the institutional shares re-emphasize the importance of compiling these vectors separately for the states as the national product mix or national proportions of capital formation, as aggregated across institutional sectors, may not hold good at the regional level.

4.2 Trade

These estimates include only international trade and inter-state trade via rail, air and water. Gujarat, Punjab and Odisha are 'net exporters', while the other states are 'net importers'. At this stage, GSDP—Net Exports—is negative for Odisha. A look at the following GDP identity—

$$\text{GDP} = \text{PFCE} + \text{GFCE} + \text{GCF} + (\text{Exports} - \text{Imports})$$

re-emphasizes the importance of confronting the information in a supply–use framework, product by product, and revisiting the data sources.

Table 1 gives the value of exports for the eight states.

A simple glance of Table 1 suggests that the largest volumes of export herald from the states of Gujarat, Maharashtra and Tamil Nadu over the period 2012–2015. While the average variation in export volumes remains relatively stagnant, the states of Haryana, Karnataka and Maharashtra have witnessed sustained growth. On the other hand, Odisha and West Bengal experience a fall in absolute volume of export following a marginal rise. Among the Indian states, the lowest quantity of export seen pertains to Odisha. West Bengal and Karnataka form a strong middle-range group in this regard.

A deeper look into the state composition of exports indicates a diversification of exported goods by states. For instance, Gujarat appears to export large volumes of 'crops', 'coke and refined petroleum products' and 'basic metals' with a recent trend of exporting high amounts of chemicals and chemical products'. Haryana, too exported relatively more 'crop' products, 'livestock products', 'textiles, apparel and leather products' and 'machinery and equipment'. Karnataka, Maharashtra, Odisha, Punjab, Tamil Nadu and West Bengal follow both Gujarat and Haryana with relatively large amounts of exports of 'basic metals and metal products other than M&E' and 'machinery and equipment'. Tamil Nadu, Punjab and West Bengal also serve as large exporters of 'Textiles and Apparels'.

A sectoral analysis finds that Maharashtra is largest state exporter of 'livestock products', 'textiles and apparel', 'wood, paper and paper products', 'chemicals, chemical products and botanical products', 'rubber, plastic and other mineral

Table 1 Value of exports for the years 2012–13, 2013–14 and 2014–15 (Rs. in lakh)

State	2012–13	2013–14	2014–15
Gujarat	46,326,432	51,224,529	45,811,803
Haryana	1,936,403	2,356,712	2,683,174
Karnataka	8,492,350	10,168,502	12,058,398
Maharashtra	48,312,997	57,920,113	59,559,323
Odisha	427,971	684,814	253,008
Punjab	2,239,323	2,823,546	2,616,271
Tamil Nadu	18,390,201	20,917,063	20,489,557
West Bengal	6,798,566	8,508,228	7,224,504

Source Calculations by the author

products', 'basic metals', 'machinery and equipment', and 'other manufactured products' in the country increasingly and consistently. Gujarat tops the exporters list in the 'forest products', 'crops', 'food, beverages and tobacco' and 'coke and refined petroleum products'. Tamil Nadu and Maharashtra find themselves competing for the spot of the largest exporter of 'fish and other fishing products' closely followed by West Bengal.

Turning to imports—Table 2 gives the value of imports for the eight states.

Table 2 suggests that the states Gujarat, Maharashtra, Karnataka, West Bengal and Tamil Nadu have the highest volumes of imports into the state. Of particular interest is the increasing nature of imports in all states on average except Odisha and West Bengal which have seen marginal gradual declining trends. As of the year 2015, Gujarat appears to have the highest volume of imports into the state.

A further analysis of the results, focusing on the commodity group-wise values (as given in Appendix), suggests that Gujarat has consistently highest imports of 'Coke and refined petroleum products', 'Chemicals, chemical products and botanical products', 'basic metals and metal products other than M&E'. Haryana, on the other hand, sees similar trends in large volumes of 'machinery and equipment', 'rubber, plastic and non-metallic mineral products' and 'basic metals and metal products'. Karnataka, Maharashtra, Tamil Nadu and Odisha also have import large quantities of 'coke and refined and petroleum products', 'basic metals' and 'machinery and equipment'. Maharashtra and Odisha also import large volumes of 'chemicals, chemical products and botanical products'.

A sectoral analysis reveals that the highest importer of 'crops', 'wood, paper and paper products', 'minerals', 'food, beverages and tobacco', 'chemicals, chemical products and botanical products', 'rubber, plastic and non-metallic mineral products' and 'other manufactured products' in the country is Maharashtra. In the case of 'livestock products' and 'textiles, apparel and leather', Tamil Nadu appears to import the highest value. West Bengal ranks as the largest importer of 'forest products'. In the 'coke and refined petroleum products' sector, Gujarat appears to

Table 2 Value of imports for the years 2012–13, 2013–14, 2014–15 (Rs. in lakh)

State	2012–13	2013–14	2014–15
Gujarat	87,926,142	90,415,342	83,605,999
Haryana	1,138,787	1,412,351	1,715,018
Karnataka	12,290,083	16,279,294	17,035,264
Maharashtra	55,944,788	59,909,123	64,365,909
Odisha	10,736,085	10,270,497	9,588,469
Punjab	1,077,652	1,116,476	1,309,982
Tamil Nadu	34,360,125	32,857,529	32,641,793
West Bengal	12,650,535	12,1341,29	12,009,699

Source Calculations by the author

have the greatest magnitude consistently. Gujarat and Maharashtra also rank the highest in the ‘basic metals and metal products other than M&E’. And, Maharashtra and Tamil Nadu import the highest amounts of ‘fish and other fishing products’.

Moreover, Gujarat, Karnataka, Maharashtra, Odisha, Tamil Nadu and West Bengal are net importers in that their total imports outweigh their exports with the highest trade deficit of Rs. 37,794,196 lakh for Gujarat in the year 2015. Punjab and Haryana emerge as the two only states with sustained trade surpluses over the considered three-year period.

The results, however, paint a different picture when the total values of trade are considered. As can be seen from Table 6 in the Appendix, in that case, though Karnataka, Maharashtra, Tamil Nadu and West Bengal continue to retain their status as ‘net importers’, Haryana is also added to this list. Further, joining Punjab as ‘net exporters’ are the states of Gujarat and Odisha.

5 Conclusion

The estimates for capital formation, by institutional sector, and external and inter-state trade (excluding inter-state road transport) were compiled for the states of Gujarat, Maharashtra, Punjab, Haryana, Tamil Nadu, Karnataka, West Bengal and Odisha for three years—2012–13, 2013–14 and 2014–15. The estimates for capital formation, by institutional sectors, were based on datasets depicting the investment by the institutional sector, thereby improving the reliability of these estimates. The estimates validated some of the well-known facts regarding investment—that Maharashtra has a significant share in the national investment scenario and these eight states (out of a total of 29 States and 7 Union Territories) account for more than 50% of the all-India total. The study also revealed a few rather unknown facts —it is not Maharashtra, but rather Gujarat, Karnataka and Odisha who are investing a better part of the income for improving the growth prospects of the state.

