New Frontiers in Regional Science: Asian Perspectives 41

John R. Madden
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Environmental Economics and Computable General Equilibrium Analysis

Essays in Memory of Yuzuru Miyata

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New Frontiers in Regional Science: Asian Perspectives

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Memorial Address for Professor Yuzuru Miyata

Professor Yuzuru Miyata, a prominent figure in computable general equilibrium modeling for city, region, and environment, passed away on July 18, 2018. He was 64 years old.

Born in Tokyo in 1954, Professor Miyata received his graduation degree from Hokkaido University's Graduate School of Environmental Science. He then earned his PhD from Hokkaido University as well. In 1968, Hokkaido University hired him as an assistant professor. He moved to Kushiro Public University of Economics and then to Toyohashi University of Technology in 1995, where he would be a professor two years later. There he served as president's adviser in 2010 and dean of the Department of Architecture and Civil Engineering in 2015.

His educational and research activities covered various fields such as regional science, environmental economics, urban and regional economics, and civil engineering. Additionally, he developed a variety of urban and regional economic models considering the environmental issues and taught many master's and PhD students. The results of his research have been presented in domestic and international conferences and have also been published in books, journals, and global conferences. His papers in Japanese have been published in domestic journals in Japan, such as *Studies in Regional Science*, *Environmental Science*, *Journal of Human and Environmental Symbiosis*, *Journal of Japan Society of Civil Engineers*, *Infrastructure Planning Review*, and *Journal of the City Planning Institute of Japan*. In a more global aspect, his contributions have been published in *Papers in Regional Science*, *Singapore Economic Review*, *Asia-Pacific Journal of Regional Science*, *Regional Science Inquiry*, and *Journal of Cleaner Production*.

Professor Miyata's primary research interests were the following:

1. Development of computable general equilibrium models with interactions between waste goods and economic activities. Here, he constructed a regional computable general equilibrium model of waste circulation and evaluated the impacts of environmental policy on regional economy.

2. Analysis of household waste pricing and the socioeconomic impacts of a recycling system using computable general equilibrium models. In this topic, he derived many policy implications for supporting urban and regional planning using the said models.
3. Theoretical analysis of a variety of urban economic activities and urban population dynamics. Here, he developed a dynamic urban economic model and proposed a methodology for evaluating urban population dynamics and configurations.
4. Evaluation of a compact city system using computable general equilibrium models. For this topic, he focused on the urban economy of Obihiro City in Hokkaido, constructing a computable general equilibrium model of waste circulation for compact city formation.
5. Evaluation of the impacts of future vehicles on urban economy and environmental emissions. Here, he constructed a computable general equilibrium model for Toyohashi City in Aichi Prefecture and evaluated how electric vehicles affect the urban economy and contribute to environmental emissions.
6. Natural disasters and environment issues. Using the urban economic model, Professor Miyata analyzed flood and environmental risks in Indonesia.

These academic achievements have been published in numerous books and papers. Additionally, Professor Miyata received paper prizes from the Society of Civil Engineers in Japan, Japan Section of the Regional Science Association International (JRSAI), and Japan Association of Human and Environmental Symbiosis (JAHES).

In addition, he was a member of the JSRSAI, JAHES, the Japan Society of Environmental Chemistry, Japanese Economic Association, City Planning Institute of Japan, Japan Association for Real Estate Sciences, Japan Association for Planning and Public Management, and Society of Civil Engineers in Japan. He served multiple roles such as vice president, director, and committee member and contributed greatly in those academic positions. In his social activities, Professor Miyata also served as chairman of committees for governments and supported planning and policy formation at the national, regional, and urban levels.

As an adviser to the president in the Toyohashi University of Technology administration, he contributed in many regional activities. He also implemented many regional services in the university through the Center for Collaborative Regional Planning and Design, Research Center for Future Vehicle City, and Safety and Security Regional Co-creation Research Center. As dean of the Department of Architecture and Civil Engineering, he supported university management.

He also served as the director of Regional Science Association International (RSAI) and the Pacific Regional Science Conference Organization (PRSCO). He worked as an editor for publications such as *Papers in Regional Science*, *Letters in Spatial and Resource Sciences*, and *Regional Science Policy and Practice*.

Professor Miyata dedicated his life to educational and research activities in the region, and his contributions were of immense importance. An essential figure for JSRSAI and RSAI, Professor Miyata is truly appreciated for his impact both on academia and life.

Toyohashi, Japan Hiroyuki Shibusawa

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Part I
Issues in Environment, Energy, and Risk Management: Analysis with CGE Models

Chapter 1
Evidence-Based Analysis of Issues in Environment, Energy, and Disaster Risks with CGE Models: An Introduction to Part I

John R. Madden

Abstract This chapter demonstrates the capabilities of CGE modeling as a tool for the numerical assessment of the likely consequences for economies of a number of severe risks. These relate to the environment, particularly climate change, energy, and disastrous events, such as a pandemic. These were issues of particular concern to Yuzuru Miyata who developed CGE models to examine them. The discussion of the Part I chapters draws out how carefully undertaken CGE analysis can provide vital numerical evidence to inform policy-makers. Particular attention is paid to two key features of the chapters: customization of general-purpose CGE models for capturing essential features of the issue under examination; and a careful examination of simulation results with explanations provided in terms of the key model mechanisms driving them.

Keywords Computable general equilibrium · Environment · Climate change · Energy policy · Risk analysis · Pandemics

1.1 Overview

At the beginning of the 2020s, following the warmest decade for mean global temperatures on record, there are heightened fears of potentially catastrophic outcomes from anthropogenic climate change. While most countries ratified the Paris Agreement with its goal of holding the average global temperature increase to well below 2 °C above pre-industrial levels, it is uncertain whether this target will

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actually be achieved.[1] In many countries, the politics surrounding climate change has constrained mitigation action.

A major component of the policy debate on climate change surrounds the cost of greenhouse gas reduction actions, a question on which there has been a good deal of public disagreement in many countries. It is of clear importance that the public debate should be informed by scrupulous analysis, which provides sound numerical estimates of the overall costs of greenhouse gases mitigation, and of inaction, and of the spread of those costs over counties, regions, and specific groups. The latter is important, since it is those who feel that they might bear a disproportionate share of the costs of mitigation (e.g., owners of fossil fuel assets, workers in high-emitting energy industries) who are probably most likely to oppose climate action.

Since global warming began to emerge as a major issue at the end of the 1980s, computable general equilibrium (CGE) has been deemed to be a method well suited to undertaking numerical analysis of climate change policies.[2] This view is founded on CGE's strong theoretical foundations combined with its extensive empirical data. These qualities are particularly important in climate change analyses, which are regularly concerned with examining future scenarios that are outside the range of previous experience. Central to CGE's strengths is its inclusion of resource constraints and price-responsive behavior. CGE's capacity for detailed treatment of many industries, occupations, regions, and household types allows the identification of winners and losers from policy changes and other economic shocks. CGE projections of the ramifications of climate change scenarios for all sectors of the economy can help move the public debate away from special pleading arguments and provide an evidence base to underpin compensation to groups that are likely to be harmed by policies aimed at reducing the likelihood of catastrophic climate change.[3]

The power of CGE modeling for economic analysis of potential natural and man-made disasters, both at local and at global levels, was well known to Yuzuru Miyata to whom this book is dedicated. He was a leading developer of CGE models in Japan and used his models to examine a range of economic issues facing Japan and

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[1]The Agreement also stated that a target of no more than a 1.5 °C should be pursued. However, the UK Met Office's forecasts suggest a 10% chance that the average mean global temperature may temporarily break the 1.5% temperature increase for a single year of the 2020s between 2020 and 2025 (Vaughan 2020).

[2]Examples of earlier CGE modeling of climate change mitigation policies are: Marks et al. (1990) for Australia, Burniaux et al. (1992) for Europe, and Madden (1991) for an Australian region. Since then CGE has become a standard method for analyzing the economic effects of climate change, mitigation policies, and related energy issues. Among numerous examples in the literature, a few examples are: McKibbin et al. (1999), Adams (2007), Adams and Parmenter (2013), Jorgenson et al. (2013) and McKibbin and Wilcoxen (2013).

[3]It is worth noting in this regard that CGE modeling for Australia has consistently shown the overall cost of substantial climate action is unlikely to be large. For instance, modeling by Philip Adams indicates that achieving Australia's 2030 Paris target by phasing in a domestic emissions trading scheme would reduce the nation's GDP by around 2% (Adams and Parmenter 2013). This is small in comparison to overall economic growth over a 20-year phase in period.

other Asian countries. A key focus of his CGE research was on environmental issues and disastrous events. For instance, in the 1990s Miyata developed a dynamic CGE model to examine waste and recycling issues within an economy-wide framework (Miyata 1995, 1997; Miyata and Pang 2000). Of particular relevance to this book is his CGE modeling of the local effects of a carbon tax (Miyata et al. 2013). The economic effects of other types of potential disasters formed another major research interest for Miyata who developed a dynamic spatial CGE model in order to examine them. Applications of the model included simulating the economic effects of a major earthquake in the Tokai region, an earthquake-prone area facing the possibility of a high magnitude occurrence (Shibusawa et al. 2009; Shibusawa and Miyata 2011).

The following eight chapters of Part I of this book comprise contributions by leading international CGE researchers reporting on model applications that are well-matched with Professor Miyata's interest in examining environmental economic issues and the economic consequences of potentially disastrous events. The major emphasis of Part I is on climate change and associated issues relating to energy, resource depletion, agricultural productivity, and food security. The final chapter in Part I (Chap. 9), however, relates to a risk of a potentially disastrous event, namely the threat of a highly virulent pathogen, Ebola, being imported into a developing country in the Asia-Pacific. With the increase in global travel in recent decades, there is a heightened risk of new (or novel strains of) infectious diseases turning into pandemics. As well as the human cost, the Ebola study shows that an outbreak can have very severe economic effects, particularly where a country lacks preparedness in the form of sufficient surveillance. Restrictions on trade and travel that may be used in an attempt to contain an outbreak—such as those put in place at the time of writing (February 2020) to combat the spread of the novel coronavirus from its epicenter in China's Hubei province—can also have profound economic effects. Dixon et al. (2011) reveal this in their CGE study of a hypothetical US border closure, which highlights the importance of selectivity in the coverage of the bans and strategic stockpiles of certain commodities.

The Part I chapters demonstrate the power of CGE models to capture the key features of policy questions and provide an evidence-based platform for informing policy formation and public debates. The models employed in the various chapters can be described as large-scale general purpose CGE models, which contain a detailed treatment of the behavior of numerous economic agents and the linkages between them.[4] A feature of many of the chapters is that, where a CGE model might not fully capture some attribute of particular importance to a specific issue, new application-specific theory and/or data is introduced. The size and complexity of CGE models mean that considerable emphasis must be placed on explaining simulation results in terms of the model's theory and data, model closure, and the

[4]Our attention in Part I is on the application of CGE models to issues of risk management, particularly the risks posed by climate change. This is just one of the wide range of policy relevant research areas in which CGE models, initially developed to examine mainly tax and trade issues, are now constantly employed.

shocks imposed. A characteristic of the chapters here is the discussion of results, using sound techniques for uncovering the major model mechanisms driving the results. Such result interpretation is necessary to ensure that simulation results are internally valid and hinge on credible theory and data. It also provides the basis for clear explanations and justifications of the findings presented to policy makers and others (see Dixon and Rimmer 2013; Giesecke and Madden 2013).

Part I has a strong focus on the Asia-Pacific, with chapters on two of the three largest Asian economies, China and India (Asia's second largest economy, Japan, is the focus of Part II). Other Asia-Pacific countries studied in Part I are Vietnam, and the small nations of Brunei, Timor-Leste, and the Pacific nation of Fiji. Two chapters report modeling of Brazil, a near neighbor of countries on South America's Pacific coast, and one that shares similar problems, such as deforestation, with a number of Asian nations. As a point of comparison, a chapter with a UK application is also included.

1.2 CGE Analysis of Environmental and Energy Issues in the Asian Region

In Chap. 2, Peter Dixon, Maureen Rimmer, Rajesh Chadha, Devender Pratap, and Anjali Tandon demonstrate the power of CGE modeling in providing the evidence base for policy advice. They examine the efficacy of India's very large agricultural subsidies, a third of which are on fertilizer and electricity inputs, which have detrimental environmental effects. The authors customize their model by giving a regional dimension to the agricultural industries attracting most of the subsidies, thus capturing interregional differences in input mixes and, for electricity, interregional differences in subsidy rates. They conduct subsidy removal simulations and find that the agricultural subsidies involve a substantial deadweight loss, most of it associated with the fertilizer and electricity subsidies. An interesting result is that these two subsidies actually lower farm income, as opposed to the other agricultural subsidies which meet the aim of raising it. The authors demonstrate that a change in the agricultural subsidy mix that involved phasing out of the fertilizer and electricity subsidies would raise real farm income and would have a small positive impact on welfare. The chapter provides an excellent illustration of a convincing explanation of results through back-of-the-envelope (BOTE) techniques. For instance, geometrical BOTE techniques are used to form an initial estimate of welfare effects and regression analysis is then used to examine the extent to which agricultural industry results are the outcome of an expected range of drivers (changes in subsidy rates). While the initial BOTE estimates explain much of the model results, the authors proceed to discover the reasons behind the gaps between the BOTE results and the actual simulation results. This uncovers mechanisms contained in the CGE model, but not in the initial BOTE. This allows the BOTE explanation to be improved, for example, by adding extra explanatory variables to a regression equation. Being able to fully explain a simulation's results in this way greatly adds to the credibility of the authors' simulation results.

Energy and greenhouse emissions in China are the subject of Chap. 3 by Philip Adams and Xiujian Peng. They conduct forecasts for the 2017–2030 period in order to examine the effects on China's growth, energy efficiency, and greenhouse gas emissions targets of alternative policies. The forecasts are carried out with an extended version of the recursive dynamic CGE model, CHINAGEM. The authors' enhancement of CHINAGEM, involved the introduction of detailed modeling of the energy industry, with separate treatment of six substitutable energy types. Domestic gas is separated into conventional and unconventional producers. China is currently experiencing a transition from investment- to services-led growth. Adams and Peng show that by 2030, compared to a business-as-usual forecast, an expected accelerating transition (Scenario 1) will boost China's growth and there would be a slight reduction in greenhouse emissions due to a cleaner energy mix. A significant reduction in greenhouse gas emissions would be achieved under Scenario 2 (a cap on coal consumption), but there would also be a small negative effect on GDP. In the case of Scenario 3 (increasing unconventional gas production), there would be a slight worsening of the level of emissions, but very little (negative) effects on the 2030 Chinese economy. Adams and Peng find that under a well-designed policy that appropriately combined the three policy scenarios, achievement of China's 2030 targets should be attainable.

Another aspect of the energy question is examined by Irene Yap, Philip Adams, and Janine Dixon in Chap. 4 for the small nation of Brunei. The authors use a recursive dynamic CGE model, BRUGEM, to consider Brunei's economic future as its oil and gas resources, on which the nation is heavily dependent, become depleted. They carry out a historical simulation to update their database and then conduct forecast simulations to 2040. Under their baseline forecast (which assumes a continuation of the current level of attempts at diversification), GDP is projected to fall substantially as the hydrocarbon resources become depleted, with a cumulative GDP decrease by 2040 of just over 40% from its 2011 level. The authors consider whether a range of possible productivity improving initiatives might temper this outcome. They simulate an all-factor-saving productivity improvement designed to add one percentage point to annual GDP growth. This would very substantially alleviate the 2040 cumulative decline in GDP. However, they find that achieving such a GDP effect would require a large productivity improvement (2.5% per annum). An important finding is that in order to maintain employment at baseline levels, the real wage would need to fall from its baseline level by 86%. This unexpected finding demonstrates how a CGE model can reveal mechanisms within an economy that might otherwise not be thought of. The explanation for what is not normally the outcome of a productivity improvement stems from some unusual features of the Brunei economy. The economy is dominated by the capital-intensive oil and gas industries, which accounts for 80% of the nation's capital, and the labor-intensive government sector, which employs half the workforce and whose output is assumed fixed for the productivity improvement simulation. With the oil and gas sectors disappearing, there are limited possibilities for the remaining sectors to absorb displaced government workers without a substantial fall in the real wage.

Climate change poses a variety of serious risks for Vietnam. In Chap. 5, Nhi Tran, Huong Pham, and James Giesecke examine the effects of climate change on 6 crops within Vietnam's agricultural sector. Six climate change scenarios are simulated for the 20 years to 2030 with a multiregional dynamic CGE model of Vietnam: three different climate change scenarios, modeled either with or without adaptation (e.g., increased agricultural extension). Results presented are for deviations from a no-climate change baseline simulation. The authors introduce a multi-household income/expenditure extension into their Vietnamese CGE model in order to capture distributional effects. While their model is for a single country, the authors take into account climate change effects on agriculture globally by applying appropriate import and export price shocks to capture changes to the world prices of rice and maize resulting from climate change. With climate change reducing crop yields and harvest areas, the simulations result in negative deviations in Vietnam's GDP and (public and private) consumption. There is considerable variation in regional effects, but with the exception of the Southeast region, all regions are negatively affected. The worst affected region, the Central Highlands that is intensive in the production of coffee, is projected to experience a GDP reduction by 2030 of 20–25% if no extra adaptation measures are put in place. The negative effects are mainly felt by the agriculture sector, with other sectors experience relatively small, and generally negative effects. All urban and regional households are negatively affected, with inequality between income groups increasing mainly due to higher food prices having a greater impact on poorer households. The simulated adaptation measures are of a size to substantially ameliorate these effects. However, for the two climate change scenarios based on the more pessimistic projected temperature increases, virtually all reported variables remain negatively affected.

1.3 Modeling Climate Change Issues in Brazil

Climate change is expected to have substantial effects on human migration. In Chap. 6, Joaquim Ferreira and Mark Horridge investigate the consequence of climate-induced effects on Brazilian agriculture for interregional migration patterns. Their analysis is carried out using the multiregional TERM-MIG model of Brazil, which incorporates an interregional migration module that computes gross bilateral flows of workers between the model's 13 regions as a function of historical migration patterns and relative regional real wages. Using IPCC 2020 worst case and 2070 best case emission scenarios, coupled with agricultural productivity and land loss estimates from the literature, Ferreira and Horridge simulate the impact of climate change on 7 agricultural crops over 55 years to 2070. Annual shocks are estimated for the years 2015–2025 based on the 2020 scenario, while for the latter period the annual shocks are based on the 2070 forecast, in line with their assumption that adaptation measures will be in place during these years. At the national level economic activity progressively falls below the baseline forecast, particularly in the earlier years before adaptation measures are assumed to be put in place. By 2070, the cumulative effect of the climate change scenarios causes real GDP to be almost 0.8% below its baseline forecast, with the real wage down by just over 1%. The effects on the 7 climate-affected crops show them falling into two groups, with 5 of the crops in a band having declines of 1.4%–5.8% below baseline by 2070, but Soybeans and Coffee down by around 40%. Regional outcomes are largely affected by the importance of negatively affected crops and the severity of climate change effects in the different regions. The authors find that the climate change scenarios would reverse current migration patterns, re-establishing some of the more traditional patterns of a few decades ago, with net migration again flowing from agricultural-oriented regions to richer states in the southeast. The decline in agriculture would also see some migration toward the Amazon. TERM-MIG incorporates occupational detail, leading to the revelation that less skilled workers would constitute the larger portion of migrants, threatening to worsen the large slums in the southeast.