The analysis of the estimates of external and inter-state trade also yielded similar results. External trade estimates validated the fact that most of these states (viz. Gujarat, Karnataka, Maharashtra, Odisha and West Bengal) are net importers, while the states of Punjab and Haryana are net exporters. However, when the total value of goods flowing into the state and those flowing out of the state were added to this value of external trade, a new insight was available. In terms of the total net value of trade (including external and inter-state trade), it is found that Gujarat, Punjab and Odisha export more goods to other countries and states than they import from other countries and states. The remaining states—Maharashtra, Karnataka, Haryana, Tamil Nadu and West Bengal—have a net ‘negative’ trade. Since inter-state road transport is not covered in these estimates, these conclusions may undergo change as and when these are incorporated.

The paper attempted to identify ways to make use of available information to improve the regional supply–use framework so as to incorporate the regional differences essential for policy analysis. The CMIE CapEx database, as also the inter-state trade or port-wise foreign data of DGCIS have been in existence for a long time and have been used for various analytical purposes. Though the information available in these datasets is limited, they might help in improving the reliability of the supply–use tables. However, there are certain limitations that need to be noted while assessing the results presented in this paper:

1. The national and state-level estimates were taken from the website of the Ministry of Statistics and Programme Implementation as on 31 March 2016. The focus being on the methodology and not the accuracy of estimates, the changes in the subsequent releases of the Ministry have not been incorporated.
2. The retrieval date of the CapEx database was 31 December 2016. This is a dynamic dataset allowing changes to affect the past data also. Though care has been taken to present the results only for the years for which data may not be subject to a significant change, these may have undergone revision since then.
3. The analysis on the trade estimates suffers from the lack of data on inter-state road trade. It is recognized that road transport is the major component, and its exclusion restricts the utility of the methodology. The TINXSYS database that has been quoted in the Economic Survey 2018 of Government of India seems to be the way forward for accounting the inter-regional trade.

But despite these limitations, the results reiterate the marked diversity among even similarly placed states in terms of development. This being the case, regional supply–use framework can only help in policy-making if appropriate local data are used for the construction of these tables. Use of national-level ratios even for some of the components, without regionalizing them with the help of appropriate datasets, may defeat the purpose for which the supply–use tables are compiled.

Appendix

See Tables 3, 4, 5, 6, 7 and 8.

Table 3 State-wise estimates of GCF and GSDP (Rupees in crore)

State	GSDP			GCF			Rate of GCF to GSDP (%)			Share in national GCF		
	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15
Gujarat	724,496	807,623	895,927	273,880	325,541	359,952	38	40	40	8.4	9.3	9.6
Maharashtra	1,448,466	1,647,506	1,792,122	377,959	409,980	429,541	26	25	24	11.4	11.5	11.3
Punjab	297,734	334,714	368,011	103,128	103,671	109,341	35	31	30	3.0	2.9	2.8
Haryana	350,407	395,748	441,864	124,538	144,061	158,896	36	36	36	3.9	4.2	4.4
Karnataka	692,224	818,167	920,061	328,722	325,904	379,545	47	40	41	9.9	9.2	9.9
Tamil Nadu	855,481	971,090	1,092,564	333,069	350,673	374,911	39	36	34	9.8	9.7	9.6
Odisha	255,273	277,271	309,807	106,123	113,672	131,732	42	41	43	3.2	3.2	3.4
West Bengal	603,311	706,561	800,868	159,870	142,044	171,591	26	20	21	4.9	4.0	4.4

Source Estimates of GSDP as retrieved from the website of MOSPI, www.mospi.gov.in; remaining items have been estimated by the author

Table 4 State-wise institutional sector-wise shares in GCF

State	Public sector			Private corporations			Household		
	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15
Gujarat	12.0	13.7	13.9	51.4	53.7	59.0	36.6	32.6	27.1
Maharashtra	26.6	27.8	27.5	36.3	38.5	42.8	37.1	33.7	29.7
Punjab	19.3	18.7	22.0	24.5	30.5	31.5	56.2	50.9	46.5
Haryana	11.9	10.5	10.4	70.2	73.4	76.4	17.9	16.1	13.2
Karnataka	22.9	17.6	20.5	38.6	43.3	47.8	38.5	39.1	31.6
Tamil Nadu	12.9	16.9	19.9	27.3	26.0	29.8	59.8	57.1	50.4
Odisha	34.0	32.3	31.7	38.5	41.0	46.2	27.5	26.7	22.1
West Bengal	21.6	26.4	24.1	55.4	46.3	54.8	23.0	27.3	21.0

Source Calculations by the author

Table 5 State-wise estimates of trade and GSDP (Rupees in crore)

State	GSDP			Outward trade			Inward trade		
	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15
Gujarat	724,496	807,623	895,927	1,803,760	2,650,829	274,8402	1,961,025	2,073,251	2,268,376
Maharashtra	1,448,466	1,647,506	1,792,122	1,647,610	1,749,241	2,018,521	2,131,478	2,548,675	2,893,865
Punjab	297,734	334,714	368,011	860,661	1,490,413	1,739,965	447,516	471,494	486,412
Haryana	350,407	395,748	441,864	710,793	1,728,706	1,384,979	1,587,101	2,913,873	2,476,130
Karnataka	692,224	818,167	920,061	753,666	1,023,316	1,129,955	1,339,689	1,878,402	1,732,008
Tamil Nadu	855,481	971,090	1,092,564	483,437	659,592	467,710	705,714	780,665	766,442
Odisha	255,273	277,271	309,807	1,698,728	1,754,385	2,068,895	370,415	499,135	363,173
West Bengal	603,311	706,561	800,868	525,231	875,741	580,976	1,117,480	1,006,793	936,423

Source Estimates of GSDP as retrieved from the website of MOSPI, www.mospi.gov.in; remaining items have been estimated by the author

Table 6 State-wise trade rates to GSDP

State	Outward trade			Inward trade		
	2012–13	2013–14	2014–15	2012–13	2013–14	2014–15
Gujarat	249	328	307	271	257	253
Maharashtra	114	106	113	147	155	161
Punjab	289	445	473	150	141	132
Haryana	203	437	313	453	736	560
Karnataka	109	125	123	194	230	188
Tamil Nadu	57	68	43	82	80	70
Odisha	665	633	668	145	180	117
West Bengal	87	124	73	185	142	117

Source Calculations by the author

Table 7 State-wise commodity group-wise outward trade (Rupees in lakh)