Brazil's commitment to the Paris Agreement on Climate Change is substantially based on reducing deforestation. One idea for achieving this is an increase in livestock productivity to release pasture land for crops, easing deforestation pressures. However, livestock price reductions consequent on the productivity improvement would also increase demand for livestock products, leading to an increase in emissions from a larger herd. In Chap. 7, Leandro Stocco, Joaquim Ferreira, and Mark Horridge examine the question of which of these two opposite effects on greenhouse gas emissions might dominate with the aid of TERM-BR, a recursive dynamic multiregional CGE model of Brazil. The model contains two enhancements that enable their study: a land-use module and a greenhouse emissions module. The former module determines land-use transitions, based on historical patterns (revealed by satellite imagery) and relative prices of agricultural products. The latter module computes emissions from two sources: firstly fuel use and activity of productive sectors; and secondly land-use changes, which captures changes in carbon sinks via deforestation/reforestation. The authors make an important innovation in the emissions module so that it takes into account the effects on "activity" emissions of changes in rates of carbon sequestration in soils. With the use of municipal data and satellite imagery, the authors compute the gap between actual and potential livestock productivity, the latter being based on the most productive Brazilian municipalities, adjusted by land aptitude for pasture. They then simulate a 50% reduction in the yield gap and find that this does have an overall positive effect on the economy and does reduce emissions. Taking account of the improved carbon storage in soils associated with pasture improvement is crucial to the emissions reduction result. It turns out that emissions from the increase in herd size do outweigh emission reductions from reduced deforestation, but taking into account increased carbon sequestration more than offsets this, leading to an overall emissions reduction.

1.4 Fiscal Policy and Its Effects on Meeting Energy and CO_2 Emissions Targets in the United Kingdom

The next chapter returns to the questions of emissions and energy, which were the subject of analysis for Asia's most populated country in Chap. 3, and one of its least populated in Chap. 4. The Chap. 8 analysis is for the United Kingdom, one of the foremost countries in the regional science community outside the Asia-Pacific for CGE analysis since the 1980s, principally due to the work of the University of Strathclyde team. In Chap. 8, Andrew Ross, Grant Allan, Gioele Figus, Peter McGregor, Graeme Roy, Kim Swales, and Karen Turner consider the interaction between: (1) a fiscal policy that alters the output mix between the private sector and the lower energy using/CO_2 emitting public sector, and (2) the energy system and overall CO_2 emissions. Their analysis is carried out with their UK CGE model, UK-ENVI, custom built to encapsulate the interdependence between the energy system and the rest of the economy. The model is used to conduct a set of fiscal policy experiments under a range of long-run labor market environments. The labor market is central to their analysis and they initially provide a detailed partial equilibrium analysis of the likely effect of the alternative labor market environments on their results via several diagrams. Their preferred labor market alternative is that of a bargained real wage (BRW), for which they provide supporting evidence of it being the most likely to reflect reality. Other alternatives are for the polar opposites of either exogenous employment or a fixed real wage, the former often employed in CGE modeling, while the latter is sometimes considered to reflect past periods of "real wage resistance" in the United Kingdom. The authors' interest in these alternatives is partly to consider alternative views of how the UK labor market works and partly to benchmark opposite end limits in order to test the sensitivity of results to different labor market assumptions. Simulations are carried out for unfunded increases in government expenditure and for changes in income tax rates to alter debt levels. Their results show GDP to be considerably more sensitive to tax changes than government expenditure changes under the BRW alternative. A balanced budget simulation is then undertaken for a 5% tax increase under the alternative labor market assumptions. Only under the probably unlikely case of a fixed real wage in pre-tax terms is a reduction in emissions accompanied by a long-term increase in GDP. The more elastic are labor supply curves the greater the emissions reduction, but the greater too are the negative effects on GDP. With exogenous employment, GDP declines only slightly due to a compositional move toward a slightly lower capital intensity. The authors also simulate the case of social wage bargaining involving some type of agreement between government and trade unions to modify wage demands in exchange for the benefits received from greater government expenditure. Under this labor market alternative, a rightward shift in the labor supply curve accompanies an increase in government expenditure. This results in a balanced budget increase in government expenditure reducing emissions and increasing employment with only a trivial fall in GDP. The authors note that wage bargaining in the United Kingdom is probably not centralized enough for a social wage bargain. The modeling does suggest, however, the importance of coordination of fiscal and energy policies.

1.5 Modeling Catastrophic Disasters: The Case of a Potential Ebola Outbreak in Small Asia-Pacific Nations

The subject of the last chapter of Part I relates to another major research interest of Professor Miyata, the economic impact of disastrous events. The hypothetical disastrous event considered in Chap. 9 by Nic Geard, James Giesecke, John Madden, Emma McBryde, Rob Moss, and Nhi Tran is a pandemic occurring in developing countries in the Asia-Pacific. Specifically, they considered the economic consequences that might have eventuated if the 2014 West African Ebola pandemic had reached the small nations of Timor-Leste and Fiji. Simulations were carried out for a number of alternative intervention strategies. Pandemics differ in their health effects, and the authors, therefore, developed a stochastic disease transmission model which they tailored to the key characteristics of Ebola. This allowed them to estimate the economic shocks arising from an outbreak in a particular country, prior to applying these shocks to a quarterly version of the GTAP model, GTAP-Q. Some of the key characteristics of Ebola captured by the disease model were: long incubation period, not airborne, very high fatality rate, and continued infectiousness after death. For each intervention strategy, the stochastic disease model was run 500 times, providing a range of outcomes for disease states of the population, varying from outbreaks fading out to them becoming uncontrollable. Typical daily country outcomes for controlled and uncontrolled outbreaks under 5 alternative intervention strategies were converted to quarterly disease state results, which in turn were used in the estimation of GTAP-Q shocks to country-specific health costs and labor productivity during the outbreak, and permanent reductions in each country's population and labor force due to mortality. Estimations for behavioral consequences—severe reductions in international tourism and crowd avoidance—formed further shocks. The GTAP-Q simulations revealed very large economic costs associated with uncontrolled Ebola outbreaks, and in the case of Fiji, which has a significant tourism sector, considerable economic costs for controlled outbreaks. The authors find that purely reactive strategies had virtually no effect on preventing uncontrolled outbreaks, but preemptive strategies substantially reduced the proportion of uncontrolled outbreaks, and in turn the likely economic and social costs.

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Chapter 2
Do Fertilizer and Electricity Subsidies Benefit Indian Farmers? A Hybrid Regional CGE Analysis with Back-of-the-Envelope Explanations

Peter B. Dixon, Maureen T. Rimmer, Rajesh Chadha, Devender Pratap, and Anjali Tandon

Abstract This chapter uses a national computable general equilibrium (CGE) model with regional industries (a hybrid model) to investigate the effects on India of removing or modifying agricultural subsidies which account for about 2.5% of Indian GDP. A third of the subsidies are applied to inputs of fertilizers and electricity to agriculture. The other two-thirds are on production and sales of agricultural products. The deadweight loss associated with the subsidies is 0.20% of GDP. We find that the fertilizer and electricity subsidies contribute most of the deadweight loss and do not contribute to the objective of supporting farm income. If these input subsidies were phased out and replaced with additional production and sales subsidies, then real farm income would be increased by about 4% with no deterioration in the public sector budget, almost no effect on food security, and small increases in GDP and overall welfare. Rather than requiring readers to understand the intricacies of the CGE model, we explain the principal results by back-of-the-envelope calculations invoking familiar mechanisms and identifying key data items and assumptions in our model.

Keywords Fertilizer subsidies · Electricity subsidies · India · CGE model

JEL Classification: C68, Q18, H25

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2.1 Introduction

This chapter presents an analysis of the effects on the Indian economy of India's agricultural subsidies. These subsidies have two objectives: to assist Indian farmers who are among the poorest members of Indian society and to enhance food security. The subsidies are huge: about 2.5% of GDP in 2007–2008, the base year for our study. This puts considerable strain on the public sector budget. There are also environmental concerns. The subsidies encourage farmers to use fertilizers and electricity with potentially adverse implications for water and air quality. Our analysis adds a new layer of concern. We show that the present subsidies are an ineffective way of assisting poor farmers and achieving food security.

The analytical tool for our study is computable general equilibrium (CGE) modelling. By adopting this tool, we can quantify the effects of subsidy removal not only on India's agricultural sector but also on other parts of the Indian economy. An economy-wide perspective is important in dealing with policies (in this case subsidy withdrawal) in which there were obvious losers. As has been recognized in previous CGE modelling of agricultural policies in developing countries, a balanced assessment of reform options requires a tool capable of identifying potential winners as well as losers, see, for example, Giesecke et al. (2013), Mariano and Giesecke (2014) and Mariano et al. (2015).

The CGE model that we use in this study is NCAER-VU. This model was created as a joint project between the National Council of Applied Economic Research in New Delhi and the Centre of Policy Studies at Victoria University in Melbourne. The development of the model and its formal properties are described in a working paper, Dixon et al. (2016). Here, we focus on the results. In addition to elucidating the effects of India's agricultural subsidies, we aim to show that CGE results can be understood via back-of-the-envelope (BOTE) techniques. Readers can accurately assess results without poring through equations, data sets, and computer code. The BOTE techniques illustrated in this chapter are national income arithmetic, demand and supply diagrams, welfare triangles, and explanatory regressions applied to CGE industry results.

The chapter is organized as follows. In Sect. 2.2, we present two tables showing key data elements for the agricultural sector in NCAER-VU. The tables show agricultural subsidies and the division adopted in NCAER-VU of the agricultural sector into 35 producing industries. Although NCAER-VU is a national model, we introduce considerable regional detail by defining agricultural industries on a regional basis. This is the hybrid approach to regional CGE modelling, see Higgs et al. (1988) and Giesecke and Madden (2013). By having several region-based Paddy industries, for example, we can recognize that Paddy is produced in different regions of India with different input mixes and different rates of subsidy. Section 2.3 sets out and analyses four simulations on subsidy removal. Concluding remarks are in Sect. 2.4.

2.2 Introducing Region-Based Agricultural Industries to NCAER-VU

Confronted with a particular policy issue, it is rare for an off-the-shelf CGE model to be suitable for tackling it. Almost always, we need to modify the database or the underlying theory or both. As explained in Dixon et al. (2016), we initially implemented NCAER-VU with the 127-industry input–output data for 2007–2008 published by India Statistics. These tables identify 18 agricultural industries. To facilitate analysis of agricultural subsidies we expanded the agricultural sector from the initial 18 industries to 35 by splitting 6 agricultural industries, accounting for about 80% of subsidies, into 23 region-based subindustries. The splits were based on data supplied by NCAER identifying agricultural industries by their product, input mix, and region. For example, Sugarcane1 is a fertilizer intensive method for producing sugarcane. Table 2.1 shows that Sugarcane1 accounts for 19.97% of national fertilizer use in the production of sugarcane but only 10.92% of national sugarcane output. Table 2.2 shows that Sugarcane1 is undertaken only in Tamil Nadu.

Table 2.1 reveals no differences across agricultural activities in the rate of Fertilizer subsidy. In every case, the subsidy rate is 47.7%, that is, Fertilizer with a value of Rs. 100 costs the farmer Rs. 52.3 [Table 2.1, column (6)]. For Electricity, the subsidy rates vary between 24.5 and 92.0% with an average over all the crops of 62.6% [column (10)].

Columns (11) and (12) of Table 2.1 show Production and sales subsidies and subsidy rates. The rates vary from −0.5 to 32.9% with an average rate of 9.9%.

Column (13) shows the total for each industry of Fertilizer, Electricity and Production and sales subsidies. In column (14), we express these totals as percentages of industry outputs, which we refer to as total subsidy rates. These total subsidy rates vary from −0.5 to 42.7%, and average 14.2%.

2.3 Removing Agricultural Subsidies

We present four simulations with the NCAER-VU model. These can be described as follows:

1. Remove subsidies on Fertilizer inputs to agricultural industries, holding rates of all other subsidies constant. In the 2007–2008 database, the agricultural Fertilizer subsidies total Rs. 213,428 m [Table 2.1, column (5)]. This is 0.428% of GDP, which in 2007–2008 was Rs. 49,866 billion.
2. Remove subsidies on Electricity inputs to agricultural industries, holding rates of all other subsidies constant. In the 2007–2008 database, the agricultural Electricity subsidies total Rs. 172,646 m [Table 2.1, column (9)] or 0.346% of GDP.

Table 2.1 Output, input, and subsidy data for agricultural industries in 2007–2008

Industry	Output (Rs. m)[a]	Share in output of aggregate industry	Fertilizer input (Rs. m)	Share in flow of fertilizer to aggregate industry	Subsidy on fertilizer (Rs. m)	Subsidy rate on Fertilizer	Electricity input (Rs. m)	Share in flow of electricity to aggregate industry	Subsidy on Electricity (Rs. m)	Subsidy rate on Electricity	Subsidy on prodn. and sales (Rs. m)	Subsidy rate on prodn. and sales	Total subsidy (Rs. m)	Total subsidy rate
	(1)	(2)	(3)	(4)	(5)	(6)[b]	(7)	(8)	(9)	(10)[c]	(11)	(12)[d]	(13)[e]	(14)[f]
Paddy1	1,028,505	0.7838	83,657	0.7374	39,908	47.7	84,025	0.7846	52,573	62.6	179,368	17.4	271,849	26.4
Paddy2	215,059	0.1639	21,416	0.1888	10,217	47.7	17,547	0.1638	10,979	62.6	37,384	17.4	58,580	27.2
Paddy3	68,667	0.0523	8379	0.0739	3997	47.7	5523	0.0516	3456	62.6	11,890	17.3	19,343	28.2
Wheat1	298,390	0.3298	25,752	0.3277	12,285	47.7	21,828	0.3304	15,901	72.8	97,931	32.9	126,117	42.3
Wheat2	422,329	0.4668	37,821	0.4812	18,042	47.7	30,808	0.4663	17,420	56.5	138,274	32.8	173,736	41.1
Wheat3	120,695	0.1334	12,707	0.1617	6062	47.7	8812	0.1334	5994	68.0	39,517	32.8	51,574	42.7
Wheat4	63,415	0.0701	2316	0.0295	1105	47.7	4616	0.0699	2020	43.8	20,831	32.9	23,955	37.8
CoarseCereal1	35,111	0.1270	4185	0.1541	1996	47.7	1365	0.1269	851	62.4	1757	5	4605	13.1
CoarseCereal2	75,711	0.2739	6521	0.2401	3111	47.7	2947	0.2739	2251	76.4	3791	5	9153	12.1
CoarseCereal3	35,394	0.1281	4670	0.172	2228	47.7	1376	0.1279	783	56.9	1771	5	4782	13.5
CoarseCereal4	130,176	0.4710	11,783	0.4338	5621	47.7	5073	0.4714	2848	56.1	6517	5	14,986	11.5
Gram	127,505		6026		2875	47.7	4238		2651	62.6	8618	6.8	14,144	11.1
Pulses	448,667		15,087		7197	47.7	4027		2520	62.6	701	0.1	10,418	2.3
Sugarcane1	38,331	0.1092	5897	0.1997	2813	47.7	1499	0.1089	1378	92.0	6711	17.5	10,902	28.4
Sugarcane2	135,615	0.3863	14,320	0.4849	6831	47.7	5314	0.3863	3304	62.2	23,764	17.5	33,900	25.0
Sugarcane3	38,527	0.1097	806	0.0273	385	47.7	1513	0.11	999	66.0	6772	17.6	8156	21.2

Sugarcane4	138,590	0.3948	8508	0.2881	4059	47.7	5432	0.3948	2926	53.9	24,318	17.5	31,304	22.6
OilSeeds1	118,074	0.1973	6835	0.1607	3261	47.7	1253	0.1976	872	69.6	4327	3.7	8461	7.2
OilSeeds2	391,019	0.6536	28,364	0.667	13,531	47.7	4146	0.6536	2580	62.2	14,318	3.7	30,429	7.8
OilSeeds3	68,918	0.1152	7089	0.1667	3382	47.7	727	0.1146	463	63.8	2519	3.7	6364	9.2
OilSeeds4	20,288	0.0339	238	0.0056	114	47.7	217	0.0343	53	24.5	745	3.7	912	4.5
Coconut	71,020		3141		1498	47.7	1		1	62.6	124	0.2	1622	2.3
Jute	19,422		1541		735	47.7	0		0	62.6	0	0	735	3.8
Cotton1	48,021	0.1640	3163	0.1101	1509	47.7	2230	0.1642	1595	71.5	10,280	21.4	13,384	27.9
Cotton2	133,253	0.4550	12,730	0.4431	6073	47.7	6177	0.4548	4040	65.4	28,521	21.4	38,633	29.0
Cotton3	100,170	0.3420	10,650	0.3707	5081	47.7	4650	0.3423	2584	55.6	21,438	21.4	29,103	29.1
Cotton4	11,428	0.0390	2186	0.0761	1043	47.7	525	0.0386	280	53.3	2445	21.4	3768	33.0
Tea	37,585		1295		618	47.7	0		0	62.6	1203	3.2	1821	4.8
Coffee	27,440		0		0	47.7	0		0	62.6	369	1.3	369	1.3
Rubber	70,807		4012		1914	47.7	0		0	62.6	2	0	1916	2.7
Tobacco	25,569		3749		1788	47.7	1735		1086	62.6	2412	9.4	5286	20.7
Fruits	654,907		9615		4587	47.7	5353		3349	62.6	−2468	−0.4	5469	0.8
Vegetables	851,418		14,088		6721	47.7	6450		4035	62.6	−371	0	10,386	1.2
Other Crops	1,093,746		68,849		32,844	47.7	36,522		22,851	62.6	182,499	16.7	238,194	21.8
Milk Prods	1,651,590		0		0	47.7	0		0	62.6	−8176	−0.5	−8176	−0.5
Total or ave	8,815,360		447,400		213,428	47.7	275,929		172,646	62.6	870,107	9.9	1,256,181	14.2

[a]The values in this column are from the NCAER-VU 2007–2008 database
[b]Calculated as 100 times column (5) divided by column (3)
[c]Calculated as 100 times column (9) divided by column (7)
[d]Calculated as 100 times column (11) divided by column (1)
[e]Calculated as sum of columns (5), (9), and (11)
[f]Calculated as 100 times column (13) divided by column (1)

Table 2.2 Value of outputs in agricultural industries by region (Rs. m, 2007–2008)[a]

Region agricultural industry	1 Punjab	2 Haryana	3 Gujarat	4 UttarPradesh	5 Rajasthan	6 Bihar	7 Mad-hyaPrad	8 WestBen-gal	9 Uttarak-hand	10 JamKash-mir	11 Maha-rashtra	12 Jharkhand
1 Paddy1	164,861	68,492	30,196	279,844	0	121,208	15,709	175,751	0	0	27,786	5873
2 Paddy2	0	27	7463	17,130	0	21,963	27,245	48,620	0	0	20,283	35, 760
3 Paddy3	206	0	0	10,349	0	13,138	4379	17,527	0	0	5734	3112
4 Wheat1	218,369	142,246	0	0	0	0	0	0	0	0	0	0
5 Wheat2	0	0	53,369	356,907	98,956	0	0	0	0	0	0	0
6 Wheat3	0	0	0	0	0	61,713	83,625	0	0	0	0	0
7 Wheat4	0	0	0	0	0	0	0	12,819	11,286	6967	28,981	1951
8 CoarseCereal1	0	0	0	0	0	0	0	0	0	0	0	0
9 CoarseCereal2	0	9430	0	0	0	10,401	0	0	0	0	0	0
10 CoarseCereal3	0	0	14,918	21,232	0	0	0	0	0	0	0	0
11 CoarseCereal4	4016	0	0	0	49,302	0	14,680	1870	2354	3462	49,095	2701
12 Gram	0	1213	5087	9213	13,813	1700	42,177	488	0	0	27,152	0
13 Pulses	0	4004	29,631	63,265	62,064	20,021	98,101	6006	0	0	120,925	12,012
14 Sugarcane1	0	0	0	0	0	0	0	0	0	0	0	0
15 Sugarcane2	0	0	0	0	0	0	0	0	0	0	94,837	0
16 Sugarcane3	7181	9510	16,304	0	0	0	0	0	8254	0	0	0
17 Sugarcane4	0	0	0	133,830	0	4133	3414	1363	0	0	0	0

18 OilSeeds1	0	0	105,406	0	0	0	0	0	0	0	0	0
19 OilSeeds2	0	14,241	0	0	93,460	0	141,302	0	0	0	108,369	0
20 OilSeeds3	0	0	0	25,666	0	0	0	15,846	0	0	0	0
21 OilSeeds4	1765	0	0	0	0	3088	0	0	0	0	0	0
22 Coconut	0	0	0	0	0	0	0	1729	0	0	850	0
23 Jute	0	0	0	0	0	2529	0	14,363	0	0	52	0
24 Cotton1	26,921	21,560	0	0	0	0	0	0	0	0	0	0
25 Cotton2	0	0	94,623	0	0	0	0	0	0	0	0	0
26 Cotton3	0	0	0	0	9813	0	0	0	0	0	80,105	0
27 Cotton4	0	0	0	0	0	0	9915	0	0	0	0	0
28 Tea	0	0	0	0	0	0	0	9312	0	0	0	0
29 Coffee	0	0	0	0	0	0	0	0	0	0	0	0
30 Rubber	0	0	0	0	0	0	0	0	0	0	0	0
31 Tobacco	0	0	4105	7314	0	805	0	0	0	0	364	0
32 Fruits	11,521	2570	56,710	43,242	4721	36,261	26,615	27,035	7064	14,982	106,409	3856
33 Vegetables	22,779	26,005	45,467	126,573	4921	89,408	9389	151,649	7197	6837	42,534	24,293
34 OtherCrops	29,272	33,419	58,428	162,657	6323	114,896	12,066	194,881	9249	8786	54,660	31,218
35 MilkProds	142,114	90,134	121,123	288,776	174,190	88,542	100,622	62,575	18,694	23,257	110,390	22,078
	629,006	422,853	642,831	1,545,999	517,563	589,805	589,241	741,833	64,099	64,291	878,524	142,855

(continued)

Table 2.2 (continued)

Region agricultural industry	13 HimachalPrad	14 Assam	15 Karnataka	16 AndhraPrad	17 TamilNadu	18 Odisha	19 Chhattisgarh	20 Kerala	21 Goa	22 Meghalaya	23 Others	Total
1 Paddy1	0	8425	64,676	243,556	105,668	120,298	71,344	9623	0	0	0	1,513,310
2 Paddy2	0	28,987	7357	0	2246	42,917	54,786	1372	0	0	0	316,157
3 Paddy3	0	17,269	1928	2284	635	14,670	8595	417	0	0	0	100,245
4 Wheat1	0	0	0	0	0	0	0	0	0	0	0	360,615
5 Wheat2	0	0	0	0	0	0	0	0	0	0	0	509,232
6 Wheat3	0	0	0	0	0	0	0	0	0	0	0	145,339
7 Wheat4	6967	975	3623	0	0	0	0	0	0	0	2926	76,494
8 CoarseCereal1	6244	0	0	29,623	0	0	0	0	0	0	0	35,867
9 CoarseCereal2	0	0	48,122	0	9430	0	0	0	0	0	0	77,383
10 CoarseCereal3	0	0	0	0	0	0	0	0	0	0	0	36,150
11 CoarseCereal4	0	0	0	0	0	1454	1593	0	0	0	2493	133,019
12 Gram	0	0	8962	22,064	0	725	5087	0	0	0	1700	139,383
13 Pulses	0	0	50,852	68,070	7608	15,216	21,622	0	0	0	11,612	591,009
14 Sugarcane1	0	0	0	0	40,873	0	0	0	0	0	0	40,873
15 Sugarcane2	0	0	28,138	21,768	0	0	0	0	0	0	0	144,743
16 Sugarcane3	0	0	0	0	0	0	0	0	0	0	0	41,248
17 Sugarcane4	0	1052	0	0	0	1181	0	0	0	0	3145	148,118

18 OilSeeds1	0	0	0	0	25,627	0	0	0	0	0	0	131,033
19 OilSeeds2	0	0	0	75,435	0	0	0	0	0	0	0	432,807
20 OilSeeds3	0	0	34,593	0	0	0	0	0	0	0	0	76,105
21 OilSeeds4	0	3088	0	0	0	4412	0	0	0	0	10,147	22,501
22 Coconut	0	660	7939	5433	24,122	1340	0	27,390	621	0	1505	71,589
23 Jute	0	1179	0	866	0	260	0	0	0	87	87	19,424
24 Cotton1	0	0	0	0	0	0	0	0	0	0	0	48,481
25 Cotton2	0	0	0	39,883	0	0	0	0	0	0	0	134,506
26 Cotton3	0	0	8901	0	2282	0	0	0	0	0	0	101,101
27 Cotton4	0	0	0	0	0	0	0	0	0	0	1614	11,529
28 Tea	169	19,838	202	0	5668	0	0	2024	0	0	371	37,585
29 Coffee	0	6	16,301	212	2072	212	0	8603	0	6	29	27,440
30 Rubber	0	0	1571	0	2469	0	0	66,767	0	0	0	70,807
31 Tobacco	0	0	2391	9092	472	0	0	0	0	0	1084	25,627
32 Fruits	6084	15,338	51,328	111,106	4648	14,930	9318	24,924	858	2871	84,472	666,864
33 Vegetables	8442	19,481	51,597	35,183	58,066	56,556	20,312	23,441	385	2777	28,851	862,144
34 OtherCrops	10,849	25,035	66,306	45,213	74,620	72,680	26,103	30,123	494	3569	37,076	1,107,927
35 MilkProds	15,418	11,514	64,979	136,648	100,132	24,880	13,259	34,495	888	1179	6660	1,652,549
	54,172	152,849	519,765	846,438	466,639	371,730	232,019	229,179	3247	10,490	193,775	9,909,204

[a]Output values in this table differ from those in Table 2.1. As explained in Dixon et al. (2016), values in this table include diagonal flows (sales of own product within an industry) whereas these are excluded from Table 2.1

Table 2.3 Percentage effects on Macro variables of removing agricultural subsidies on Fertilizer, Electricity, and Production and sales

	Simulation	Fertilizer (1)	Electricity (2)	Fertilizer and electricity (3)	Fertilizer, electricity, production, and sales (4)
1	Aggregate employment	0.000	0.000	0.000	0.000
2	Aggregate capital and land	0.000	0.000	0.000	0.000
3	Technology	0.000	0.000	0.000	0.000
4	Balance of trade *(change)*	0.000	0.000	0.000	0.000
5	Nominal exchange rate	0.000	0.000	0.000	0.000
6	Real GDP	0.060	0.089	0.156	0.204
7	Real private consumption	0.097	0.100	0.202	0.241
8	Real aggregate investment	0.097	0.100	0.202	0.241
9	Real public consumption	0.097	0.100	0.202	0.241
10	Real aggregate exports	−0.690	−0.081	−0.768	−0.788
11	Real aggregate imports	−0.415	−0.022	−0.436	−0.492
12	Terms of trade	0.186	0.053	0.240	0.192
13	Price deflator for GDP	0.460	0.241	0.705	1.710

3. Remove subsidies on both Fertilizer and Electricity inputs to agricultural industries, holding rates of all other subsidies constant. This is a combination of (1) and (2) above.
4. Same as (3) plus remove Production and sales subsidies on agricultural commodities. In the 2007–2008 database, these latter subsidies total Rs. 870,107 m [Table 2.2, column (11)] or 1.745% of GDP. The total for all subsidies removed in simulation (4) is Rs. 1,256,181 m [Table 2.1, column (13)] worth 2.519% of GDP.

2.3.1 *Macroeconomic Results*

2.3.1.1 Assumptions

Results for macroeconomic variables from the four simulations are given in Table 2.3. The first five rows are entirely filled with zeros. They are included in the table to make our main macroeconomic assumptions explicit. We assume that the removal of subsidies has no effect on aggregate employment, aggregate capital and land, technology,[1] the balance of trade, and the nominal exchange rate. The first

[1]By technology, we mean A variables in production functions of the form $Y_j = F_j\left(\frac{X_{1j}}{A_{1j}}, \frac{X_{2j}}{A_{2j}}, \ldots, \frac{X_{nj}}{A_{nj}}\right)$ where Y_j and X_{ij} are output and inputs for industry j.

three of these assumptions mean that our simulations are focused on efficiency effects of subsidy removal, that is, the benefits of reallocating a given quantity of resources (labor, capital, and land) with given technologies away from subsidized uses in which marginal benefits are less than in alternative unsubsidized uses. The fourth assumption means that the economy uses the efficiency benefit (the increase in GDP) as extra absorption (an increase in C + I + G), leaving no change in the balance of trade. The fifth assumption determines the price level. It has no implications for real variables such as the effects on real GDP. We have chosen the exchange rates as the numeraire. Adjustments in the real exchange rate (competitiveness) necessary to ensure zero outcomes for the change in the balance of trade take place via changes in the domestic price level, indicated by movements in the price deflator for GDP (row 13, Table 2.3).

2.3.1.2 Simulations (1)–(3)

The first two simulations (removal of subsidies on Fertilizer inputs to agriculture and removal of subsidies on Electricity inputs to agriculture) show GDP gains of 0.060 and 0.089% (row 6 in Table 2.3). These results can be explained in terms of consumer and producer surplus diagrams, see Figs. 2.1 and 2.2. In these figures, we measure quantity as the amount that had a basic value of Rs. 1 m in the initial situation. By basic value, we mean the value at the point of production for domestic commodities (factory door or farm gate) and the landed-duty-paid value for imported commodities. Figure 2.1 shows the basic price of Fertilizer in the initial

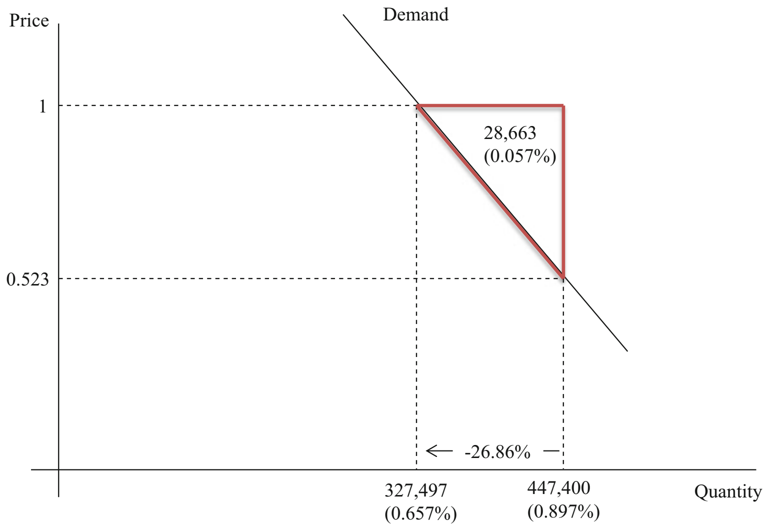

Fig. 2.1 Removing the subsidy on Fertilizer inputs to Agriculture: calculating the GDP or welfare triangle

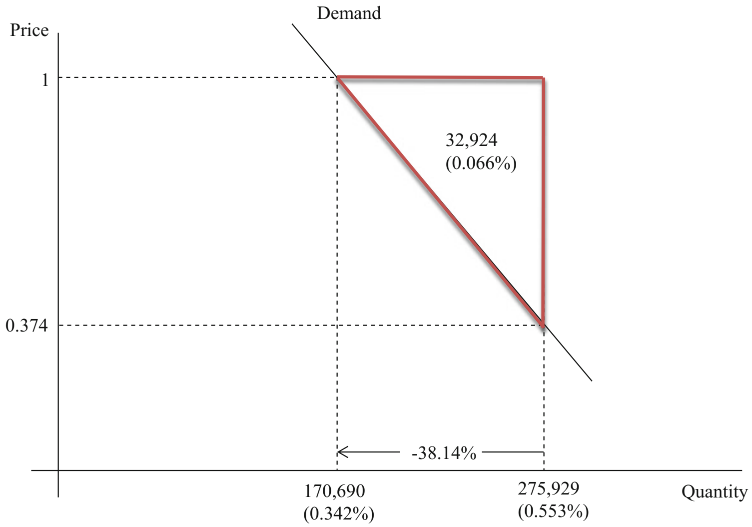

Fig. 2.2 Removing the subsidy on Electricity inputs to Agriculture: calculating the GDP or welfare triangle

situation as 1 and the quantity purchased as 447,400 units, corresponding to the basic value in our database of Fertilizer purchases by farmers of Rs. 447,400 m, which is 0.897% of GDP. The purchasers' value is 52.3% of the basic value, reflecting the average subsidy rate of 47.7%. Removal of the fertilizer subsidy increases the price of Fertilizer to farmers from 0.523 to 1. The simulated effect on their demand for Fertilizer is a reduction of 26.86%. As shown in Fig. 2.1, this suggests a GDP gain of Rs. 28,663 m or 0.057% of GDP. For removal of the subsidy on Electricity inputs to agriculture, Fig. 2.2 suggests a GDP gain of Rs. 32,924 m or 0.066% of GDP.

The back-of-the-envelope calculations in Figs. 2.1 and 2.2 understate the simulated gains shown in Table 2.3: a back-of-the-envelope gain of 0.057% compared with a simulated gain of 0.060% in the Fertilizer simulation; and a back-of-the-envelope gain of 0.066% compared with a simulated gain of 0.089% in the Electricity simulation. The principal reason is that the demand curves implied by NCAER-VU are concave from above rather than linear, meaning that the GDP triangles in Figs. 2.1 and 2.2 underestimate the gains from reducing the use of subsidized Fertilizer and Electricity. NCAER-VU also captures gains and losses from induced changes in taxed/subsidized flows apart from the directly affected Fertilizer and Electricity flows to agriculture. Detailed inspection of our results indicates that these secondary effects are more favorable in simulation (2), the Electricity simulation, than in simulation (1), the Fertilizer simulation. Reductions in the use of fertilizer reduce imports of fertilizer, which bear a tariff. At the same time, a reduction in imports causes a general reduction in exports (recall that we assume zero effect on the balance of trade), which bear export taxes. By contrast, reductions in the use of electricity have relatively little impact on tax-bearing trade flows. These trade effects can be seen in rows 10 and 11 of Table 2.3. In simulation (1), aggregate export and import volumes fall by 0.690 and 0.415% whereas in simulation (2) aggregate export and import volumes fall by only 0.081 and 0.022%.

In simulation (1), it is clear why trade contracts: as we have already explained, the main reason is the contraction in fertilizer imports. But there is a secondary reason, which applies to simulation (2) as well as simulation (1). Removal of subsidies increases the prices of agricultural and agriculture-intensive exports thereby reducing foreign demands. Then, under our assumption of balanced trade, there is a corresponding reduction in imports.

Results for aggregate private consumption, investment, and public consumption are given in rows 7–9 of Table 2.3. In each column, percentage movements in these variables are the same: we assume that subsidy removal does not affect the broad composition of gross national expenditure (C + I + G). Under our assumption of a fixed balance of trade, the percentage movement in gross national expenditure (GNE) is an indicator of welfare. For the Fertilizer and Electricity simulations, the welfare effects (0.097 and 0.100%) measured in this way exceed those in GDP (0.060 and 0.089%).

The source of the extra GNE increases beyond those in GDP is the terms of trade. In NCAER-VU, India faces downward-sloping foreign demand curves for exports but flat supply curves for imports. Consequently, trade contractions in simulations (1) and (2) generate terms-of-trade improvements (row 12, Table 2.1). This explains why the percentage reductions in exports are greater than in imports, even though we assume zero change in the balance of trade. It also explains why in both simulations (1) and (2) the percentage expansions in GNE exceed those in GDP.[2] The deterioration in the real trade balances (and the consequent increases in real GNE relative to real GDP) are facilitated in NCAER-VU by real appreciation (increases in the price deflator for GDP, row 13).

The results in Table 2.3 for simulation (3), in which both the Fertilizer and the Electricity subsidies are removed, show GDP and GNE effects that are greater than the sum of the effects in simulations (1) and (2). For example, the GDP effects in simulations (1) and (2) sum to 0.149%, whereas the GDP effect in simulation (3) is 0.156%. Removal of the subsidy on Fertilizer [simulation (1)] introduces a distortion in the choice by farmers between subsidized electricity inputs and the now unsubsidized fertilizer inputs. This acts as a small offset to the gains associated with the elimination of the distortion in the choice between fertilizer and other inputs excluding electricity. Similarly, removal of the subsidy on Electricity [simulation (2)] introduces a distortion in the choice by farmers between subsidized fertilizer inputs and the now unsubsidized electricity inputs. This acts as a small offset to

[2]In change form we can write the GDP identity as: $Y \times y = B \times b + X \times x - M \times m$ leading to $b = (Y/B) \times y - (X/B) \times x + (M/B) \times m$, where y, b, x, and m are percentage changes in real GDP, real GNE, real exports and real imports, and Y, B, X, and M are corresponding initial values. With trade broadly balanced we can approximate the percentage movement in GNE by: $b = y + (X/B) \times (m - x)$. With $m - x$ greater than zero, b is greater than y.

the gains associated with the elimination of the distortion in the choice between electricity and other inputs excluding fertilizer. When the Fertilizer and Electricity subsidies are removed together, then the fertilizer/electricity choice is not distorted, generating gains from joint removal that are greater than the sum of the gains in the two individual removals. However, from a practical point of view, simulation (3) is close to the sum of simulations (1) and (2): the interaction effects are quantitatively small.

2.3.1.3 Simulation (4)

As can be seen from the descriptions of the simulations at the beginning of this section, the Fertilizer and Electricity subsidies removed in simulation (3) are worth 0.774% of GDP (0.428 plus 0.346). In simulation (4), there is additional removal of subsidies worth more than twice as much, 1.745% of GDP. Nevertheless, simulation (4) shows relatively small GDP and GNE benefits beyond those in simulation (3): a 0.204% increase in GDP in simulation (4) compared with 0.156% in simulation (3); and a 0.241% increase in GNE compared with 0.202%. The relatively small gain from removing Production and sales subsidies on agricultural products reflects low demand and supply elasticities and relatively low subsidy rates.