State	Year	Crops	Livestock products	Forest products	Fish and other fishing products	Minerals	Food, beverages and tobacco	Textiles, apparel and leather products
Gujarat	2012–13	2,820,707	10,138	642,549	300,313	429,203	1,905,601	2,116,357
	2013–14	3,334,186	49,184	387,294	372,303	509,581	2,065,744	2,785,920
	2014–15	3,396,713	20,181	298,024	356,660	512,741	1,412,203	2,506,868
Haryana	2012–13	228,623	209,047	418,243	0	6755	4663	234,377
	2013–14	445,533	247,765	185,765	0	7294	6374	367,605
	2014–15	472,060	291,425	159,231	2	9114	13,086	424,922
Karnataka	2012–13	404,358	5623	472	66,390	51,191	81,538	689,194
	2013–14	417,523	7923	1194	108,949	57,399	93,992	783,926
	2014–15	439,497	7633	780	132,364	69,028	125,472	798,018
Maharashtra	2012–13	1,531,544	1,016,081	31,932	282,743	103,215	1,086,794	7,173,217
	2013–14	1,649,055	1,456,897	22,526	414,558	139,963	1,157,366	8,081,148
	2014–15	1,453,369	1,482,715	16,500	429,996	88,929	904,391	8,069,032
Odisha	2012–13	59	0	0	0	109,821	0	0
	2013–14	512	0	0	0	410,760	0	0
	2014–15	0	0	0	1437	58,891	0	0
Punjab	2012–13	342,616	18,148	5198	0	217	189,898	750,494
	2013–14	484,935	18,728	5298	0	242	216,003	995,859
	2014–15	409,465	15,507	3459	0	238	133878	899817
Tamil Nadu	2012–13	955,729	70,252	1528	341,191	697,833	649,765	5,016,311
	2013–14	961,462	97,403	1850	488,557	715,109	504,171	6,625,910
	2014–15	966,034	74,890	3477	513,107	656,539	374,047	6,668,263
West Bengal	2012–13	664,542	2921	34,039	190,525	129,986	156,738	124,0273
	2013–14	1,026,396	5220	44,180	334,973	163,537	231,861	1,444,189
	2014–15	947,210	7615	23,276	390,299	73,050	223,504	1,484,449

(continued)

Table 7 (continued)

State	Year	Wood, paper and paper products	Coke and refined petroleum products	Chemicals, chemical products and botanical products	Rubber, plastic and non-metallic mineral products	Basic metals and metal products other than M&E	Machinery and equipment	Other manufactured products, n.e.c
Gujarat	2012–13	173,885	25,982,179	2,692,377	1,209,937	6,624,132	1,359,562	59,493
	2013–14	196,352	30,392,947	3,302,065	1,667,238	4,596,116	1,510,880	54,717
	2014–15	168,615	26,072,294	3,393,272	1,702,510	4,424,588	1,482,344	64,789
Haryana	2012–13	14,892	68	39,030	147,791	210,991	406,561	15,363
	2013–14	23,944	4	54,992	139,451	286,438	556,204	35,343
	2014–15	24,389	169	77,184	153,035	280,752	740,051	37,755
Karnataka	2012–13	14,727	4,184,874	838,381	70,052	176,341	1,898,112	11,098
	2013–14	19,849	3,381,541	945,643	65,870	1,818,713	2,450,485	15,495
	2014–15	20,556	4,122,770	899,104	73,876	2,236,980	3,117,185	15,136
Maharashtra	2012–13	283,236	1,923,826	7,739,679	1,722,535	16,828,756	8,097,729	491,711
	2013–14	324,215	2,515,526	8,885,899	1,881,202	21,052,918	9,641,610	697,231
	2014–15	354,789	1,902,606	9,323,648	1,906,715	22,103,848	10,892,152	630,634
Odisha	2012–13	37	1251	4918	1930	261,968	47,684	302
	2013–14	0	2320	0	0	271,220	1	0
	2014–15	0	4445	0	0	188,235	0	0
Punjab	2012–13	43,886	2015	57,413	135,812	347,495	330,925	15,207
	2013–14	49,858	2049	71,428	144,457	395,344	418,924	20,421
	2014–15	52,243	685	76,104	137,032	416,382	453,614	17,846
Tamil Nadu	2012–13	128,971	387,255	844,800	575,434	1,745,126	6,868,118	107,888
	2013–14	139,276	831,966	911,598	698,786	1,704,025	7,083,309	153,642
	2014–15	155,094	680,268	997,689	725,409	1,722,523	6,769,430	182,789
West Bengal	2012–13	26,287	474,455	316,043	352,641	2,598,304	577,832	33,980
	2013–14	32,643	680,376	315,567	416,801	2,868,806	873,903	69,776
	2014–15	31,586	352,781	241,179	328,972	2,251,623	809,643	59,317

Source Calculations by the author

Table 8 State-wise commodity group-wise inward trade (Rupees in lakh)

State	Year	Crops	Livestock products	Forest products	Fish and other fishing products	Minerals	Food, beverages and tobacco	Textiles, apparel and leather products
Gujarat	2012–13	115,221	231	20	329	2,146,986	2,331,589	145,263
	2013–14	137,627	844	0	295	2,333,321	2,020,187	173,453
	2014–15	156,337	2073	0	46	1,941,733	2,671,197	208,023
Haryana	2012–13	32,925	485	0	0	13,269	245	49,857
	2013–14	29,675	304	0	0	13,001	307	53,998
	2014–15	17,756	0	0	0	15,464	2313	72,306
Karnataka	2012–13	97,053	198	2	68	21,051	356,183	151,428
	2013–14	105,664	52	194	146	31,646	336,720	172,620
	2014–15	183,492	55	1004	166	45,743	347,335	183,738
Maharashtra	2012–13	1,301,511	15,687	3273	9622	292,780	1,035,761	908,775
	2013–14	1,245,534	17,536	2600	13,072	315,712	1,098,368	997,904
	2014–15	1,585,968	26,256	1168	12,385	397,578	1,259,274	1,139,132
Odisha	2012–13	0	0	0	0	173,159	48,323	0
	2013–14	0	0	0	0	122,705	34,459	4
	2014–15	26	0	0	0	229,228	10,268	23
Punjab	2012–13	114,460	59	0	0	10,929	14,569	102,820
	2013–14	172,249	167	0	0	20,327	13,786	117,794
	2014–15	189,097	166	0	0	30,292	12,569	139,663
Tamil Nadu	2012–13	721,355	30,024	97	6745	1,635,516	846,599	938,290
	2013–14	858,278	31,746	3	13,361	1,528,046	830,688	1,012,165
	2014–15	1,045,727	35,227	30	10,611	1,789,974	776,830	1,140,136
West Bengal	2012–13	233,674	5318	16,837	9379	282,902	1,174,018	314,697
	2013–14	274,093	6847	4072	4766	256,836	1,136,594	335,322
	2014–15	442,254	11,699	5270	5931	362,675	1,254,270	394,467

(continued)

Table 8 (continued)