From column (11) in Table 2.1, we can see that Production and sales subsidies are applied predominantly on Paddy, Wheat, Sugarcane, Cotton, and Other crops. Figure 2.3 represents the demand and supply curves for these highly subsidized crops. It shows the initial quantity of output as 3,954,739 m units, calculated from

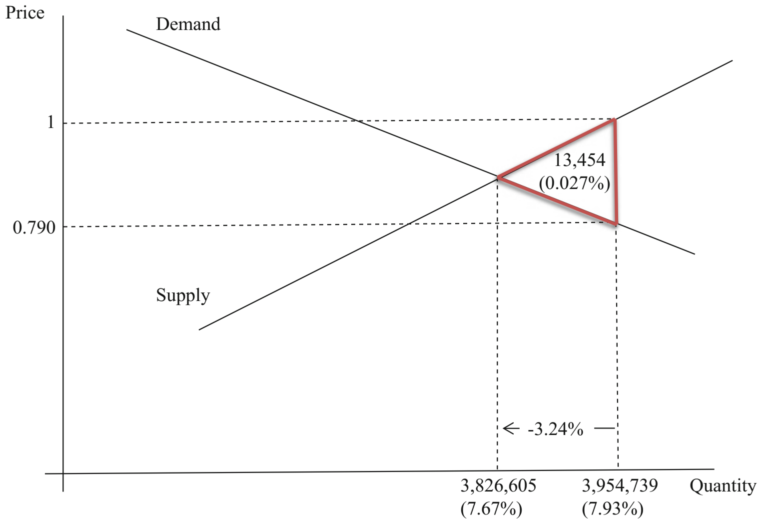

Fig. 2.3 Removing subsidies on Production and sales of agricultural commodities: calculating the GDP or welfare triangle

the values in column (1) of Table 2.1 under the assumption that a unit is the quantity that had a basic price in 2007–2008 of one. The Production and sales subsidies cause purchasers prices to be 0.790 times the basic price [a subsidy rate of 21.0% calculated as 100 × 831946/3954739]. Our simulation results for commodity outputs [Table 2.4], imply that removal of Production and sales subsidies reduces output of the highly subsidized commodities by 3.24%. Via Fig. 2.3, this suggests a GDP gain of Rs. 13,454 m or 0.027%.

The simulated GDP gain is 0.048% [= 0.204 − 0.156, row 6, Table 2.3]. We traced the extra 0.021% gain (the difference between 0.048 and 0.027) to induced movements in tax/subsidy-carrying flows apart from the directly affected sales and output of agricultural commodities. For example, removal of Production and sales subsidies on agricultural commodities changes the composition of Indian exports away from agriculture-intensive commodities such as Apparel, Miscellaneous textile products, Cotton textiles, Miscellaneous food products, and Leather products toward nonagricultural manufactured products and services such as Motor vehicles, Communications, Petroleum products, Business services, and Other services. Our database shows high export taxes for this latter group relative to those for the former group.

While the removal of agricultural Production and sales subsidies increases real GDP by 0.048%, the increase in real GNE is only 0.039% (= 0.241 − 0.202, Table 2.3, rows 7–9). The reason for the subdued response of GNE is that the terms-of-trade improvement is reduced in simulation (4) relative to simulation (3) [0.192% in simulation (4), down from 0.240% in simulation (3)]. At first glance, the lower terms-of-trade improvement in simulation (4) relative to (3) seems surprising in view of the greater contraction in exports in (4) than in (3) [0.788% compared with 0.768%]. The explanation is found in the export demand elasticities adopted in NCAER-VU. The agriculture-intensive exports that contract when Production and sales subsidies are removed have higher export demand elasticities than the nonagricultural exports that expand.

2.3.1.4 Efficiency of Input Subsidies versus Production and Sales Subsidies

Table 2.3 and our discussion of simulations (3) and (4) give the strong impression that subsidies on Fertilizer and Electricity inputs are a relatively inefficient way of supporting producers and consumers of agriculture commodities (the agricultural sector). The Electricity and Fertilizer subsidies provide the agricultural sector with support worth Rs. 386,074 m, but cost the economy 0.156% of GDP [simulation 3, row 6, Table 2.3]. The agricultural Production and sales subsidies provide the agricultural sector with a much greater level of support, Rs. 870,107 m, but cause a smaller reduction, 0.048%, in GDP (0.204 − 0.156, row 6, Table 2.3).

The split of the GDP effect of removing all agricultural subsidies (0.204%) into the part attributable to input subsidies (0.156%) and the part attributable to Production and sales subsidies (0.048%) depends on the ordering of our simulations.

Table 2.4 Percentage effects on commodity outputs of removing agricultural subsidies on Fertilizer, Electricity, production and sales

	Commodity	Fertilizer (1)	Electricity (2)	Fertilizer and electricity (3)	Fertilizer, electricity, production and sales (4)
1	Paddy	−0.49	−0.50	−0.96	−3.09
2	Paddy1	0.08	−0.51	−0.41	−2.55
3	Paddy2	−1.92	−0.52	−2.37	−4.53
4	Paddy3	−4.48	−0.32	−4.69	−6.65
5	Wheat	−0.91	−0.84	−1.78	−6.26
6	Wheat1	−1.13	−1.50	−2.63	−6.75
7	Wheat2	−1.16	−0.53	−1.73	−6.26
8	Wheat3	−2.55	−1.27	−3.79	−8.60
9	Wheat4	4.92	1.07	5.83	0.51
10	CoarsCereal	−0.51	−0.24	−0.73	−1.23
11	CoarsCereal1	−3.13	−0.34	−3.41	−4.06
12	CoarsCereal2	1.00	−0.69	0.31	−0.27
13	CoarsCereal3	−4.82	−0.06	−4.80	−4.94
14	CoarsCereal4	0.51	0.00	0.50	−0.02
15	Gram	−0.35	−0.20	−0.54	−2.48
16	Pulses	−0.34	−0.13	−0.46	−0.74
17	Sugarcane	−0.87	−0.46	−1.29	−3.83
18	Sugarcane1	−7.83	0.13	−7.59	−10.56
19	Sugarcane2	−2.99	−0.57	−3.47	−6.33
20	Sugarcane3	5.41	−0.82	4.52	2.40
21	Sugarcane4	1.42	−0.43	1.00	−1.21
22	OilSeeds	−1.28	−0.38	−1.64	−2.76
23	OilSeeds1	0.02	−0.46	−0.44	−1.43
24	OilSeeds2	−1.35	−0.37	−1.71	−2.88
25	OilSeeds3	−5.00	−0.48	−5.41	−6.52
26	OilSeeds4	5.51	0.23	5.69	4.54
27	Coconut	−0.69	−0.16	−0.83	−1.16
28	Jute	−0.48	0.12	−0.36	−1.28
29	Cotton	−1.14	−0.50	−1.61	−5.65
30	Cotton1	2.26	−0.97	1.27	−2.07
31	Cotton2	−0.93	−0.68	−1.58	−5.72
32	Cotton3	−1.87	−0.13	−1.97	−6.20
33	Cotton4	−11.33	0.35	−10.86	−14.98
34	Tea	−0.52	−0.17	−0.68	−1.13
35	Coffee	−0.44	−0.14	−0.58	−0.97
36	Rubber	−1.36	−0.19	−1.56	−1.12
37	Tobacco	−0.66	−0.39	−1.06	−1.48

(continued)

Table 2.4 (continued)

	Commodity	Fertilizer (1)	Electricity (2)	Fertilizer and electricity (3)	Fertilizer, electricity, production and sales (4)
38	Fruits	−0.42	−0.25	−0.66	−0.58
39	Vegetables	−0.23	−0.14	−0.37	0.03
40	OtherCrops	−0.47	−0.24	−0.71	−3.94
41	MilkProds	−0.10	−0.05	−0.15	0.04
42	AnimServ	0.38	0.39	0.75	−5.96
43	PoultEggs	−0.03	0.00	−0.03	−0.15
44	OthLiveSt	−0.17	0.11	−0.06	−1.53
45	Forestry	0.08	0.11	0.19	0.45
46	Fishing	−0.01	0.03	0.02	0.10
47	Coal	−0.02	−0.43	−0.45	−0.16
48	NatGas	−0.08	0.02	−0.05	0.20
49	CrudeOil	−0.05	0.04	−0.01	0.21
50	IronOre	0.03	0.15	0.18	0.70
51	ManganOre	−0.06	0.25	0.20	0.88
52	Bauxite	0.02	0.20	0.22	0.90
53	CopperOre	0.04	0.40	0.44	1.40
54	OthMetMin	0.01	0.13	0.14	0.60
55	Limestone	0.00	0.10	0.10	0.25
56	Mica	0.13	0.65	0.79	2.72
57	OthNonMetMin	−0.03	0.14	0.10	0.65
58	Sugar	−1.41	−0.77	−2.09	−6.09
59	Khandsari	−0.18	−0.06	−0.23	−0.87
60	Vanaspati	−0.25	−0.05	−0.29	−0.52
61	OthEdibleOil	−1.94	−0.60	−2.51	−4.22
62	TeaCoffee	−0.60	−0.19	−0.78	−1.25
63	MiscFoodProd	−0.34	−0.17	−0.51	−1.19
64	Beverages	−0.05	0.02	−0.03	−0.15
65	TobaccoProd	0.03	0.05	0.08	0.15
66	Khadi	−0.81	−0.25	−1.06	−3.66
67	CottonText	−1.22	−0.58	−1.77	−6.19
68	WoolenText	−0.74	−0.23	−0.97	−3.69
69	SilkText	−0.59	−0.06	−0.65	−2.10
70	SynthFibText	−0.56	−0.14	−0.70	−2.53
71	JuteHemp	−0.41	0.19	−0.22	−0.97
72	CarpetWeav	−0.91	0.08	−0.83	−1.05
73	Apparel	−0.76	−0.16	−0.93	−2.97
74	MiscTextProd	−0.44	−0.10	−0.54	−1.99

(continued)

Table 2.4 (continued)

	Commodity	Fertilizer (1)	Electricity (2)	Fertilizer and electricity (3)	Fertilizer, electricity, production and sales (4)
75	FurnitFixt	0.08	0.06	0.15	0.41
76	WoodProd	−0.04	0.08	0.04	0.14
77	Paperprod	−0.16	−0.01	−0.17	−0.14
78	PrintPub	0.03	0.05	0.08	0.25
79	Footwear	−0.10	0.04	−0.06	−0.54
80	LeathProd	−0.69	−0.10	−0.79	−2.15
81	RubberProd	−0.29	0.07	−0.22	0.06
82	PlasticProd	−0.16	0.10	−0.06	0.08
83	PetrolProd	−0.16	−0.07	−0.24	−0.17
84	CoalProd	0.06	0.07	0.13	0.44
85	InorgChem	−2.58	0.18	−2.42	−2.60
86	OrganChem	−1.05	0.01	−1.05	−1.53
87	Fertilizers	−19.82	0.88	−19.19	−20.68
88	Pesticides	−0.43	0.43	−0.02	−0.84
89	Paints	−0.15	0.09	−0.06	0.07
90	DrugsMedic	−0.34	0.00	−0.34	−0.71
91	SoapsCosmet	0.08	0.15	0.24	0.47
92	SynthFiber	−0.41	0.10	−0.32	−0.39
93	OthChem	−0.53	−0.11	−0.65	−1.06
94	StrClayProd	0.07	0.08	0.16	0.22
95	Cement	0.08	0.08	0.16	0.22
96	OthNMMinProd	0.05	0.14	0.19	0.45
97	IronSteel	0.05	0.25	0.31	0.88
98	ISForge	0.05	0.20	0.25	0.74
99	ISFound	0.06	0.23	0.29	0.78
100	NonFerMetals	0.03	0.67	0.71	1.87
101	HandTools	−0.02	0.17	0.16	0.66
102	MiscMetProd	0.06	0.17	0.24	0.64
103	Tractors	0.15	0.19	0.35	0.41
104	IndMachFT	−0.02	0.22	0.20	0.71
105	IndMachOth	−0.06	0.23	0.17	0.85
106	MachineTool	0.02	0.21	0.23	0.86
107	OthNonEleMac	0.01	0.19	0.21	0.95
108	ElecIndMach	0.08	−0.24	−0.16	0.41
109	WiresCables	0.05	0.19	0.24	0.70
110	Batteries	−0.02	0.20	0.18	0.87
111	ElectApp	0.14	0.18	0.33	0.77
112	CommunEquip	0.04	0.32	0.36	1.49
113	OthEleMach	0.00	0.02	0.02	0.93

(continued)

Table 2.4 (continued)

	Commodity	Fertilizer (1)	Electricity (2)	Fertilizer and electricity (3)	Fertilizer, electricity, production and sales (4)
114	ElectronEqu	0.05	0.26	0.31	1.24
115	Ships	−0.02	0.17	0.15	1.06
116	RailEquip	−0.04	0.03	−0.01	0.30
117	MotorVeh	0.08	0.14	0.22	0.57
118	MotorCycle	0.14	0.17	0.31	0.75
119	Bicycles	0.09	0.14	0.22	0.56
120	OthTranEquip	0.15	0.30	0.46	1.05
121	WatchClock	0.04	0.21	0.26	1.03
122	MedicalInst	0.01	0.17	0.18	0.67
123	Jewelry	0.04	0.21	0.25	0.97
124	Aircraft	0.02	0.18	0.20	0.94
125	MiscManu	−0.08	0.18	0.11	0.96
126	Construction	0.08	0.08	0.17	0.20
127	Electricity	0.10	−7.05	−7.06	−7.40
128	WaterSupply	0.08	0.04	0.13	0.27
129	Railways	−0.09	−0.09	−0.18	−0.02
130	LandTransp	−0.12	0.03	−0.09	−0.17
131	WaterTrans	−0.83	−0.47	−1.31	−1.02
132	AirTrans	−0.08	0.21	0.13	1.12
133	TranspServ	−0.40	−0.15	−0.55	−0.69
134	Storage	−0.11	0.00	−0.10	−0.25
135	Communic	0.02	0.07	0.09	0.58
136	Trade	−0.11	0.01	−0.10	−0.26
137	HotelRest	−0.01	0.03	0.02	0.00
138	Banking	0.01	−0.04	−0.03	0.06
139	Insurance	−0.08	0.04	−0.05	0.19
140	OwnDwell	0.24	0.22	0.48	0.91
141	Education	0.17	0.17	0.34	0.71
142	MedicalServ	0.17	0.17	0.35	0.67
143	BusinServ	−0.23	0.13	−0.10	0.90
144	ComputServ	−0.05	0.29	0.24	2.09
145	LegalServ	0.08	0.23	0.32	1.16
146	RealEstate	0.14	0.18	0.33	0.80
147	RentingME	0.12	0.16	0.29	0.67
148	SocialServ	0.03	0.09	0.13	0.13
149	OtherServ	−0.01	0.28	0.27	1.87
150	PublicAdmin	0.10	0.10	0.20	0.24

The split is different if we remove the Production and sales subsidies first and the input subsidies second. The reason is that in a simulation in which Production and sales subsidies are removed first, there is a GDP benefit from the induced contraction in subsidized Fertilizer and Electricity inputs to agriculture caused by the contraction in agriculture. When the Production and sales subsidies are removed second [as was done in simulation (4)], there is no extra benefit in reducing Fertilizer and Electricity inputs because they are no longer subsidized.

To test the quantitative importance of this idea, we conducted a simulation in which the Production and sales subsidies were eliminated first. In this case, the split of the total GDP effect (0.204%) was 0.134% for input subsidies and 0.070% for production and sales subsidies, still strongly pointing to the conclusion that input subsidies are a costly way of providing support to the producers and consumers of agricultural products.

Relative to a situation in which a given monetary value of support is provided through either subsidizing producers or consumers or both, providing support through subsidies on particular inputs to production generates additional welfare losses by distorting input choices.

2.3.2 Industry Results

The effects on industry and commodity variables of removing agricultural subsidies are given in Tables 2.4, 2.5 and 2.6. We divide our discussion of these tables into three parts. The first two are concerned with agriculture and food. The third part is a brief discussion of results for nonagricultural industries.

Table 2.4 shows the effects on outputs in 150 industries of removing agricultural subsidies. Why 150? As mentioned earlier, the original India Statistics' input–output tables identified 127 industries. We split 6 of the agricultural industries into 23 region-based sub-industries, taking the total to 144. Then we added 6 mixing industries: one for each of the 6 agricultural industries that we had previously disaggregated. The mixing industry for commodity *i* "buys" all of the commodity *i* produced by the relevant sub-industries and "sells" it to rest of the economy including exports in accordance with the sales pattern in India Statistics' input–output table. This took the total to 150 industries.

2.3.2.1 (a) Outputs of Agricultural Commodities/Industries, 1–41

Column (4) of Table 2.4 shows a wide range of results for the outputs of agricultural industries, from −14.98 for Cotton4 to 4.54 for Oilseeds4. The output-weighted average over all agricultural industries (excluding the 6 artificial mixing industries) is a contraction of 2.30%.

A useful technique for explaining industry results from a CGE model is regression analysis [see, for example, Dixon et al. (1977, 1982) and Dixon and

Table 2.5 Percentage effects on real (CPI deflated) farm income of removing agricultural subsidies on Fertilizer, Electricity, Production and sales, and of an income enhancing revenue-neutral subsidy package

		Fertilizer	Electricity	Fertilizer and electricity	Fertilizer, electricity, production and sales	Production and sales	Revenue-neutral farm income enhancing package
	Components of real farm income	(1)	(2)	(3)	(4)	(4a) = (4)–(3)	(5) = (3)–0.44 × (4a)
1	Capital	−0.042	−0.018	−0.077	−3.572	−3.495	1.474
2	Labor	0.027	0.080	0.092	−3.453	−3.545	1.665
3	Land	2.277	1.900	4.170	−2.610	−6.780	7.178
4	Total real farm income	1.041	0.893	1.922	−3.089	−5.011	4.145

Table 2.6 Percentage effects on real prices[a] and consumption (quantities) of food products from removing agricultural subsidies on Fertilizer, Electricity, Production and sales, and of an income enhancing revenue-neutral subsidy package

	Fertilizer		Electricity		Fertilizer and electricity		Fertilizer, electricity, production and sales		Production and sales		Revenue-neutral farm income enhancing package	
	(1)		(2)		(3)		(4)		(4a) = (4)–(3)		(5) = (3)–0.44 × (4a)	
Food prod.	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity
Paddy	2.88	−0.42	3.17	−0.46	6.12	−0.86	21.34	−2.68	15.22	−1.82	−0.63	−0.05
Wheat	2.79	−0.41	2.68	−0.39	5.50	−0.77	36.39	−3.94	30.89	−3.17	−8.21	0.64
Coarse cereal	3.44	−0.51	1.68	−0.24	5.18	−0.73	8.46	−1.24	3.28	−0.51	3.72	−0.50
Gram	1.87	−0.27	1.64	−0.23	3.53	−0.49	7.14	−1.07	3.61	−0.58	1.93	−0.23
Pulses	1.36	−0.19	0.66	−0.07	2.03	−0.26	1.16	−0.22	−0.87	0.04	2.42	−0.28
Sugarcane	2.98	−0.44	1.69	−0.24	4.71	−0.66	18.00	−2.34	13.29	−1.68	−1.19	0.09
OilSeeds	2.47	−0.36	0.62	−0.07	3.11	−0.42	4.66	−0.73	1.55	−0.31	2.42	−0.28
Coconut	1.47	−0.21	0.12	0.01	1.59	−0.19	−0.40	0.02	−1.99	0.21	2.47	−0.28
Fruits	0.70	−0.09	0.54	−0.05	1.24	−0.14	−1.99	0.28	−3.23	0.42	2.67	−0.33
Vegetables	0.86	−0.11	0.60	−0.06	1.46	−0.17	−1.36	0.17	−2.82	0.34	2.71	−0.32
OtherCrops	2.52	−0.37	1.76	−0.25	4.31	−0.60	20.82	−2.62	16.51	−2.02	−3.02	0.30
MilkProds	0.50	−0.09	0.39	−0.05	0.89	−0.14	−0.92	0.17	−1.81	0.31	1.69	−0.28
PoultEggs	0.25	−0.03	0.18	0.00	0.44	−0.02	0.35	−0.16	−0.09	−0.14	0.48	0.04
OthLiveSt	0.19	−0.01	0.10	0.03	0.29	0.02	2.16	−0.61	1.87	−0.63	−0.54	0.30
Fishing	−0.56	0.19	−0.38	0.15	−0.94	0.35	−2.66	0.64	−1.72	0.29	−0.18	0.22
Sugar	1.17	−0.19	0.61	−0.08	1.79	−0.26	7.31	−1.28	5.52	−1.02	−0.66	0.19
Khandsari	1.19	−0.19	0.62	−0.08	1.82	−0.27	7.37	−1.29	5.55	−1.02	−0.64	0.18
Vanaspati	0.86	−0.13	0.12	0.02	0.98	−0.12	0.42	−0.13	−0.56	−0.01	1.23	−0.12
OthEdibleOil	0.83	−0.13	0.11	0.02	0.94	−0.11	0.58	−0.16	−0.36	−0.05	1.10	−0.09
TeaCoffee	0.02	0.02	−0.14	0.06	−0.12	0.09	−1.12	0.16	−1.00	0.07	0.32	0.06
MiscFoodProd	0.27	−0.02	0.18	0.00	0.46	−0.02	0.68	−0.18	0.22	−0.16	0.36	0.05
Average[b]	1.25	−0.17	0.98	−0.11	2.25	−0.27	7.15	−0.74	4.90	−0.47	0.08	−0.06

[a]These are price movements relative to the movement in the CPI. In this table, we show estimates of movements in real purchasers prices to households, assuming that margins are 25% of purchasers prices and that the prices of margins services are not affected agricultural subsidies

[b]Calculated using household expenditure weights

Rimmer (2013)]. We develop hypotheses about features of the model and shocks (in this case subsidy removal) that we think are likely to explain the results. Then we test the hypotheses by regression equations in which CGE results appear on the left-hand side. On the right-hand side, we can include data and parameter values from the model as well as exogenous shocks. Of course, we should not include on the right-hand side endogenous outcomes from the model. If we did, then we would be in danger of circularity: explaining result *x* by result *y*, but what explains result *y*?