State	Year	Wood, paper and paper products	Coke and refined petroleum products	Chemicals, chemical products and botanical products	Rubber, plastic and non-metallic mineral products	Basic metals and metal products other than M&E	Machinery and equipment	Other manufactured products, n.e.c
Gujarat	2012–13	841,814	57,744,494	5,075,478	532,813	16,481,566	2,185,817	324,520
	2013–14	971,173	64,784,519	4,518,960	638,800	12,471,061	2,121,260	243,842
	2014–15	1,107,504	54,661,041	5,306,767	815,066	13,984,537	2,562,217	189,456
Haryana	2012–13	24,481	1922	32,902	175,327	295,519	492,132	19,724
	2013–14	33,128	2280	38,243	203,036	338,596	678,417	21,367
	2014–15	65,505	2426	58,203	267,806	376,082	820,657	16,499
Karnataka	2012–13	168,331	5,711,589	375,315	215,014	1,957,415	3,191,312	45,124
	2013–14	195,148	7,890,501	392,887	257,072	3,169,476	3,680,402	46,765
	2014–15	153,501	6,1379,08	469,203	296,606	4,396,157	4,766,276	54,080
Maharashtra	2012–13	1,117,977	8,274,631	7,611,724	3,678,293	13,070,587	17,355,481	1,268,684
	2013–14	1,109,667	8,870,640	9,209,035	4,142,112	13,604,509	18,107,286	1,175,149
	2014–15	1,107,391	7,545,713	9,843,836	4,632,271	15,361,416	20,453,666	999,855
Odisha	2012–13	8	8,746,849	792,109	9863	180,627	274,948	510,200
	2013–14	0	9,258,273	552,856	12	50,113	121,710	130,365
	2014–15	0	8,541,021	571,712	27	14,300	45,791	176,073
Punjab	2012–13	61,806	10,947	45,270	87,501	453,015	168,375	7899
	2013–14	67,043	2935	57,117	115,390	333,772	206,347	9550
	2014–15	87,699	2425	54,877	133,561	430,487	217,816	11,330
Tamil Nadu	2012–13	775,924	4,736,088	2,532,728	1,590,498	7,571,729	12,509,741	464,790
	2013–14	869,155	6,301,026	2,516,387	1,809,613	5,030,258	11,400,281	656,523
	2014–15	892,886	5,374,130	2,658,905	1,880,674	5,011,510	1,1359,553	665,599
West Bengal	2012–13	284,275	2,422,741	1,123,622	402,794	3,478,894	2,134,002	767,381
	2013–14	324,281	2,295,988	1,353,733	408,706	2,949,160	2,297,509	486,219
	2014–15	328,504	2,321,292	1,285,261	466,930	2,688,282	2,037,437	405,427

Source Calculations by the author

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Extension of the Leontief Input–Output Model to Accommodate New Concepts of Sustainability and Social Well-Being

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Abstract The phenomenon of production and consumption of commodities and services is at the centre stage of economic theory and policy. However, it is now well known that any production process will have a bio-physical foundation, and the entropy law will have a role to play in economic processes. Consequently, sustained economic growth will require a continued support of the ecosystem for the economy by way of resource supply and waste absorption. Characterizing sustainability as a process of non-declining inter-temporal well-being of a society, the paper first expands the Leontief input–output model to incorporate the environment as a sector of resource extraction and waste disposal, in addition to the usual sectors of industrial production. Secondly, it factors in the ecological processes of resource regeneration and waste absorption by the ecosystem explicitly into the dynamic version of the Leontief model of multi-sectoral growth. This is helpful for deriving the sustainability condition of economic growth, by recognizing the economy–ecosystem interactive linkages. Since sustainability is conceptualized as a monotonic behaviour of some well-being index, which has as its basis the satisfaction derived by households from consumption, the paper further builds on Leontief's model of inter-industrial inter-dependence, with a view towards developing an index of well-being, as an alternative to that of per capita GDP. It offers a new approach to modelling an economy, with the objective of optimizing the use of a production system with inter-sectoral

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interdependence for attaining a level of human satisfaction at the societal level, without any requirement for monetary evaluation of satisfaction conceived at an abstract level. In this context, the paper shows how the essence of Leontief's notion of interdependence can be extended not only to the ecosystem–economy interactive interface, but also to the analysis of the level, composition and distribution of consumption for delivering social well-being as an output of such consumption.

Keywords Input–Output models · Leontief interdependence · Environment and natural resources · Sustainable development · Ecological economics

JEL Code C67 (Input–output models) · O13 (Natural resource and environment under economic development) · Q56 (Environment and development: sustainability) · Q57 (Ecological economics)

1 Introduction

Leontief's model of input–output analysis, which is based on his model of production, essentially shows how inter-sectoral interdependence determines the structural features of an economy, the sectoral composition of its production, the generation of income, the pattern of inputs—primary or intermediate—and their final uses. The final users comprise households, government, the business sector and the rest of the world. Input–output analysis has provided an immensely powerful tool of analysis of the behaviour of an aggregate economy in a multi-sectoral framework. It has contributed immensely to our understanding of an economy in multiple ways, ranging from macroeconomic accounting, with its linkages to sectoral accounting, to both macroeconomic and sectoral planning, and policy analysis. Its versatile potential applications have covered almost all sectoral issues in agriculture, industry and services, including power and energy, transport and other infrastructure (irrigation), natural resources, environmental protection and climate change through pollution abatement. As sectoral interdependences must be recognized when deriving implications for planning and policies in any of these areas, the input–output literature has been dominant in the arena of methodology of planning and policies for over six decades. The removal of poverty, redistribution, the inflow and dependence of foreign capital, and many other issues from disparate areas have also often required, directly or indirectly, the incorporation of inter-sectoral interdependences for a full assessment of the economy-wide implications of any specific planning or policy measures.

The recent focus on sustainable development and the notion of human well-being has attracted the attention of not only economists, but also other natural and social scientists, who have explored how the Leontief-type relations of interdependence could be used to analyse such issues by appropriate extension or restructuring of the basic model in an interdisciplinary context.

This paper shows how Leontief's notion of interdependence can be extended to the ecosystem–economy interactive interface, as well as to the analysis of the level, composition and distribution of consumption for delivering the output of social well-being out of such consumption.