The most obvious explanator of the effects on the outputs of agricultural industries of removing agricultural subsidies is the initial rate of the subsidies. We expect industries with initially high subsidy rates to show negative results in column (4) of Table 2.4 relative to industries with initially moderate subsidy rates. We tested this idea by regressing the output results for 35 agricultural industries (we exclude the 6 mixing industries) against the subsidy rates in column (14) of Table 2.1. The result is:

$$\begin{array}{ll} \mathrm{Y}(i) = -0.164 - 0.170 \times \mathrm{SR}(i) & \mathrm{R}^2 = 0.36 \\ (\mathit{0.87}) \quad (\mathit{0.04}) & \end{array} \tag{2.1}$$

where

Y(i) is the percentage change in the output of agricultural industry i [column (4), Table 2.4];

SR(i) is the initial subsidy rate for agricultural industry i [column (14), Table 2.1]; and the numbers in brackets are standard errors.

While the coefficient on SR in Eq. (2.1) has the expected negative sign, the *R*-squared of only 0.36 suggests that there must be other factors operating in NCAER-VU that are important for determining the Y(i)s for agricultural industries. This impression is confirmed in Fig. 2.4 that shows large gaps between NCAER-VU values for percentage changes in industry outputs and fitted values computed from Eq. (2.1).

What does NCAER-VU know that the regression in (2.1) does not capture? For example, why does NCAER-VU show a much less favorable outcome for Cotton4 and a much more favorable outcome for Oilseeds4 than are indicated by the regression equation? The answer is competitive effects within the cotton group of industries and within the oilseeds group. Cotton4 is intensive in the use of Fertilizers, accounting for 7.61% of Fertilizer use in cotton production but only 3.90% of cotton output [columns (4) and (2) in Table 2.1]. Thus, removal of Fertilizer subsidies harms Cotton4 in competition with other cotton industries, leading to a strongly negative output result for Cotton4 (−11.33%) in column (1) of Table 2.4, which explains most of the strongly negative result for Cotton4 (−14.98%) in column (4). By contrast, Oilseeds4 is a light user of Fertilizers, accounting for 0.56% of Fertilizer use in oilseed production but 3.39% of oilseed output [columns (4) and (2) in Table 2.1]. Thus, removal of Fertilizer subsidies favors Oilseeds4 in competition with other oilseed industries, leading to a positive

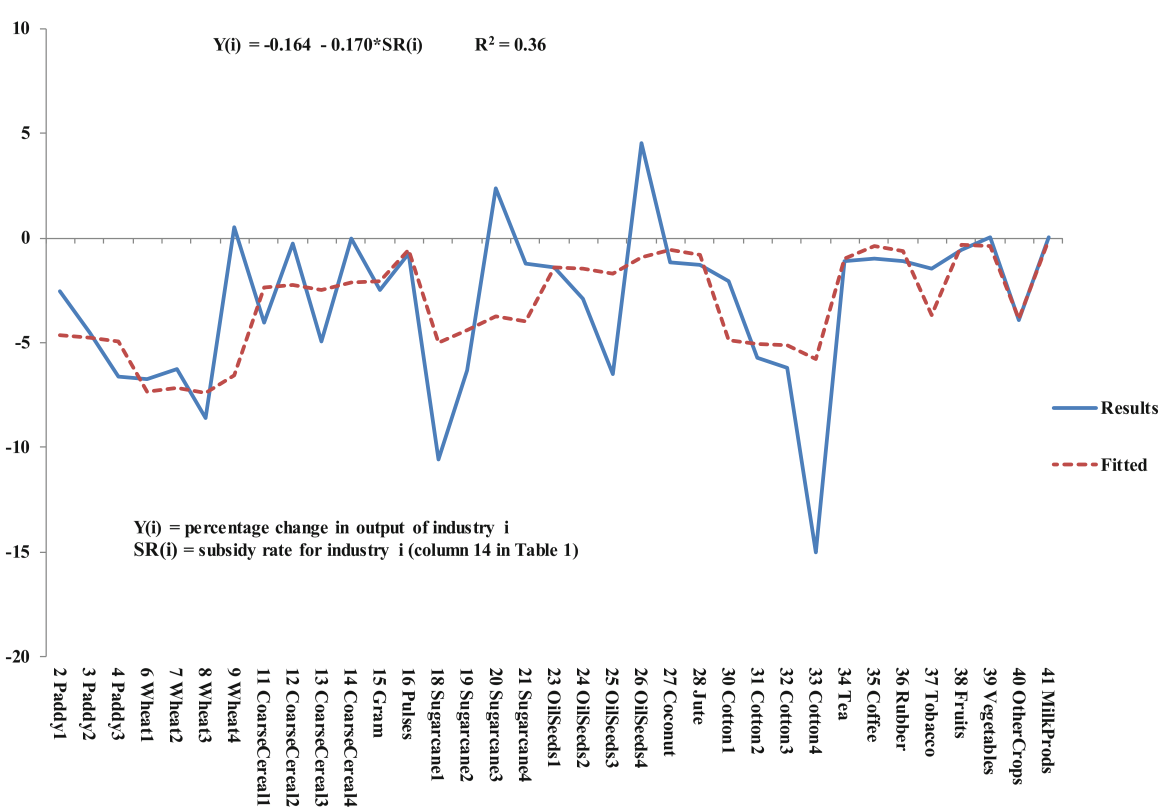

Fig. 2.4 NCAER-VU results for the output of Agricultural industries explained by initial subsidy rates

output result for Oilseeds4 (5.51%) in column (1) of Table 2.4, which explains the positive result for Oilseeds4 (4.54%) in column (4).

To test the competitiveness idea, we expanded the regression described in (2.1) to include variables that take account of the subsidy for each industry relative to the subsidy applied to other industries producing the same crop. For example, we included variables that take account of the difference between the subsidy rate for Paddy1 [26.4%, column (14), Table 2.1] and the average subsidy rate over Paddy1, Paddy2, and Paddy3 [27.3%]. We expect the coefficients on these additional variables to be negative. The loss of a high relative subsidy will have a negative effect on an industry, beyond what can be explained simply by the level of the subsidy. The result from the expanded regression is:

$$\begin{aligned} &\mathrm{Y}(i) = -0.575 - 0.146 \times \mathrm{SR}(i) - 2.206 \times \mathrm{D\_P}(i) - 1.615 \times \mathrm{D\_W}(i) - 2.554 \times \mathrm{D\_CC}(i) \\ &(\mathit{0.34}) \quad (\mathit{0.02}) \quad (\mathit{0.99}) \quad (\mathit{0.31}) \quad (\mathit{0.76}) \\ &- 1.619 \times \mathrm{D\_SC}(i) - 2.173 \times \mathrm{D\_OS}(i) - 2.298 \times \mathrm{D\_COT}(i) \quad \mathrm{R}^2 = 0.92 \\ &(\mathit{0.22}) \quad (\mathit{0.35}) \quad (\mathit{0.31}) \end{aligned} \tag{2.2}$$

where

D_P(i) is the deviation of i's subsidy rate from the average subsidy rate for Paddy industries if i is a Paddy industry, else 0

D_W(i) is the deviation of i's subsidy rate from the average subsidy rate for Wheat industries if i is a Wheat industry, else 0

D_CC(i) is the deviation of i's subsidy rate from the average subsidy rate for Coarse cereal industries if i is a Coarse cereal industry, else 0

D_SC(i) is the deviation of i's subsidy rate from the average subsidy rate for Sugarcane industries if i is a Sugarcane industry, else 0

D_OS(i) is the deviation of i's subsidy rate from the average subsidy rate for Oilseed industries if i is an Oilseed industry, else 0

D_COT(i) is the deviation of i's subsidy rate from the average subsidy rate for the Cotton industries if i is a Cotton industry, else 0

The coefficients on all variables on the right-hand side of (2.2) have the expected negative sign. The *R*-squared is 0.92 implying that (2.2) captures the main mechanisms in NCAER-VU that are important for determining the Y(i)s for agricultural industries. This is confirmed in Fig. 2.5 that shows small gaps between NCAER-VU simulation values for percentage changes in industry outputs and fitted values computed from Eq. (2.2).

Although the gaps in Fig. 2.5 are small, they have one obvious systematic feature: the fitted values for the 4 cotton industries lie noticeably above the NCAER-VU simulated values. A factor recognized by NCAER-VU but missing in (2.2) is exposure to price-sensitive export markets. While most of the Indian agriculture faces little competition from imports and has little dependence on exports, this is not true for cotton. There are no direct imports or exports of cotton. However,

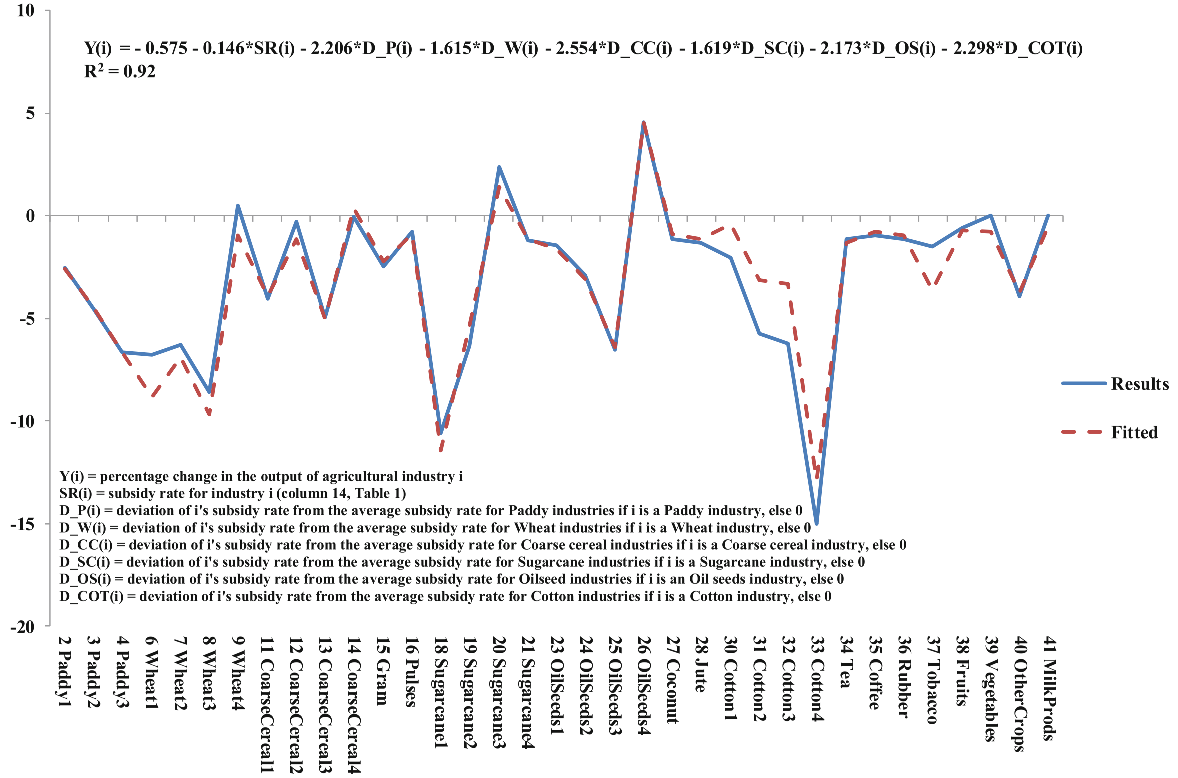

Fig. 2.5 NCAER-VU results for the output of Agricultural industries explained by initial subsidy rates and dummies for relative subsidy rates

there are large indirect exports through Cotton textiles and Apparel. Removal of subsidies from cotton increases input costs to these price-sensitive exporting industries. Via high export demand elasticities, this reduces their exports and consequently their demand for inputs of cotton. This connection of cotton output to high-elasticity, price-sensitive export markets is built into NCAER-VU but not into (2.2). Consequently, (2.2) understates the NCAER-VU projection of damage to cotton industries from subsidy removal.

To test the quantitative importance of export connection in explaining the NCAER-VU output results for agricultural products, we expanded the regression (2.2) to include a variable [PS_X(i)] that reflects the share of each industry's output that is sold in price-sensitive export markets. In accordance with our adoption of mixing industries, we define this variable to reflect the assumption that exposure to export markets is the same for all producers of any given commodity i. Our export-exposure variable is defined by:

$$\begin{aligned} \mathrm{PS\_X}(i) &= \mathrm{T4}(i) \times \gamma(i) \times \left[\mathrm{SRFEP}(i) + \left(\sum_{k\in \mathrm{Agric}} \mathrm{CSH}\,(k,i) \times \mathrm{SR}(k)\right)\right] \\ &+ \sum_{\substack{j \in \mathrm{Ind} \\ j \neq i}} \mathrm{T1}\,(i,j) \times \mathrm{T4}(j) \times \gamma(j) \times \left[\mathrm{SRFEP}(j) + \left(\sum_{k\in \mathrm{Agric}} \mathrm{CSH}\,(k,j) \times \mathrm{SR}(k)\right)\right] \end{aligned} \tag{2.3}$$

where

T4(i) is the export share in the sales of the commodity produced by industry i, e.g., T4(Paddy1) is the share of the national output of Paddy that is exported.

$\gamma(i)$ is the absolute value of the export demand elasticity for the commodity produced by industry i.

SRFEP(i) is the combined Fertilizer, Electricity and Production subsidy rate (excludes subsidies on sales, see explanation below) applying to the production of the commodity produced by industry i.

CSH(k,i) is the share of k in the costs (combined across the i-producing industries) of producing commodity i.

T1(i,j) is the share of the sales of commodity i (combined across the i-producing industries) that go to industry j as an intermediate input.

SR(k) is the total subsidy rate applying to industry k.

The first term on the right-hand side of (2.3) is a spreadsheet calculation of the effect of subsidy removal on industry i's output via the *direct* exports of commodity i. It takes account of the importance exports in the sales of i [T4(i)], the sensitivity of exports to changes in their price [$\gamma(i)$], and an estimate of the percentage price change induced by subsidy removal [$\mathrm{SRFEP}(i) + \sum_{k \in \mathrm{Agric}} \mathrm{CSH}(k, i) \times \mathrm{SR}(k)$]. In estimating the induced price movement in i relevant for export markets, we take account of subsidies on Fertilizer, Electricity, and Production: sales subsidies do not apply to exports.[3] We also take account of subsidies on agricultural inputs to the production of *i*: the total subsidy rate SR(*k*) is relevant here because the price that industry *i* pays for agricultural product *k* depends on all of the subsidies (including sales subsidies) applying to *k*.

The second term on the right-hand side of (2.3) is a spreadsheet calculation of the effect of subsidy removal on industry *i*'s output via *indirect* exports. This encompasses the first round implications for *i*'s output of movements in *j*'s output (for $j \neq i$) caused by movements in *j*'s exports. The induced movement in *j*'s output is estimated in the same way as the induced export-related movement in *i*'s output. The implication for the output of *i* is then estimated taking account of the share of the sales of *i* that goes to industry *j* as an intermediate input.

With PS_X(*i*) included, our regression explanation of the results for agricultural outputs becomes:

$$\begin{aligned} \mathrm{Y}(i) = &-0.376 - 0.128 \times \mathrm{SR}(i) - 2.223 \times \mathrm{D\_P}(i) - 1.633 \times \mathrm{D\_W}(i) - 2.572 \times \mathrm{D\_CC}(i) \\ &(\mathit{0.27}) \quad (\mathit{0.03}) \quad (\mathit{0.76}) \quad (\mathit{0.24}) \quad (\mathit{0.59}) \\ &- 1.637 \times \mathrm{D\_SC}(i) - 2.191 \times \mathrm{D\_OS}(i) - 2.316 \times \mathrm{D\_COT}(i) - 0.384 \times \mathrm{PS\_X}(i) \quad \mathrm{R}^2 = 0.95 \\ &(\mathit{0.17}) \quad (\mathit{0.27}) \quad (\mathit{0.24}) \quad (\mathit{0.09}) \end{aligned} \tag{2.4}$$

The signs on all variables on the right-hand side of (2.4) are negative as expected. The standard errors are even smaller than in Eq. (2.2). The fit has been improved from an *R*-squared of 0.92 in Eq. (2.2) to an *R*-squared of 0.95 in Eq. (2.4). As can be seen by comparing Figs. 2.5 and 2.6, the inclusion of PS_X(*i*) has strongly improved the fit of the regression equation to the NCAER-VU results for the cotton industries. This confirms our hypothesis that export connection was a missing factor in Eq. (2.2).

The process of adding explanators to the right-hand side of the regression equation could be continued indefinitely. For example, on looking at Fig. 2.6 we could ask: what does NCAER-VU know about Tobacco which is not captured in (2.4), causing the fitted result to underestimate the simulated result. We suspect that the factor missing from (2.4) but which is included in NCAER-VU is that Tobacco faces an atypically low price elasticity of demand, implying that damage to its output from increased prices is muted. While this idea could be checked out by adding further terms to our regression equation, it is clear at this stage that we have already captured the major features of NCAER-VU that are important for the results we are explaining.

[3]Data given in Dixon et al. (2016) but not included here in Table 2.1 enabled us to separate production taxes from sales taxes.