2 The Ecosystem and the Economy: The Entropy Law, Limitationalism and Issues of Sustainable Development

In the conventional Leontief-based input–output model, the interdependence analysis was confined to the boundaries of economic sectors of production and use. However, this missed a very important aspect of interdependence between the economy and natural ecosystems, which lay outside the boundary of the economy. Indeed, it is now well known and recognized that there exists a bio-physical foundation of production, which points to the interactive relationship between the natural ecosystem and the human economy (Ayres 1978). There are two-way flows of materials and resources from the natural ecosystem to the economy and a return flow of used resources in the form of compounds of wastes from the economy to nature. As pointed out by Georgescu-Roegen, Daly and others, the operation of the law of entropy[1] in economic processes and the bio-geochemical cycles of the earth drive these flows and regenerate resources to the extent permitted by the regenerative power of the ecosystem concerned and the laws of material balance, especially the law of conservation of matter and energy (Georgescu-Roegen 1971; Daly 1973; Ayres 1978; Daly and Farley 2004; Sengupta 2013). These considerations raise the issue of sustainability of resource supply from the ecosystem, on the one hand, and the capacity limit of absorption of waste by nature, on the other. However, the waste arising from the economic system, if not degraded by the ecosystem, accumulates in our ecosystem as non-degraded waste or pollution, which is a source of negative externalities that cause damage to human health, as well as to that of the ecosystem; what is more, the damage to the ecosystem is, in turn, either directly or indirectly harmful to human well-being. These developments partly offset the well-being that humans derive from the material consumption of the products of the economic system. The phenomenon of scarcity of eco-services of resource supply and that of waste absorption have led to the issue of sustainable development. Development is held to be "sustainable" if the size of an economy and its pace of

[1]The second law of thermodynamics is the entropy law. In our context, it is important to note that this law plays an important role in ecological economics by providing justification for the view that all economies would have limits to their growth. Any economy uses low entropy energy and matter drawn from its surrounding natural environment or ecosystem to produce a good for consumption or capital use, and some residual high entropy wastes and heat for being sent back into the environment. Georgescu-Roegen defines a closed thermodynamic system to be the one in which there is no exchange of matter or energy with its environment. An economy as situated in its eco-environment is conceived as a closed system. As a result, the molecular structure of any biochemical compound defining a resource gets disrupted once used in the production process due to no possibility of replenishment of the basic molecular constituents. In view of this, those residual high entropy molecular substances cannot be put back to the same use with same efficiency again and become a waste from anthropocentric point of view. The process of continuous use of resources in production processes is one of continuous degeneration in this finite planet. It is in this philosophical sense we characterize, following Georgescu-Roegen, any process of economic production as an entropic one and can explain "Limitationalism" in the context of economic growth (see Georgescu-Roegen 1971; Ayres 1978).

growth do not disrupt the equilibrium of the ecosystem's functioning or produce any consequent inequity in the distribution of benefits from the use of the limited resources.

Nevertheless, developments in science and technology have provided ways of conserving resources, as well as abating pollution, so as to facilitate the support of the eco-services of nature for economies. Even so, such conservation and abatement efforts involve costs and require part of the resources to be used for such purposes. This calls for an integrated environment–economy analysis so that the problem of allocation of resources recognizes both the cost and the benefit of conservation of scarce natural resources as well as those of abatement of pollution. These considerations obviously require appropriate extension or alteration of the conventional input–output model, to take care of the requirements of an integrated analysis.

Neoclassical economics has suggested introducing the environment as an economic sector. It is, however, not the ecosystem as such that has been reoriented to define an environmental sector. What has been done is that two types of activities, in particular, resource extraction and waste disposal, have been characterized as the activities of the environmental sector (Leontief 1970; Perman et al. 1999; Sengupta 2013). The input–output flows that would be involved in such activities would characterize the additional columns and rows of the input–output table of such an extended model, yet this would represent a somewhat trivial extension of the linear model of Leontief in the activity analysis framework. Indeed, the proper incorporation of the ecosystem–economy interaction would further require the incorporation of some module describing the resource-regenerative function and waste degradation functions of nature and their interface with the environmental sector of an economy-wide input–output model, with sectors comprising the resource extraction and waste disposal activities of an economy. These two functions of the ecosystem operate over time as a dynamic process, which delivers the eco-services needed by an economy. Both the dynamics of resource growth in an economy and the degradation of wastes in the sink of the ecosystem would depend on a complex of interactive dynamic flows driven by the solar energy, bio-geochemical cycles, weather and climate system of our natural environment. Unlike economic production activities, these vital activities or functions of ecosystem supporting economy are not immediately amenable to any input–output representation with linear (fixed coefficient) structure. These can be factored into the economy-environment model of integration, by incorporating them in the concerned dynamic equations of growth of resource stocks or degradation of stock of pollution which would very likely involve nonlinearity.

The issue of the sustainability of economic development or growth can, in fact, be analysed in a dynamic version of Leontief's multi-sectoral input–output model (Dorfman et al. 1958; Chakravarty 1971). The model does need to factor in the interdisciplinary issue of resource regeneration and waste degradation as a subsystem of the equations. We present below a dynamic model of resource use for sustainability developed for this purpose, extending the framework of Leontief's dynamic input–output model. The model characterizes the sustainability of dynamic resource use as one that requires utilization of man-made capital and other natural capital of the ecosystem over time, so that the value of the total inter-temporal well-being yielded by the economic process does not decline over time. It will, in fact, be shown to imply that the environmentally adjusted saving or investment, after taking into account the depreciation of the value of natural capital stocks in addition to those of man-made capita due to their depletion or degradation, should be non-negative over the entire time trajectory of development (Dasgupta 2001; Dasgupta and Mäler 2000). Such measure of genuine savings provides an alternative indicator of sustainability, based on the integration of environmental resource costs with the benefits of economic growth.

3 Extension of the Dynamic Leontief Model for Sustainable Resource Use

Here we extend the dynamic Leontief model to incorporate the development and extraction of natural resources and the disposal into the sink of nature of the wastes arising from the entropic use of those resources. This is achieved by adding new sectors and activities to the analysis. The two-way interaction between the ecosystem and economy, in terms of the flow of virgin natural resources, as regenerated by the ecosystem and flowing to the economy to supply various natural resources and eco-service inputs, and the return flow of wastes from the economy to the sink of nature for their absorption, is the basis for extending the scope of the Leontief modelling framework. It is not only conventional industrial activities but also agriculture, livestock raising, forestry, aquaculture and fishery development that require eco-services because these are essentially products of photosynthetic activities of nature, as aided by human energy, science and technology. Besides, the solar energy flows through the food chain as well as through the atmospheric system of our planet. The bio-geochemical cycles as driven by these flows degrade the degenerated material compounds called wastes and facilitate their absorption into the environment and ecosystem of the planet.

Production activities require as inputs the eco-service of waste absorption that arises at different stages of the life cycle of the resource product chain. Furthermore, since the ecosystem has an upper bound on its capacity to provide such eco-services of supply of natural resources and waste absorption per unit of time, it is the bio-physical foundation of production and the finiteness of our planet that ultimately pose the challenge of sustainability of economic growth and expansion of the human economic system. In order to encompass sustainability, the Leontief-type dynamic model structure needs to incorporate relevant ecological functions and stock dynamic equations, as we describe in the model presented below (Dorfman et al. 1958; Chakravarty 1971; Perman et al. 1999).