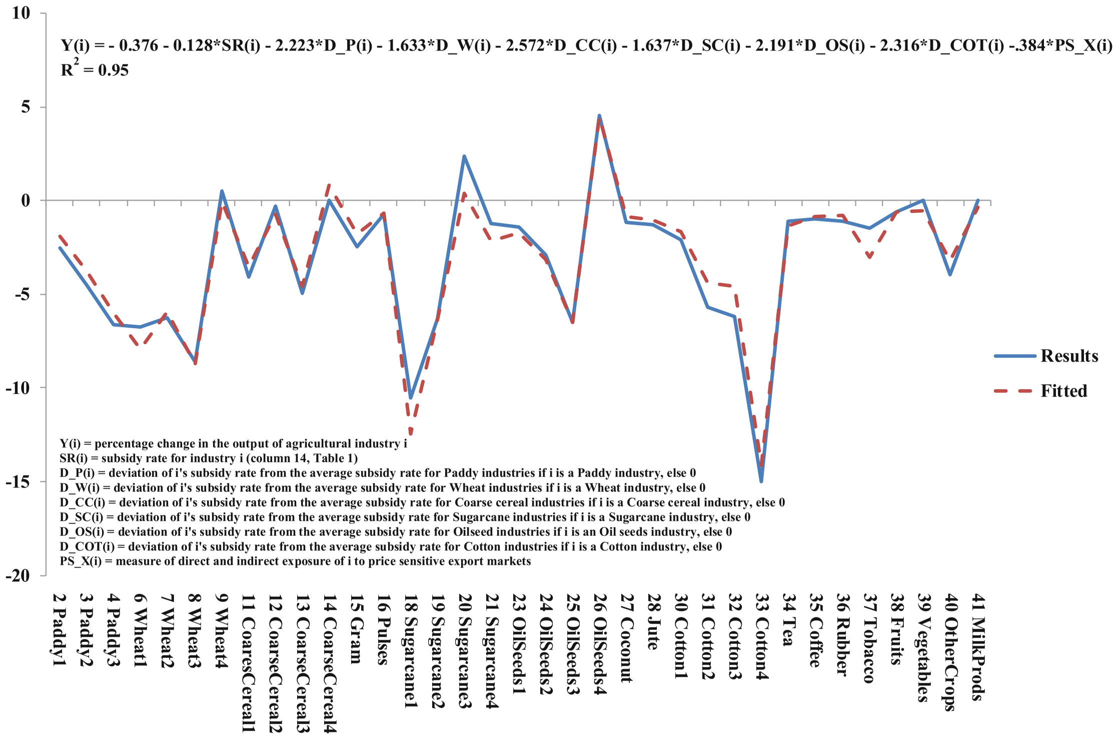

Fig. 2.6 NCAER-VU results for the output of Agric. industries explained by initial subsidy rates, relative subsidy rates, and exposure to price-sensitive exports

2.3.2.2 (b) Real Farm Income and the Prices of Food Products

The two principal objectives of agricultural subsidies are to support farm incomes and to reduce the prices to households of food products. In this subsection, we examine the efficacy of the current set of agricultural subsidies in India for achieving these objectives.

The Effect of Fertilizer and Electricity Subsidies on Real Farm Income

Columns (1) to (4) of Table 2.5 show the effects on real farm income and its components of removing agricultural subsidies. The striking result in the table is that removal of subsidies on Fertilizer and Electricity inputs increases farm income. In column (1), removal of Fertilizer subsidies increases real farm income by 1.041%. In column (2), removal of Electricity subsidies increases farm income by 0.893%. Removing both these input subsidies increases real farm income by 1.922%. Far from supporting farm income, NCAER-VU implies that Fertilizer and Electricity subsidies harm farm income.

Removing Fertilizer and Electricity subsidies has two broad effects on farm income: one negative and one positive. The negative effect is that removing subsidies increases costs of production and contracts outputs,[4] leading to reduced demand for factors that contribute to farm income (agricultural land, and capital and labor used in farm industries). The positive effect is that removing these particular subsidies causes substitution in the production of agricultural products towards factors that contribute to farm income and away from Fertilizer and Electricity that do not contribute to farm income. Even with a moderate substitution elasticity (0.5) between factors that contribute to farm income and factors that do not, the positive substitution effect dominates the negative output-contraction effect.

By switching demand in agricultural industries onto primary factors, removal of Fertilizer and Electricity subsidies causes a much larger percentage increase in the demand for agricultural land (which is used entirely in agriculture) than in the demands for capital and labor (which are used throughout the economy and are mobile between sectors). Consequently, the rental price of agricultural land rises sharply relative to the prices for using capital and labor. In row 3 of Table 2.5, there are large positive entries in columns (1), (2), and (3). Combined removal of Fertilizer and Electricity subsidies increases real rents (and therefore real incomes) from land by 4.170%.

Despite substitution towards capital and labor in agricultural industries, rows 1 and 2 of Table 2.5 show that removing Fertilizer and Electricity subsidies has close to zero effects on capital and labor income in agriculture [−0.077 and 0.092 in column (3)]. Removing these subsidies increases the employment of capital and

[4]Notice that column (3) of Table 2.4 shows negative output effects for almost all agricultural industries from removing Fertilizer and Electricity subsidies.

labor in agriculture but reduces real rental prices for capital and real wage rates for labor. It turns out that from the point of view of agricultural income, the reductions in real factor prices for capital and labor closely offset the increases in their agricultural employment.

Why does removing Fertilizer and Electricity subsidies reduce the real factor prices of capital and labor even in agriculture in which demands for capital and labor increase? In economy-wide terms, we can think of real GDP as a function of capital, labor, land, technology, and efficiency (the triangles considered in Sect. 2.3.1). With factor inputs and technology held constant, the movement in real GDP is confined to the relatively small efficiency effects. Real GDP is also equal to returns to each of the factors plus net indirect taxes, all divided by the price deflator for GDP. With a sharp increase in real rental rates on land, and an increase in net indirect taxes (withdrawal of subsidies), there must be a reduction in the average of the real returns (rentals and wage rates) accruing to capital and labor. In fact, in simulations (1) and (2) the real rental rate for capital and the real wage rate for labor both fall, and with capital and labor mobile between sectors these falls apply throughout the economy, including the agricultural sector.

The Effect of Production and Sales Subsidies on Real Farm Income

Column (4) of Table 2.5 shows the effects on farm income and its components of removing all agricultural subsidies. Production and sales subsidies do not cause substitution effects within agricultural industries. Consequently, removing them has only the negative output-contraction effect mentioned above. Production and sales subsidies are large relative to Fertilizer and Electricity subsidies (Rs. 870,107 m compared with Rs. 386,070 m), allowing the negative effect on farm income of removing production and sales subsidies to overwhelm the positive effect of removing Fertilizer and Electricity subsidies. Thus, column (4) in Table 2.5 shows negative entries for total real farm income and all its components.

The difference between columns (4) and (3), see column (4a), shows that removal of Production and sales subsidies reduces real farm income by 5.011%, with a particularly strong effect on land income (a real reduction of 6.780%). The contraction in agricultural demand for primary factors induced by removal of Production and sales subsidies has a strong negative effect on the rental rate of agricultural land (which is employed only in agriculture) relative to its effects on the real prices of capital and labor (which are employed throughout the economy). However, capital and labor incomes in the agricultural sector fall significantly (3.495 and 3.545%) reflecting a combination of reduced use of these factors in agriculture (output contraction effect) and reduced economy-wide real capital rentals and real labor wage rates.[5]

A Revenue-neutral Package for Increasing Farm Income

Fertilizer and Electricity subsidies reduce farm income while Production and sales subsidies increase farm income. Consequently, at no budgetary cost (a fixed total expenditure on subsidies) farm incomes in India could be increased by converting Fertilizer and Electricity subsidies into Production and sales subsidies.

This idea is illustrated by a back-of-the-envelope calculation in column (5) of Table 2.5 which shows the effects of eliminating Fertilizer and Electricity subsidies [column (3)] combined with the effects of increasing Production and sales subsidies by 44% [calculated as the negative of 0.44 times column (4a)]. Why 44%? Removal of the Fertilizer and Electricity subsidies would allow a budget-neutral 44% increase in Production and sales subsidies ($44 = 100 \times 386{,}070/870{,}107$).

With this reorganization of subsidies, real farm income increases by 4.145%. There are increases in all components of farm income, with a strong increase, 7.178%, in real land rents. Returning to Table 2.3, we can calculate the GDP effect of subsidy reorganization: a gain of 0.135% [$= 0.156 - 0.44 \times (0.204 - 0.156)$]. Similarly there is an overall welfare gain measured by consumption of 0.185% [$= 0.202 - 0.44 \times (0.241 - 0.202)$].

The Effect of Agricultural Subsidies on Food Security

Table 2.6 provides NCAER-VU results relevant for assessing the effect of agricultural subsidies on food prices and consumption of food products (often referred to as food security variables).

Removal of agricultural subsidies increases food prices and reduces food consumption. Price increases and consumption reductions reflect the initial rates of subsidies. Thus, for example, panel 4 (removal of all agricultural subsidies) shows particularly sharp price and quantity movements for Paddy, Wheat, Sugarcane, and Other crops, all of which have high subsidy rates [column (14), Table 2.1].[6]

Unlike the situation with farm income, from the point of view of food security, the form of agricultural subsidies is not critical. This can be seen by comparing the results in Table 2.6 in the last row of panel 3 (Fertilizer and Electricity subsidies) with those in the last row of panel 4a (Production and sales subsidies). Recall that Fertilizer and Electricity subsidies are 44% as large as Production and sales

[5] Removal of subsidies worth about 1.7% of GDP causes a reduction in real factor prices for capital and labour of about 1.7%. The welfare of capital owners and workers could be safeguarded by cuts in taxes.

[6] Cotton and Tobacco also have high subsidy rates but we do not include them among food products.

subsidies. If we multiply the average price and quantity movements (4.90 and −0.47%) in panel 4a by 0.44, we obtain 2.17 and −0.21, approximately the average price and quantity movements in panel 3. Agricultural subsidies, whatever their form, reduce the costs of supplying food to households approximately in proportion to the value of the subsidy, which is then reflected in the prices that households pay. Consistent with this, panel 5 in Table 2.6 shows that reorganizing agricultural subsidies in a budget-neutral way has little effect on average prices for food products or on food consumption.

2.3.2.3 (c) Outputs of Nonagricultural Commodities/Industries, 42–150

In this subsection, we return to Table 2.4 and look briefly at the output results for nonagricultural industries.

Removal of all agricultural subsidies [column (4)] reduces outputs of Fertilizer and Electricity (commodities 87 and 127) directly by causing substitution in agricultural industries against these inputs. The percentage reduction in Fertilizer output [20.68%, contributed mainly by the reduction in Fertilizer subsidies, column (1)] is much greater than that in Electricity output [7.40%, contributed mainly by the reduction in Electricity subsidies, column (2)]. This is because the use of fertilizer is concentrated in agriculture whereas electricity is used throughout the economy.

Cotton textiles (commodity 67), Sugar (58), Other edible oil (61), Woollen textiles (68), Khadi (66), and Apparel (73) all show output loses in column (4) of Table 2.4 of about 3% or more. These commodities have significant exports and rely on inputs of subsidized agricultural products. Consequently, they are damaged by a loss in international competitiveness when agricultural subsidies are removed. The only other nonagricultural commodity shown in column (4) of Table 2.4 with an output loss of more than 3% is Animal services (42). Demand for this product contracts with a decline in agricultural output.

Five nonagricultural commodities have output increases in column (4) of Table 2.4 of about 1.5% or greater. All of these commodities are trade exposed: Mica (commodity 56) faces overwhelming import competition while Communication equipment (112), Other services (149), Nonferrous metals (100), and Computer services (144) have significant export shares in their sales. None of these commodities relies on agricultural inputs and all experience enhanced international competitiveness via economy-wide reductions in the real costs of using capital and labor.

2.4 Concluding Remarks

Detailed CGE models such as NCAER-VU are specified by enormous systems of equations implemented with databases containing thousands of items. Uncertainty surrounds the validity of the equations as descriptions of the world and the correctness of the data items. Even when comprehensive documentation is available it is difficult for anybody apart from the creators to know precisely what has gone into a model. It is not surprising that many academic economists are wary of CGE, often dismissing models as black boxes and results as incomprehensible and unconvincing.

As CGE modellers we must accept that economists outside our field cannot take the time to understand in any depth the intricacies of our models. Nor is it reasonable to expect them to take our word for the validity of our results. So, how can we communicate? How can we convince them to take our results seriously and enter into proper debate?

Our approach, illustrated in this chapter, is to explain key results through back-of-the-envelope (BOTE) calculations. The theory of CGE modelling suggests that, in *qualitative* terms, every result depends on every assumption and data item. However, in *quantitative* terms, for any given set of results there is always a small number of key determining assumptions and data items. By identifying these through BOTE analyses, we provide a basis for assessing results and answering questions such as: are the key assumptions and data items sufficiently plausible for us to have faith in the results; and how would the results be affected if we changed a particular assumption or data item. BOTE analyses can dispel the black-box perception and become the basis for productive communication.

In this chapter, we have used NCAER-VU, a detailed CGE model, to project the effects on the Indian economy of removal of agricultural subsidies worth about 2.5% of GDP. One-third of these subsidies are on inputs to agriculture of fertilizer and electricity and two-thirds are subsidies on production and sales of agricultural products. Among the principal results from NCAER-VU are:

- Agricultural subsidies inflict a GDP loss (a dead-weight loss) on India of about 0.20%, most of which is associated with the subsidies on fertilizer and electricity. The percentage loss in economic welfare measured by foregone consumption is about 0.24%.
- Agricultural output is about 2.3% greater with subsidies than it would be without subsidies.
- Agricultural subsidies increase output and exports of Cotton textiles, Edible oil, Woollen textiles, Khadi, and Apparel, but reduce output and exports of Communication equipment, Nonferrous metals, and Computer services.
- Agricultural subsidies increase output and exports of Cotton textiles, Edible oil, Woollen textiles, Khadi, and Apparel, but reduce output and exports of Communication equipment, Nonferrous metals, and Computer services.
- About 20% of the output of fertilizer and 7% of the output of electricity in India depend on agricultural subsidies.
- Fertilizer and electricity subsidies do not contribute to the objective of supporting farm income. In fact, they reduce real farm income by about 2%. By contrast, India's production and sales subsidies on agricultural products boost real farm income by about 5%.

- All of the current agricultural subsidies contribute positively to the objective of food security. The subsidies reduce food prices relative to the CPI by about 7% and increase food consumption by about 0.7%.
- If government provision of fertilizer and electricity subsidies to the agricultural sector were phased out and replaced with the additional provision of agricultural production and sales subsidies, then real farm income would be increased by about 4% with no deterioration in the public sector budget, almost no effect on food security, and gains in GDP and overall welfare of about 0.13 and 0.18%.

Using a variety of BOTE techniques we have identified the key assumptions and data items that cause NCAER-VU to generate these results. Our aim is to give readers a basis for understanding and assessing the results without requiring from them familiarity with our model. One reaction that we have had to BOTE presentations is: why do you need the model? Apart from helping us organize the relevant data, the model acts as a great teacher. Without the model, we would not have thought of the right BOTE theory and calculations.

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Chapter 3
Can China Achieve over the Medium-Term Strong Economic Growth with Ambitious Targets for Energy Efficiency and Greenhouse Gas Emissions?

Philip D. Adams and Xiujian Peng

Abstract China's new growth pattern, with relatively strong growth in household consumption and an accelerating transition from investment-led to service-led growth is projected to change significantly its economic structure over the next 20 years. This will have significant implications for energy demand and greenhouse gas emissions. Using an extended version of a large computable general equilibrium model of China, we explore alternative futures for the Chinese economy and its energy needs over the period from 2017 to 2030. The simulation results show that without additional action the share of coal consumption in total energy use will rise, and that renewable forms of energy will only slowly penetrate the energy market. The model simulations show, however, that with a well-designed policy, the Chinese government can meet the challenges of strong economic growth and low carbon emissions, while improving overall energy security. Moreover, our modelling shows that the Chinese government's goal of peaking carbon emissions in 2030 is achievable.

Keywords Dynamic computable general equilibrium model · Economic transition · Energy demand · Greenhouse gas emissions · China

JEL: C68, D58, O13, Q48

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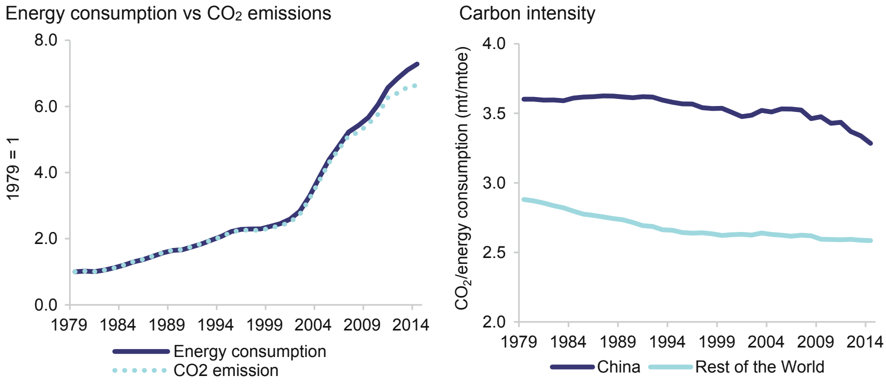

Fig. 3.1 Relationships between energy consumption and CO_2 emissions and carbon intensity in China, 1979–2014. Source: BP (2015) and authors' calculations

3.1 Introduction

Strong growth in energy demand and increasing carbon dioxide (CO_2) emissions have accompanied strong economic growth in China during the last four decades. Figure 3.1 (left panel) shows that by 1994, China's energy consumption had doubled from 0.4 billion tonnes of oil equivalent (toe) in 1979. After 1994, growth in China's energy demand increased significantly. By 2014, energy consumption had reached nearly 7.5 toe. Interestingly, up to 2010, energy consumption and CO_2 emissions followed similar upward paths. However, after 2010, growth in CO_2 emissions started to decline relative to growth in energy demand.[1] In terms of CO_2 intensity (emissions per unit of energy consumption), China experienced a mild decline up to 2014 (see Fig. 3.1, right panel). By 2014, China's carbon intensity was 3.3%, down from previous levels, but still significantly higher than that of the rest of the world.

One reason for the high CO_2 intensity in China is its energy structure, which is dominated by coal. In 2014, China consumed about 3 billion toe of coal, which comprised 66% of China's total primary energy consumption. This was 10 percentage points higher than India, 38 percentage points higher than Japan, and 46 percentage points higher than the United States (see Fig. 3.2). Concerns for self-sufficiency and energy security have also led to high levels of coal usage and high rates of production from domestic resources. Coal self-sufficiency, as measured by the ratio of domestic coal production to consumption, was 94% in 2014.

Despite the concern for self-sufficiency, coal's share of China's total energy consumption has fallen gradually from 87% in the mid-1960s to 66% in 2014,

[1]Carbon intensity is the amount of carbon dioxide generated (in metric tonnes) per unit of energy consumed (in million toe).