In the extended input–output framework for sustainable development analysis, we can classify the *input flows* into the following categories:

i. Intermediate inputs of produced goods and services. These would include the extracted or harvested natural resources that are ready for use for conversion into products.[2]
ii. Primary inputs of labour and capital, where capital includes goods produced in earlier periods for use as means of production, including fixed capital and circulating or inventory capital. Labour can also be conceived as human capital owing to skill and capability acquired through spending on education and health.
iii. Natural resources in place or as geo-resources as primary resource[3] for the economic or human system in any given period, but generated only by the functioning of the ecosystem which has only been mapped as information and therefore been given as primary input for the economic system.
iv. Environmental services of abatement or disposal of waste or pollution.

The *producing sectors* of the economy can be classified into the following categories:

(a) Environmental sectors of development and extraction of natural resources, e.g. coal, oil and minerals. It is the products of these resources that are used by other sectors as intermediate inputs. Such products are distinct from the natural resources of coal, oil or minerals, which represent geological reserves made available by nature through their generation via a geological process.
(b) Environmental protection activities, including safe disposal or abatement of wastes, so that no economic agent or the ecosystem suffers from negative externalities owing to damage to human health or to that of the ecosystem. It may be noted here that the degradation of wastes by the ecosystem is a natural process carried out by the laws of functioning of the ecosystem.
(c) Other industrial or non-industrial production activities (including so-called primary producing sector or service activities).

Let $\boldsymbol{A_1}$ be the inter-sectoral intermediate coefficient matrix for non-environmental goods and services by the non-environmental goods and services producing sector and $\boldsymbol{A_2}$ be the corresponding matrix for the waste disposal sector for environmental protection. Note that a subscript 1 denotes a non-environmental sector, whereas a subscript 2 denotes an environmental sector. Let X be the level of production or activity of the industrial sectors other than the environmental one, and let Z be the level of production or activity of the waste abatement or disposal sectors. However, we integrate the activities of non-environmental sector group (c) and those of environmental protection activities

[2]The resources as converted into products like "coal extracted from mines and ready for use in power industry". It is an intermediate good produced with the help of human labour, and service of machinery of coal mines and other inputs.

[3]*Geological resource such as* coal as lying in the seam underground, but not yet extracted, yet only discovered as prior geological information obtained through seismic survey or satellite imagery, etc.

of group (b) separately and vertically with those of group (a) so that the shares of input requirements of natural resource development and extraction, i.e. of activities of group, (a) are integrated with the concerned activities of group (b) and (c)—both of which use the outputs of the former as inputs.

Let B_1 and B_2 be the Leontief capital coefficient of its dynamic system,[4] i.e. coefficients of non-environmental goods required for stock use in basic industrial activities and those in waste abatement and disposal sector.

Let $\boldsymbol{D_1}$ and $\boldsymbol{D_2}$ denote the matrices of coefficients of primary labour and capital services. As regards environmental inputs, $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ represent the matrices of coefficients of requirements of in situ raw material for extraction or exploitation by the two subsectors. W_1 and W_2, on the other hand, represent the sets of coefficients of waste arising in the different activities of the two groups; W_2 is likely to be near null matrix. W_f is the waste of various kinds arising from the final use of all goods and services, $\overline{W}$ is the vector of flow of wastes to the sink in unabated form, while Z is the total gross wastes abated in the economy, as already mentioned. Finally, let $d = D_1X + D_2Z$ be the total primary factor service required by X and Z, and $r = R_1X + R_2Z$ be the vector of total requirement of natural resources in the different sectoral production activities.

In our simple model, we assume the economy to be closed and final consumption to consist of the expenditure of households and government, denoted by C and G, respectively. We assume investment to be endogenized in the dynamic formulation of this Leontief-type model. If $\dot{X}$ and $\dot{Z}$ denote the change in X and Z per unit of time, the investment use of the sectoral products would be $B_1\dot{X} + B_2\dot{Z}$. We denote again the waste arising from the final uses of the sectoral products W_f, which would be determined by $C + G + B_1\dot{X} + B_2\dot{Z}$.

Let p and t be the vectors of prices of goods of group (i) goods of conventional sectors and group (iv) waste disposal and abatement services. Let v and π further represent prices of primary factors of labour and capital services and those of in situ in-place natural resources groups of (ii) and (iii).

We can present the multi-sectoral dynamic resource-allocation problem as follows. We assume some given initial stocks of natural capital, man-made stock of goods and services, as congealed or contained in the fixed capital and inventory stock of physical capital, and finally pollution stock. We can consider labour here as a kind of capital good (human capital) produced by spending on goods and services like education and health.

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[4]$\mathbf{B_1}$ and $\mathbf{B_2}$ are matrices of capital coefficients of the Leontief dynamic model for the sectors of non-environmental goods and services corresponding to our production group of activities (c) denoted by subscript 1 here, and those of environmental protection services corresponding to our activities of production group (b) denoted by the subscript 2 here, respectively. The typical element b_{ij} of matrices would represent the amount of the concerned good i that would be required for capital stock use for capital formation for a unit increase of output capacity in sector j over time.

$$X = A_1X + A_2Z + B_1\dot{X} + B_2\dot{Z} + C + G \quad (1)$$

$$Z = W_1X + W_2Z + W_f - \overline{W} \quad (2)$$

$$N = r(N, P) - R_1X - R_2Z \quad (3)$$

$$P = W_1X + W_2Z + W_f - \overline{W} - Q(P) \quad (4)$$

$$X \geq 0, Z \geq 0, N \geq 0, P \geq 0, C \geq 0, G \geq 0 \quad (5)$$

$S(0)$: Vector of initial stock of goods as contained in the fixed capital stocks of various sectors and goods inventory,[5]

$N(0)$: the initial stock of natural resources,

$P(0)$: the initial stock of pollutants.

Control variables: C, G and $\overline{W}$ whence C and G are aggregate macro-level private consumption and government consumption, respectively, as already noticed and $\overline{W}$ is the residual unabsorbed aggregate waste vector.

Any dynamic path of $X(t), Z(t), C(t), G(t), N(t), P(t), S(t)$, which would satisfy Eqs. (1)–(5) along with the initial condition, and $\dot{S} = B_1\dot{X}(t) + B_2\dot{Z}(t)$,[6] would describe a feasible path. In order to evaluate the welfare contribution of any such feasible path, we need an inter-temporal social welfare function. Let us assume the following as one such welfare function:

$$V(\tau) = \int_{\tau}^{\infty} \{u((C(t), G(t), P(t)) \exp(-\rho(t - \tau))\} \mathrm{d}t \quad (6)$$

where u is the current utility out of the flow of consumption and environmental quality in terms of level of concentration of pollution as a stock, $P(t)$ is the stock of the pollutant, $V(\tau)$ thus represents the discounted present equivalent value of the stream of current utility where ρ is the time rate of discount. In accordance with the meaning of capitalized value of any flow of benefit like utility, $V(\tau)$ can be shown to be equivalent to the total value of the initial stocks according to their accounting prices based on their respective marginal value contributions.

[5]Where $Q(P)$ is the depreciation of the stock of pollutant due to its degradation as an ecological process, where P is the stock of pollutant.