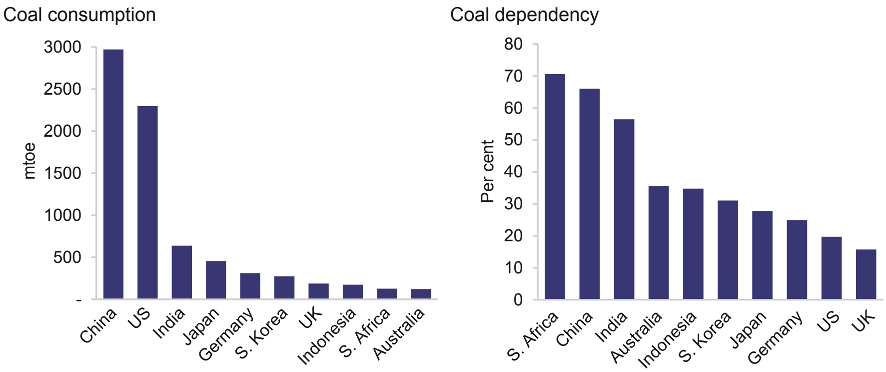

Fig. 3.2 Total coal consumption and coal dependency for selected countries, 2014. Source: BP (2015) and authors' calculations

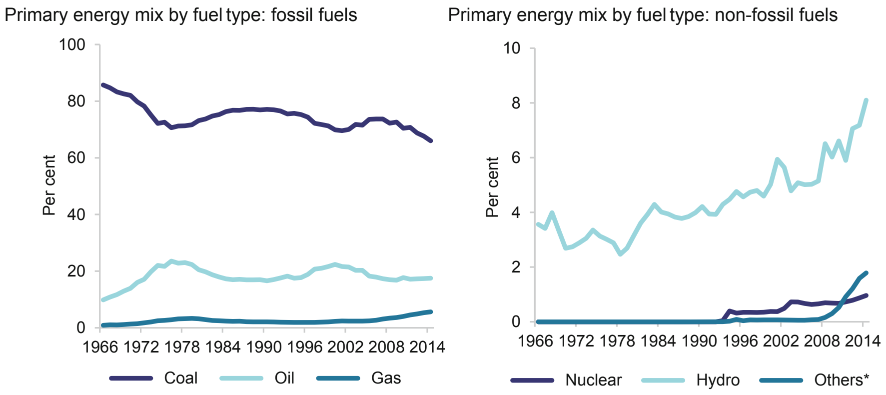

Fig. 3.3 Trends in China's primary energy mix by fuel type, 1966–2014. Note: Other types of fuels include solar, wind, geothermal, and biofuel-based energy. Source*:* BP (2015) and authors' calculations

with increasing shares of natural gas and renewables in the primary energy mix, particularly since 2000 (see Fig. 3.3).

With this as background, in this paper, we use an extended version of a large computable general equilibrium model of China (called CHINAGEM) to explore alternative futures for the Chinese economy and its energy needs.

We report the results for five scenarios, starting in 2014 and ending in 2030.

The first scenario is a baseline. The baseline is based on business-as-usual assumptions and extrapolation of medium-term trends. It serves as a control scenario against which alternative scenarios are compared.

There are four alternative scenarios, which add additional policy responses and technological progress that are likely to occur beyond those assumed in the business-as-usual baseline.

1. *Scenario 1—Accelerating the economic transition* (increasing the share of the service sector in the economy). In this scenario, relative to the baseline China's future growth is driven more by consumption and less by investment.
2. *Scenario 2—Capping coal consumption by 2020*. In this scenario, China's policy makers impose a cap on coal consumption after 2020. This policy is currently under consideration in China.
3. *Scenario 3—Accelerating unconventional gas production*. In this scenario, there is a significantly increased investment in unconventional gas production facilities in China, reflecting current concerns that China is and will be relying too much on imported gas.
4. *Scenario 4—Scenarios 1, 2, and 3 combined.*

The rest of this chapter is organized as follows. An overview of the modelling framework used in the analysis is given in Sect. 3.2. Section 3.3 presents the baseline scenario, while Sect. 3.4 discusses the policy scenarios and simulation results. Section 3.5 summarizes the key findings and concludes the chapter.

3.2 Modelling Framework

3.2.1 CHINAGEM

For this study, we incorporated a climate change module that also includes energy accounting and carbon emission accounting. The extended CHINAGEM model includes 143 sectors, calibrated to a database representing the year 2010. The core CGE structure of CHINAGEM is based on ORANI, a static CGE model of the Australian economy (Dixon et al. 1982), and the dynamic mechanisms of CHINAGEM are based on the MONASH model of the Australian economy (Dixon and Rimmer 2002). CHINAGEM captures three types of dynamic links: physical capital accumulation, financial asset/liability accumulation, and lagged adjustment processes in the labor market.

In CHINAGEM, production is modelled using nested constant elasticity of substitution (CES) and Leontief (i.e., fixed proportion) production functions, which allow substitution between domestic and imported sources of produced inputs (the Armington assumption) and between labor, capital, and land. The production functions assume constant returns to scale. Household demand is modelled by the linear expenditure system. Trade is modelled using the Armington assumption for import demand and a constant elasticity of transformation for export supply. China is treated as a large economy in the import markets for some commodities whose Chinese import shares comprise over 10% of the world market. Changes in China's imports for these commodities are allowed to affect world prices. For the remaining commodities, foreign import prices are determined in world markets in isolation from developments in China. Chinese exporters are assumed to face downward-sloping world demand schedules.

3.2.2 *Energy Extensions of CHINAGEM*

The original version of CHINAGEM lacks the capacity to model energy issues in detail. For example, primary energy is supplied by only two industries: the coal industry and a composite crude oil and gas industry. There are also two secondary energy industries, which produce refined oil products and electricity.

For this study, we modified CHINAGEM to enable more detailed energy modeling. Specifically, we

- Separated the crude oil and gas industry into two separate industries.
- Disaggregated domestic gas production into separate conventional and unconventional gas producers.
- Identified two sources of imported natural gas—pipeline gas and LNG.
- Disaggregated electricity generation across six unique fuel technologies—coal, gas, oil, nuclear, hydro, and other renewables and introduced inter-fuel substitution into electricity generation.
- Made allowance for cost-responsive changes in the relative supplies of conventional and unconventional gas.
- Defined price-responsive substitution mechanisms that allow for substitution between pipeline gas and LNG demands.

3.2.2.1 Disaggregation of Oil and Gas

The initial database represents crude oil and gas production as a single industry producing a single product. We separate this industry into three parts: crude oil, conventional gas, and unconventional gas. We also separate the single commodity into crude oil and gas. The crude oil industry produces only crude oil and is the only domestic industry that does so. The two gas industries each produce a single product (gas) and are the only domestic industries that do so. Oil and gas are also imported. For each commodity, total supply equals domestic production plus imports.

3.2.2.2 Cost-Responsive Changes in the Relative Supplies of Conventional and Unconventional Gas

By introducing a two-industry structure for gas supply, we provide the model with the means to implement cost-responsive changes in relative supplies. This is illustrated in Fig. 3.4.

Initially, the intersection of market supply and demand determines the overall quantity of gas supplied (Q) to match demand at the market price (P). At this price, the amount of unconventional gas supplied is Q^{uncon} and the amount of conventional gas supplied is Q^{conv}. For example, suppose that there is a change in supply brought about by, say, a cost-reducing change in the technology for producing unconventional gas. As indicated in Fig. 3.5 by the black arrow, this shifts the supply

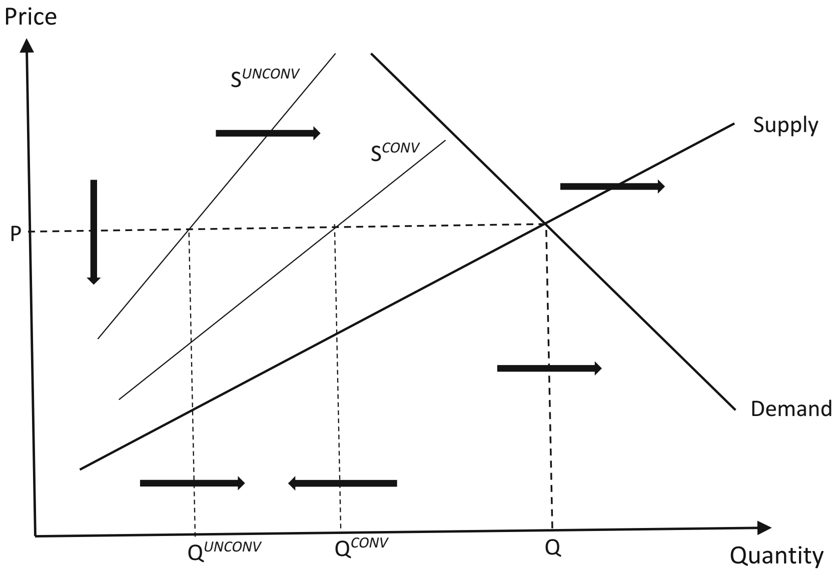

Fig. 3.4 Cost-responsive changes in the relative supplies of conventional and unconventional gas

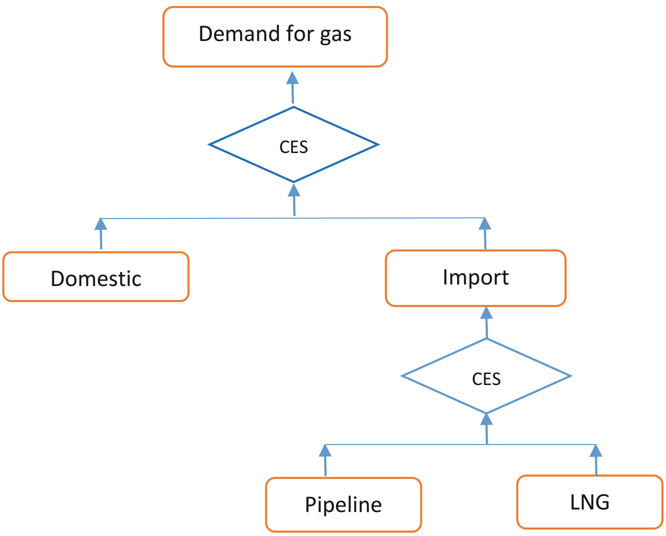

Fig. 3.5 Demand for gas from alternative imported sources

schedule for unconventional gas to the right. If the supply schedule for conventional gas remains unchanged, there will be a shift to the right in market supply. If the market demand schedule remains unchanged, this leads to a lower market price and increased overall supply. For the total supply, the share of unconventional gas supply rises and that of conventional gas falls.

3.2.2.3 Two Sources of Imported Gas Supply

China's demand for natural gas is met by domestic production and imports. As explained above, domestic gas is supplied by conventional and unconventional producers. There are two primary sources of the imported supply: pipeline gas and shipments of LNG.

To model the two sources of gas imports, we require data on expenditure by source of supply for each gas user represented in the model. Currently, such data are not available for individual users. Accordingly, we use national shares to allocate the purchases of imported gas for each user to pipeline and LNG sources.

To model the alternative sources of imported gas, we assume that pipeline gas is an imperfect substitute for LNG. Thus, the landed cost, insurance, and freight (CIF) price of pipeline gas can differ from the landed CIF price of LNG, and any change in the relative price will lead to a change in the ratio of use. This is illustrated in Fig. 3.5, which shows the input structure for gas for a typical gas user in the model. At the top level, the overall demand for gas is met by a combination of domestically produced gas and imported gas. The aggregator function has a CES form. As explained above, domestic gas can be sourced from conventional and unconventional producers.

The idea that domestically produced gas is an imperfect substitute for imported gas is a part of the existing model structure. To this, we add a new specification that allows for imported gas to be sourced from LNG and pipeline gas. Again, the aggregator has a CES form.

3.2.2.4 Electricity Disaggregated by Generation Type and Supply

The current CHINAGEM recognizes one electricity sector that generates electricity as well as provides services associated with its transmission, distribution, and retailing. Intermediate inputs to electricity, including fuels, are combined in fixed proportions. Accordingly, there is no possibility of inter-fuel substitution in the electricity generation.

Following Adams and Parmenter (2013), we correct this by introducing inter-fuel substitution in electricity generation using the "technology bundle" approach. In the revised model, we split the composite electricity sector into generation and supply. Electricity-generating industries are distinguished based on the type of fuel used. The end-use supplier (electricity supply) purchases generation and provides electricity to electricity users. When purchasing electricity, it can substitute among

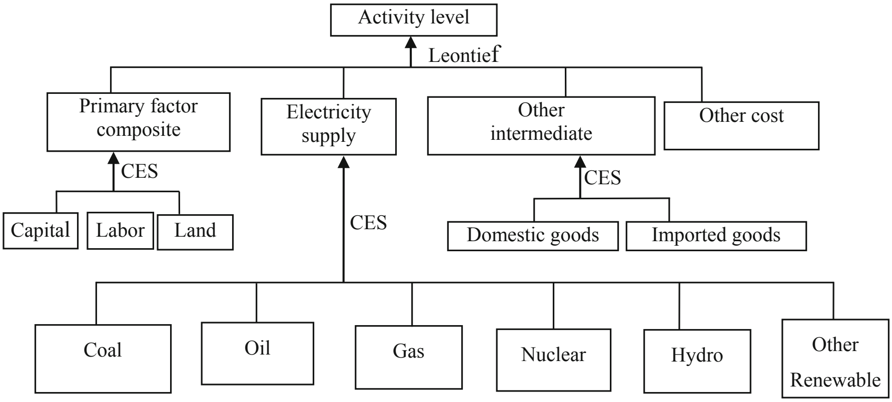

Fig. 3.6 Nested production structure in the CHINAGEM model

the different generation technologies in response to changes in generation costs. Such substitution is price induced, with the elasticity of substitution among the technologies typically set at five.

The model distinguishes six types of electricity generation. Coal, oil, and gas generation use fossil fuels; nuclear generation uses imported nuclear fuel; and hydro and other renewable methods of generation rely on renewable energy sources. The model treats each type of electricity generation as one industry with a unique output, such that electricity produced by different fuels may, and indeed are likely, to have different prices in different scenarios. The electricity generation industries sell only to the electricity supply industry. The electricity supply industry sources from these electricity generation industries according to a CES substitution function (Fig. 3.6). We set the value of the substitution elasticity to five.[2]

3.3 Baseline Scenario

The baseline forecast is a business-as-usual scenario for the Chinese economy over the period from 2014 to 2030. It is constructed on the assumption that there will be no changes in government policies beyond those already announced. More specifically, for the macro variables, the baseline is developed under the assumptions that

1. The Chinese economy will continue to grow strongly, but, following recent trends, overall growth will slowly diminish.

[2]If the value of the substitution variable is 0, then this effectively creates a Leontief production structure. This reflects the fact that dispatching orders in China's electricity market react more to administrative orders than price signals.

Table 3.1 Baseline scenario: calibrated growth rate of GDP components, industry groups, and other variables (%)

	Average annual growth rate				
	2014	2015–2016	2017–2020	2021–2025	2026–2030
Household consumption	8.84	8.37	7.79	7.22	6.64
Investment	7.10	6.72	6.25	5.79	5.33
Government consumption	7.70	7.29	6.79	6.28	5.79
Exports	8.17	7.73	7.20	6.67	6.14
Imports	10.15	9.60	8.94	8.28	7.62
Agriculture	3.87	3.88	3.73	3.57	3.40
Industry	8.00	7.61	7.31	7.00	6.68
Services	7.59	8.01	7.70	7.38	7.04
Employment	0.35	−0.21	−0.21	−0.04	−0.29
Population	0.42	0.44	0.44	0.22	0.06
Real GDP	7.40	7.00	6.50	6.00	5.50

GDP gross domestic product
Source: Employment and population data are from the UN (2015), the growth rates of the GDP components and three-industry group from 2014 to 2016 are from the World Bank's development indicators, and those from 2017 to 2030 are the authors' assumptions

2. The pattern of growth will favor consumption and consumption-related industries at the expense of investment and investment-related industries.
3. Import growth will exceed export growth.
4. Growth in the service sector will exceed growth in the industrial sector.

Table 3.1 shows the calibrated growth rates of the GDP components and three industry groups in the baseline scenario. These numbers are used as shocks to CHINAGEM under the forecast closure, yielding the assumed growth of real GDP for the forecast simulation from 2014 to 2030.

For the key energy industry assumption in the baseline scenario, we use the International Energy Agency (IEA)'s current policies scenario from its *World Energy Outlook 2015*, which comprises a suite of cross-cutting policies, power-sector policies, and industry sector policies (see Table 3.1). Other assumptions, such as lower growth for steel production and higher efficiencies in metallurgical coking operations, are also included in Table 3.2.

According to the IEA's current policy scenario (2015), China's coal consumption is projected to increase from 2144 million toe in 2020–2410 million toe in 2030 (see Fig. 3.7) and the share of coal in the primary energy mix will decline from 61.2% in 2020 to 57.5% in 2030. The share of gas in the primary energy mix will increase from 7.2% in 2020 to 8.8% in 2030.

Table 3.2 Key energy and industry assumptions/scenarios for baseline forecast

Cross-cutting policy assumptions by scenario	Power-sector policies and measures by scenario	Industry sector policies and measures by scenario
Implementation of measures in the 12th five-year plan, including a 17% cut in CO_2 intensity by 2015 and a 16% reduction in energy intensity by 2015 compared with 2010. Increase the share of nonfossil fuels in primary energy consumption to around 15% by 2020.	Implementation of measures in the 12th five-year plan. 290 GW of hydro capacity installed by 2015. 100 GW of wind capacity installed by 2015. 35 GW of solar capacity installed by 2015.	Small plant closures and the phasing out of outdated production, including the comprehensive control of small coal-fired boilers. Mandatory adoption of coke dry-quenching and top-pressure turbines in new iron and steel plants. Support of non-blast furnace iron making. Three industries—iron smelting, steel making and steel rolling—are assumed to grow at a low rate and will stop growth from 2020 onwards.

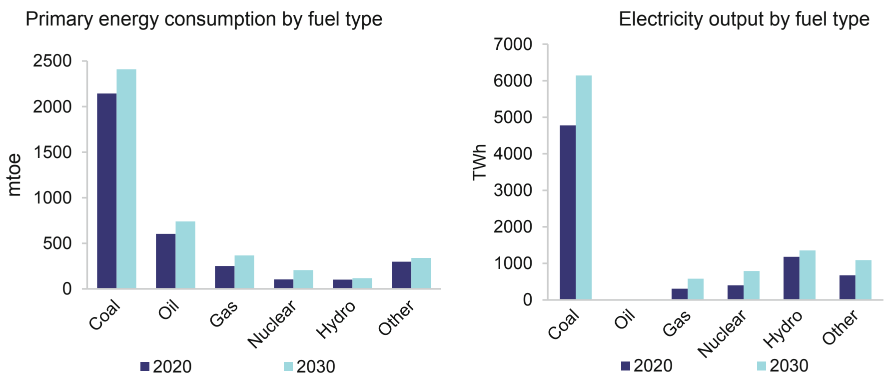

Fig. 3.7 Forecasted primary energy consumption and electricity generation mix by fuel type. Source: IEA (2015) for China's current policies

In the baseline scenario, China's gas production will continue to grow. Following the IEA, we assume that the production of unconventional gas will grow quickly (Fig. 3.8). The share of unconventional gas in domestic gas production will increase from less than 8% in 2014 to 39% in 2030. The size of China's gas imports will continue to grow while the shares of pipeline gas and LNG, which are around 50% each, will remain roughly the same as in 2014.