[6]$\dot{S}$ is not savings. It should be interpreted as change in stocks of goods per unit of time as contained in the form of fixed capital stocks of various sectors and goods inventory as already noted above.

However, the value of wealth actually obtained would depend on the behaviour of the economy with reference to its objectives. This, of course, would depend on the resource-allocation mechanism of an economy, which would be determined by the behavioural pattern of various agents of the economy, their individual values and social norms, the institutional pattern of regulation or incentives in the society and the quality of governance, among other factors (Dasgupta 2001). A given resource-allocation mechanism and the corresponding choice of a path of dynamic solution would yield a value of inter-temporal social welfare. The additional marginal value contribution from this inter-temporal welfare function (6) that would be achieved for a marginal increase (variation) of any initial stock of capital or resource would give us the shadow or accounting price of the stock concerned at the initial date τ. Sustainable development would require that the value of inter-temporal welfare, as attained for a given resource-allocation mechanism, should not decline over time.

i.e. $\frac{dV^*}{d\tau} \geq 0$, where

$$\frac{dV^*}{d\tau} = \sum_i Psi(\tau).\frac{dS_i}{d\tau} + \sum_j P_{Nj}(\tau)\frac{dN_j}{d\tau} + \sum_k p_{Wk}(\tau).\frac{dP_{Wk}}{d\tau}$$
$$= I_S(\tau) + I_N(\tau) + I_W(\tau) = I(\tau) \geq 0$$

where $p_{Si}(\tau)$, $p_{Nj}(\tau)$ and $p_{Wk}(\tau)$ denote the accounting or shadow prices of the ith man-made capital stock, the jth natural capital stock and the kth waste or pollutant stock, respectively, and $\frac{dS_i}{d\tau}$, $\frac{dN_j}{d\tau}$ and $\frac{dP_{Wk}}{d\tau}$ represent changes in these respective physical stocks in the initial period τ. Thus, $I_S(\tau)$, $I_N(\tau)$, $I_W(\tau)$ and $I(\tau)$ would indicate values of the investment or growth in assets in the form of man-made capital, natural capital, bad stock of pollutants and total investment, respectively. The prices based on marginal value contributions are likely to be non-negative for commodity and natural capital stocks, and negative for the pollutant stock. When we require the sum of all three types of investments in stocks to be non-negative for sustainability, we really take a weak view of sustainability, so that all three types of resource capital or stocks are substitutable for ultimately delivering the same level of welfare. In other words, if I_N is negative and I_W is also negative, as expected, investment in the man-made capital stock I_S has to be sufficiently high to make net total investment non-negative, which is the requirement for sustainability.

However, two issues become clear from our above discussion. First, the genuine or environmentally adjusted investment or savings that would be obtained by accounting for depreciation of not only of all kinds of man-made capital stocks, but also of all kinds of natural capital stocks due to their depletion or degradation, would be a true indicator of sustainability of the development process. For the measurement of the value of such an indicator for monitoring sustainability, it is important to inventorize the physical stocks of all the natural resources concerned and the stocks of pollutants in concentrated form, as well as to evaluate them, respectively, with appropriate prices.

In view of the public good nature of many of the environmental goods and services, and ill-defined ownership rights on the space of the ecosystem and non-tradable character of the many of the environmental goods and eco-services, both the tasks pose big challenges, requiring serious efforts in understanding and collecting environmental statistics and developing the methodology of ascertaining their shadow prices in the absence of price and market data. Substantive research and advancement have already taken place in the methodology of evaluation of environmental damages and benefits of improvement either via various indirect methods of revealed environmental preferences through various types of market transaction or through direct stated preferences for alternative contingent situations, as obtained through various types of surveys.

We also need to take note of the fact that a non-negative value of genuine investment may be necessary, but not sufficient, for environmental sustainability. The reason behind the inadequacy for non-negative investment in any particular period is that, in many countries or economies, the ecosystem has already been severely degraded owing to the past neglect of action to protect and conserve it. What is needed in many situations is not merely the conservation and protection of the existing environmental resources but a restoration of environmental conditions to their previous levels via restraint on environmentally damaging consumption and use of resources. However, such restoration would involve high investment and costs and would require finances to be mobilized for that purpose. This would again require cost–benefit analysis of such project initiatives using our conventional input–output model to yield some of the basic data. Planning for environmental enhancement projects cannot thus be taken in isolation and would have to be mainstreamed in the strategy of development. An integrated view of sustainability based on the extension of interdependence analysis to economy-ecosystem interface relations would enable us to analyse efficiency of multidimensional development. An analysis based on an economy-environment integrated model should yield better results and policy insights into the issues concerned.

4 Leontief's Interdependence in Consumption and the Notion of Social Well-Being

Leontief's input–output system has been criticized for the lack of realism of its rigid assumptions of fixed coefficient linear technology and the attendant limitations. The novelty of Leontief's approach lies in its essential idea of interdependences among different sectors, whose application need not be confined to inter-sectoral production–cost analysis, but is extendable to encompass interdependences between the economic system and ecosystem—the latter being governed by the laws of solar energy flow, geochemical cycle and, finally, very much by the entropy law characterizing interaction between the two systems, as discussed above. We have shown how the dynamic Leontief model can be extended to incorporate the role of the ecological process in economic growth and evolution and how sustainability of development can be characterized.

Sustainability, as we have defined it, is a dynamic characterization of the development of a nation's well-being. The concept of well-being is itself a functional one, which depends on the material consumption of various goods and services by a society. We will now demonstrate how Leontief's idea of interdependences can be applied to the extended context of consumption, rather than merely confining it to production. We will attempt to define well-being at the societal level in concrete terms and try to estimate this apparently abstract conceptual entity in empirical terms.

In this section, we define a concept of social well-being which is different from the one underlying Eq. (6) of the preceding section as a part of the model of sustainable resource dynamics and growth as presented. It has nothing to do with the equation under reference. Eq. (6) presents an inter-temporal welfare function where well-being was defined in a top-down approach being entirely determined by the aggregate consumption at societal level along with its inter-temporal distribution, but irrespective of interpersonal distributive consideration. We have conceived well-being of an individual household to be the satisfaction that it derives from the consumption of the different goods and services, separable in such a way that the satisfaction derived from each good is a monotonic increasing function of its amount of consumption. However, given the interpersonal distribution of its consumption (households being ordered according to monthly per capita total consumption expenditure), a typical individual of a household derives satisfaction which is dependent not on the absolute amount but on the relative amount of its consumption with respect to the maximum amount of its per capita consumption as attained by a typical household of the highest expenditure class, i.e. the top or the 10th decile class.

Accordingly for any given commodity or service and its consumption distribution across consumption expenditure classes, the level of satisfaction derived by its consumers of any given expenditure class (say of a given decile) as per such conceptualization can be taken to be the ratio of its actual consumption to the aggregate amount of supply of the concerned commodity that would have been required to provide all the households of the concerned expenditure class with the hypothetical maximum satisfaction. In other words, since any decile class has 10% of the entire population, the societal satisfaction for the consumption of consumers of any decile class of the concerned good would be the ratio or share of its mean per capita consumption to that of the mean consumption of the top (10th) decile class for the same commodity.

Table 1 describes the distribution of per capita consumption expenditure and that of a specific given good and the corresponding societal satisfaction derived for the different consumption expenditure classes for any given good or service. In Table 1, de_i and dc_i are the per capita total consumption expenditure and per capita consumption of a given specific commodity, respectively, of the households belonging to the ith decile class of monthly/yearly consumption expenditure. Q_i is the total amount of the concerned good actually consumed by the households of the

ith decile class. Since all the classes have the same number of people, Q_{10} would also provide the amount of the good that would be required for providing all the people of any decile class of monthly per capita consumption expenditure with the per capita mean consumption of the concerned good as attained by the top or 10th decile expenditure class. Normalizing the maximum achievable satisfaction to the level of 100%, we obtain (Q_i/Q_{10}) 100 as the estimate of the societal satisfaction level of the ith decile expenditure class. These are presented in column 4 of Table 1.

If S_{ij} denote the satisfaction level of the people of ith decile expenditure class derived from the consumption of the jth good, then $S_{ij} = (Q_i^j/Q_{10}^j) * 100$ where Q_i^j denotes the total consumption of the jth good by the ith decile class. Let us define for the jth good, S^j to be the societal satisfaction level from the consumption of the jth good taking all expenditure classes together. This is here taken to be the $S^j = \min_i S_{ij}$ for all i for which $S_{ij} > 0$. Again if, for all the goods and services together, the overall satisfaction level of consumptions for all households together be denoted by S, then S is defined to be min Sj over all j. In such definition, the level of social welfare is thus determined both by the household-wise distribution of consumption goods and also the commodity composition, quite independently. It would point to the necessity of both redistribution of consumption of various goods across income or expenditure class and also alter the product mix of supplies of the different goods. The latter would require the use of conventional input–output model to decide on the sectoral reallocation of resources to raise the overall level of welfare.

Once Table 1 has been generated from the data, we may fit a smooth function or curve to trace the relationship between per capita consumption of a given good and the normalized satisfaction level attained. Its inverse function would be quite useful for the purpose of policy and planning use of such empirical data and model. We have viewed here social well-being as an output of a society or economy where the consumptions of the people of various expenditure classes of the variety of commodities are the inputs. The restructuring of the consumption data in such format along with the analytical frame as presented here illuminates how both the

Table 1 Distribution of monthly per capita consumption expenditure, consumption of specific commodity and level of societal satisfaction from its consumption

Per capita consumption expenditure of decile classes	Per capita consumption of specific commodity of decile expenditure classes	Actual total consumption of the specific commodity of different decile classes	Societal satisfaction level of households of different decile classes in %
de_1	dc_1	Q_1	$(Q_1/Q_{10}) * 100$
de_2	dc_2	Q_2	$(Q_2/Q_{10}) * 100$
…	…	…	…
…	…	…	…
…	…	…	…
de_{10}	dc_{10}	Q_{10}	$(Q_{10}/Q_{10}) * 100$

restructuring of production and redistribution of goods produced among income–expenditure classes become important to remove bottlenecks or obstacles in maximizing the societal overall satisfaction which arises from relative scarcity or availability of any good as well as their sharing among different income–expenditure classes. The kind of reallocation of resources of production for changing supply structure of goods and services and redistribution of products for consumption across income classes that would be suggested by such empirical model-based analysis, is likely to be insightful and helpful for policy guidance for contributing towards greater social sustainability.

From this curve, the results in Table 2 were derived by using the inverse of the fitted function and by way of appropriate interpolation and extrapolation.

However, such basic tables would need to be moderated in the light of various experts' opinion and experience. Thereafter, we could derive the best-fitting curves or functions, so that we could use the model for various analytical and policy purposes.

From the product-wise attainable levels of satisfaction, once we have generated Table 2 for all commodities, the overall attainable level of well-being, or satisfaction, for all commodities together could be determined as follows. Given the physical availability of each product, in physical quantity or value terms, we would need to read from Table 2, for the commodity or service concerned, the maximum level of attainable satisfaction. However, this derivation would assume that, for all other commodities, there is no availability constraint. Since the actual availability of the different products need not be adequate to provide unconstrained maximum satisfaction for all commodities or services, we could determine the maximum attainable overall social satisfaction, as given by the minimum of maximum satisfaction across commodities and services. This would be read from Table 2 for the commodities and services concerned. Here we implicitly assume the non-substitutability of sectoral products for generating welfare, as all of them are required for producing certain levels of overall welfare or satisfaction.

Table 2 Social satisfaction at alternative per capita consumption levels

Social satisfaction at alternative per capita consumption levels		
Alternative satisfaction levels	Per capita consumption level of the concerned item	Total requirement of the product
100%	$\widetilde{x_1}$	$\widetilde{X_1}$
.	.	.
.	.	.
.	.	.
50%	$\widetilde{x_2}$	$\widetilde{X_2}$
.	.	.
.	.	.
.	.	.
0%	$\widetilde{x_n}$	$\widetilde{X_N}$

5 Concluding Remarks

The paper thus points to the potential of Leontief's idea of interdependences in the existing the input–output model to accommodate the following: (a) analysis of inter-temporal natural and man-made capital resource use for sustainable growth of income and capital (b) the application of input–output relationship in defining the concept and content of social welfare which is determined by inter-household distribution of consumption as well as the relative scarcity or availability of the product mix of the consumption goods. While social well-being has been conceptualized in both the parts of the paper, the former part has taken a top-down approach while the latter one a bottom-up one. Besides, the former model analysis has focused on the inter-temporal aspect of social welfare and intergenerational equity, the latter uses a cross-sectional analysis of the state of interpersonal consumption distribution with focus on intra-generational equity. The relative consumption hypothesis of welfare has extended the notion of interdependence of Leontief in the domain of consumption in producing social welfare which is an output delivered by the consumption process. Again, the overall social welfare will be ultimately determined by the most scarcely available commodity in the economy. Its relaxation would require inter-sectoral resource reallocation taking account of conventional sectoral interdependence in production. Finally, both the analytics of the two parts point to the role and importance of data of resources stocks on the one hand and consumption distribution on the other for monitoring sustainability of development process. In view of all these, the paper which has its conceptual foundation in Leontief's sectoral interdependence should have important bearing on the development of database as well as strategy for sustainable development. It is thus essentially the interdependences of consumption of various goods that would generate an overall level of social satisfaction. The paper thus points to the widening of scope of the interdependencies-based analysis, to explain not only sustainable development, but also the notion of social well-being whose monotonic rising trend characterizes sustainability.

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