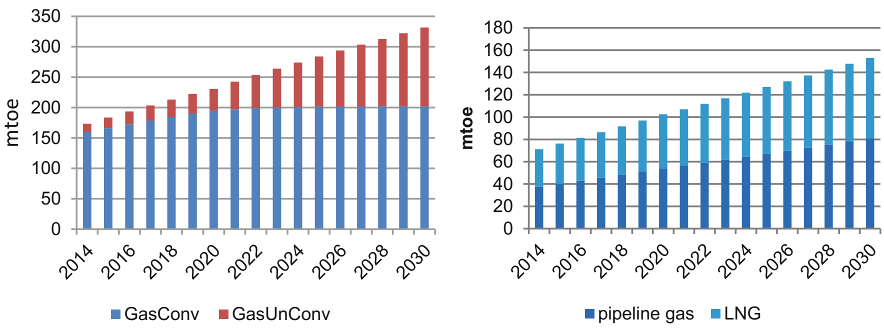

Fig. 3.8 Forecasted gas production and imports. Source: IEA (2015) for China's current policies

3.4 Policy Scenarios and Simulation Results

3.4.1 Policy Scenarios

The aim of a policy simulation is to explore how the economy would evolve when subjected to various shocks or changes in economic policy relative to the baseline (forecast) simulation. For this chapter, we report on four policy scenarios.

3.4.1.1 Scenario 1: Faster Structural Transition

Scenario 1 models accelerated economic restructuring by increasing the share of the service sector. Specifically, we assume that the share of the service sector in GDP will be about 5% higher in 2030 than it is in the baseline scenario (see Table 3.3).

The reasons for assuming a faster increase in the share of service sector than in the baseline scenario are as follows. (1) China is relying more on domestic consumption rather than the investment to drive growth and consumption has a higher service share. (2) Urbanization can be an indirect driver of consumption growth (World Bank 2014). According to the UN's World Urbanization Prospects, China's urbanization rate will increase from 56% in 2015 to 61% in 2020 and then to 71% in 2030 (UN 2018). (3) China's sustained growth in income will

Table 3.3 Comparison of economic structures of the baseline and Scenario 1

	Agriculture		Industry		Service	
Year	Baseline	Scenario 1	Baseline	Scenario 1	Baseline	Scenario 1
2015	9.0	9.0	45.8	45.8	45.2	45.2
2020	7.7	7.2	44.6	43.7	47.7	49.2
2025	6.6	5.7	42.9	40.6	50.6	53.7
2030	5.6	4.5	40.7	36.9	53.7	58.6

stimulate service demand growth. According to the World Bank, the demand for services is rising as income increases because people are becoming less concerned about material needs. For households, this leads to an increasing demand for services such as health, education, and entertainment services. In the business sector, companies recognize that many activities can be handled more efficiently by a service provider. These activities include sales and marketing, accounting, technology, service delivery, management, human resources, and finance.

To implement this scenario, the share of the service sector is treated as an exogenous variable. The targeted trajectory for the services share is imposed via endogenous (model-determined) changes in the average propensity to consume (APC).[3] We also assume that household preferences will shift toward service goods. As Chinese consumers become wealthier, they will spend more money on service products such as education, communication, travel, and financial services. We assume that if prices and income remain at their baseline values, then Chinese consumers will increase the share of services in their overall budget by 5% per year.[4]

In addition to a shift toward services, we assume that household preference for gas will be higher than in the baseline scenario. As their income increases, households can afford and are more likely to choose cleaner energy, e.g., gas rather than coal. Moreover, rapid urbanization means that more people will live in the city, where people normally consume more gas than coal. The calibration of this shock is based on the subjective judgment that urbanization will reduce household consumption of coal by 2030 by around 80% compared with baseline levels.[5]

3.4.1.2 Scenario 2: Stronger Action to Limit Coal Consumption Using a Cap

China is seeking to cap coal consumption at a maximum of 5 billion metric tons of standard coal equivalent by 2020. This cap was contained in the Five-Year Plan for 2016 to 2020, which was released in March 2016. To achieve this cap by 2020, we assume that the growth rate of primary coal consumption will gradually decline from 2015 to zero after 2020. Meanwhile, we allow the coal-use efficiency to improve for industries using coal as an input. Capping coal consumption will reduce the share of coal in the primary energy and electricity generation mixes, and the CO_2 intensity (i.e., CO_2 emissions per unit of energy consumed).

[3]Consumption is oriented towards service sectors. Thus, an increase in the average propensity to consume, all else unchanged, will lead to increased consumption and a shift in the economy towards services production.

[4]This number is calibrated at a rate which would be required to increase the service share in consumption from the current level in China to a level consistent with the Australian share of services in household consumption at the similar income level.

[5]This shift is calibrated such that, initially, the household sector's use of energy does not change, only the mix of that energy (i.e. towards gas and away from coal).

3.4.1.3 Scenario 3: Higher Unconventional Gas Production

Scenario 3 models the effect of an increase in unconventional gas production using the IEA New Policies Scenario for China as a guide (IEA 2015). The increase in unconventional gas production is achieved by improving the technology in the unconventional gas sector through investments in gas infrastructure as well as unconventional gas exploration and production.

3.4.1.4 Scenario 4: A Composite Scenario

Scenario 4 integrates all the assumptions in Scenarios 1, 2, and 3.

3.4.2 Policy Results Analysis

3.4.2.1 Macroeconomic Effect of the Various Policy Scenarios

Table 3.4 displays the deviations of macroeconomic variables for each of the different policy scenarios from the baseline case. By the end of the simulation period (2030), real GDP in Scenario 1 is nearly 7% higher than that of the baseline, whereas it is almost 1% lower in Scenario 2 and there is almost no change in Scenario 3. The combined shocks of the three policies result in a higher real GDP in Scenario 4. As Table 3.4 shows, the higher GDP (5% higher than that of the baseline) in Scenario 4 is mainly driven by the policy in Scenario 1, which is to accelerate the change in economic structure with a higher share of service sectors in the GDP.

The remaining commentary on macroeconomic effects focusses on the results for Scenario 1.

The higher share of the service sector in the GDP in our model is achieved by encouraging households to spend more and save less, with spending shifted toward

Table 3.4 Macroeconomic effect of the policy simulations in 2030 (cumulative deviation from the baseline scenario %)

Variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Real GDP	6.99	−0.99	0.0	5.07
Capital stock	10.2	−0.26	−0.03	9.37
Employment	4.8	−0.37	0.05	3.94
Real wages	6.4	−0.78	−0.16	4.82
Investment	15.6	−1.26	0.22	13.8
Real household consumption	21.1	−0.56	−0.06	18.9
Exports	−24.8	0.33	−0.37	−24.3
Imports	15.1	0.89	−0.31	15.6
Terms of trade	7.32	0.25	−0.23	7.56

service goods. Because service sectors are more labor intensive than the industry and agricultural sectors, the increase in household spending stimulates the development of service sectors and creates more employment opportunities than would occur in the baseline scenario. By 2030, employment is projected to be nearly 5% higher in Scenario 1 than in the baseline. The positive correlation between capital and labor means that the growth in employment drives up the growth of the capital stock if all else being equal. Apart from employment growth, there is one more factor that stimulates the capital stock growth: the improvement of terms of trade (discussed in the next paragraph). The simulation results show that capital stock will be 10% higher than in the base scenario. Higher employment and capital increase the real GDP.

On the expenditure side of GDP, the increased real GDP is absorbed primarily by increased real household consumption. By the end of 2030, real household consumption is more than 20% higher than in the baseline scenario.

It is assumed that government consumption is linked to household consumption. Thus, the percentage change in government consumption matches the percentage change in household consumption.

The increase in capital (relative to baseline levels) requires an increase in investment. If consumption (C + G) and investment (I) increase by more than the real GDP (Y), then the balance of trade (X − M) must deteriorate. The mechanism is the real appreciation of the Chinese RMB, which reduces the competitiveness of Chinese products leading to increased imports and reduced exports. Table 3.4 shows that imports will be 15% higher and exports will be nearly 25% lower than in the baseline scenario. For exports, we assume that China faces downward-sloping foreign demand curves for the majority of its exportable goods. Thus, the contraction in exports causes an improvement in the terms of trade (7.3% higher).

The improvement in terms of trade increases the GDP deflator relative to the price of domestic final demand (the average price deflator of consumption and investment). This is because the GDP deflator includes the price of exports and excludes the price of imports, where the opposite is true for the price of the final domestic demand. In the long run, the rate of return on capital in China will be little affected by the shocks associated with each of the policy scenarios. Thus, with the rental price of capital (the numerator in the rate of return) moving with the price of investment (the denominator), improvements in the terms of trade tend to reduce the rental price of capital relative to the price of the GDP. In other words, in the final few years of the simulation, there is a fall in the real cost of capital for the economy. At this time, as employment increases and technology remains fixed, the reduction in the real cost of capital causes the economy-wide ratio of capital to labor to rise. This leads to a percentage increase in capital that is larger than the percentage increase in employment.

By the end of the simulation period, the real wage rate is projected to be 6% higher than in the baseline (see Table 3.4).

Note that in Scenario 2, capping coal consumption without other compensating policies will slightly harm the macro economy with a real GDP that is almost

Table 3.5 Energy demand and carbon emissions in 2030 (%)

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total energy consumption					
Primary energy mix (%)					
Coal	60.3	58.9	52.7	60.3	51.1
Gas	7.5	8.1	10.5	7.9	10.7
Oil	17.6	17.0	19.9	17.5	18.5
Nonfossil fuel	14.6	16.0	16.9	14.3	19.7
Electricity generation mix (%)					
Coal	63.9	63.7	54.4	63.8	49.7
Gas	5.0	4.8	6.7	5.1	6.7
Oil	0	0	0	0	0
Nonfossil fuel	31.1	31.4	38.9	31.1	43.5
Carbon emissions (billion tonnes)					
Coal	10.7	10.5	8.0	10.7	8.1
Gas	0.6	0.6	0.7	0.7	0.8
Petrol refinery	2.3	2.3	2.3	2.3	2.3
Total	13.6	13.4	11.0	13.7	11.2

1% lower in 2030 than in the baseline.[6] However, capping coal consumption will improve China's energy consumption structure and reduce carbon emission significantly, which we discuss in the next section.

The natural gas industry has grown rapidly in recent years as a result of the government's effort toward green development; however, its share of the whole economy is still very low, only 0.5% in 2014. Even though there is a large investment increase in the unconventional gas sector to promote its production, the effect of this policy on the macro economy is very small (Table 3.4, Scenario 3).

3.4.2.2 Effects on China's Energy Structure and Carbon Emissions

Table 3.5 displays the simulation results of the primary energy mix, electricity generation mix, and carbon emissions for the various policy scenarios. Scenario 2 (capping coal consumption) has a relatively large effect on China's energy consumption structure. With the cap in place from 2020, the share of coal consumption is projected to reduce significantly to 52.7% in 2030 (compared with 60.3% in the baseline). Meanwhile, the shares of natural gas and alternative fuels will increase.

[6]This will occur because capping coal consumption will increase the cost of the downstream industries that use coal as intermediate input and therefore reduce their output. Because most coal-using industries are capital intensive, the contraction of these industries will reduce the demand for capital. The decline of capital stock will drive the demand for labor down. Employment is hence 0.37% lower than in the baseline. The lower employment combined with lower capital stock hence creates a lower GDP growth in Scenario 2.

Furthermore, the share of coal-generated electricity will drop significantly to around 54.4%, which is nearly 14 percentage points less than that of the baseline. A further consequence of this policy is a reduction in CO_2 emissions and carbon intensity.

Table 3.5 shows that, by 2030, coal-based carbon emissions in scenario 2 will be 2.7 billion tonnes lower than that of the baseline, and natural gas-based carbon emissions will be 0.1 billion tonnes higher than that of the baseline. The small increase in CO_2 emissions from gas reflects strong substitutions among coal, gas, and renewables. As a result, CO_2 emissions are 19% lower and carbon intensity is 8% lower than the baseline by 2030.

In Scenario 1, increasing household consumption and household preference for gas (relative to baseline levels) results in slightly higher economy-wide shares of gas and nonfossil fuels by the end of the projection period. The cleaner energy consumption structure reduces the carbon emissions. Table 3.5 shows that in 2020 in Scenario 1, total CO_2 emissions are 0.2 billion tonnes lower than in the baseline scenario. This lowers carbon intensity by around one percentage point.

The effects of Scenario 3 (increasing unconventional gas production) on China's energy structure are relatively small. This is because the share of gas (conventional and unconventional) is small relative to that of other forms of primary energy and because the increase in unconventional gas tends to reduce the use of conventional gas, leaving overall gas consumption relatively stable. The reduction of conventional gas in Scenario 3 is a result of the increased competition between conventional and unconventional gas whereas the increased investment improves the technology of unconventional gas production and reduces its cost.

When all scenarios are combined, we find that by 2030, there will be significant changes away from coal in China's energy needs and significant reductions in CO_2 emissions (see Table 3.5 and Fig. 3.9). The share of coal in the primary energy mix will be reduced to 51% in 2030 compared with 60.3% in the baseline scenario, while the consumption of natural gas and non-fossil fuels will increase substantially. The share of nonfossil fuels will increase to 20%, which reaches the goal that the Chinese government set in its Intended Nationally Determined Contribution.[7] In the electricity generation mix, the share of coal-generated electricity will decline to below 50% in 2030. Gas remains a minor input, growing to only 6.7% by 2030. China will gradually come to rely on nonfossil fuels to provide its electricity. Nonfossil fuels will generate nearly 43.5% of China's electricity in 2030, which is nearly 29% higher than that of the baseline (31.1%).

The change of China's energy structure will affect its carbon emissions profoundly. Figure 3.10 shows that, in Scenario 4, total CO_2 emissions grow very slowly from 2020 to 2030, with 0.4% CAGR, compared with around 2% in the baseline scenario over the same period. As a result, by 2030, total CO_2 emissions in Scenario 4 are 11.2 billion tonnes, which is 2.4 billion tonnes below the emissions

[7] On June 30, 2015, China submitted its Intended Nationally Determined Contribution. China has promised to increase the share of nonfossil fuels in primary energy consumption to around 20 percent.

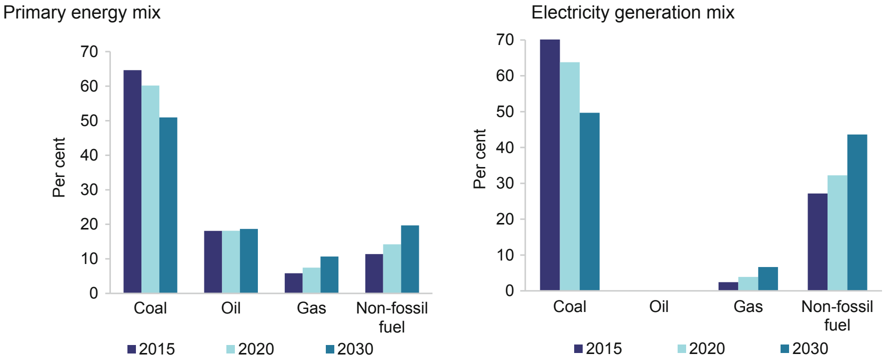

Fig. 3.9 Primary energy mix and electricity generation mix in Scenario 4, 2015–2030. Source: CHINAGEM policy simulation

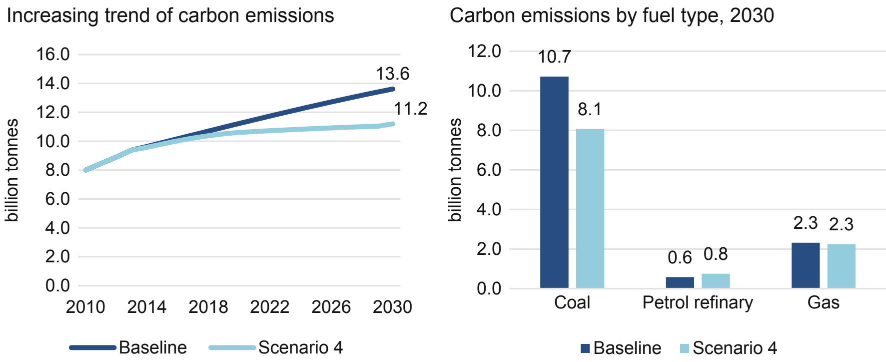

Fig. 3.10 Changes in carbon emissions: Scenario 4 vs baseline, 2015–2030. Source: CHINAGEM baseline and policy simulations

in the baseline (13.6 billion tonnes). With a slow annual growth rate, total carbon emissions come very close to peaking by 2030, in line with commitments from the Chinese government.[8]

The simulated results also show that, among the total CO_2 emissions, coal emissions reduce to 8.1 billion tonnes in 2030 compared with 10.7 billion tonnes in the baseline, which is a reduction of 24% (Table 3.5 and Fig. 3.10).

The slow growth of carbon emissions in the composite policy of Scenario 4 will also improve China's carbon intensity. The carbon intensity will be 10% lower than in the baseline case.

[8]In its Intended Nationally Determined Contribution, China has promised to achieve peak emissions by 2030 and would make their best effort to peak early.

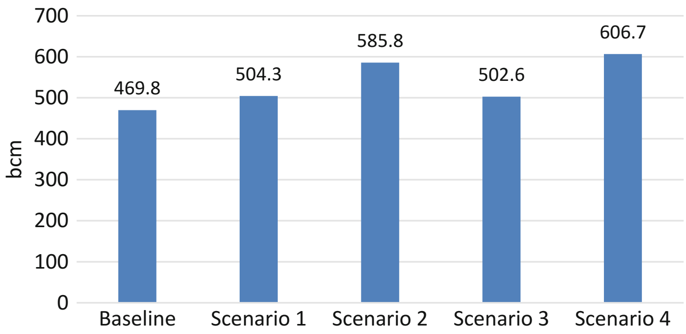

Fig. 3.11 Total gas consumption by 2030 for various policy scenarios. Source: CHINAGEM policy simulation results

3.4.2.3 Effects on China's Natural Gas Production and Import

Figure 3.11 displays the simulation results of China's natural gas consumption under the various policy scenarios. Natural gas consumption in all four policy scenarios is higher than in the baseline. As outlined already, the reasons are as follows: the changes in household consumption toward natural gas, the substitution of gas for coal, and a reduction of gas cost because of technological improvements in unconventional gas production.[9]

China's natural gas imports are expected to expand to meet the continually increasing gas demand. Table 3.6 shows that natural gas imports are higher in both Scenarios 1 and 2. By contrast, the changes considered in Scenario 3 lead to increased consumption of domestically produced gas at the expense of imports. The increasing demand for natural gas after combining all the scenarios together drives China's gas imports up dramatically. Figure 3.11 shows that total gas demand in scenario 4 will be 606.7 billion cubic meters (bcm) in 2030, which is 29% higher than that of the baseline scenario (469.8 bcm). As discussed in Sect. 3.1, China's gas imports consist of LNG and pipeline gas. Figure 3.12 shows that LNG and pipeline gas imports will increase significantly in Scenario 4 compared with the baseline. As a result, China's import dependency for natural gas would increase from 32.6 to 38.1%.

[9]Given the current state of unconventional gas production technology in China, there is significant scope for productivity gains over time. Any productivity improvement lowers the unit cost of production and increases the competitiveness of unconventional gas in the national gas market. As the competitiveness of unconventional gas improves, so does its share in the national market. Hence, in Scenario 3, there is an increase in unconventional gas production relative to conventional gas production.

Table 3.6 Natural gas consumption, production, and imports in China in 2030 (bcm)

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Consumption	469.84	504.28	585.83	502.56	606.65
Production	316.77	331.08	371.94	367.54	375.56
Imported	153.07	173.2	213.89	135.02	231.09
LNG	72.29	81.8	101.02	63.77	109.14
Import dependency	32.6	41.3	36.5	26.9	38.1

BCM billion cubic meters
Source: CHINAGEM baseline and policy simulations

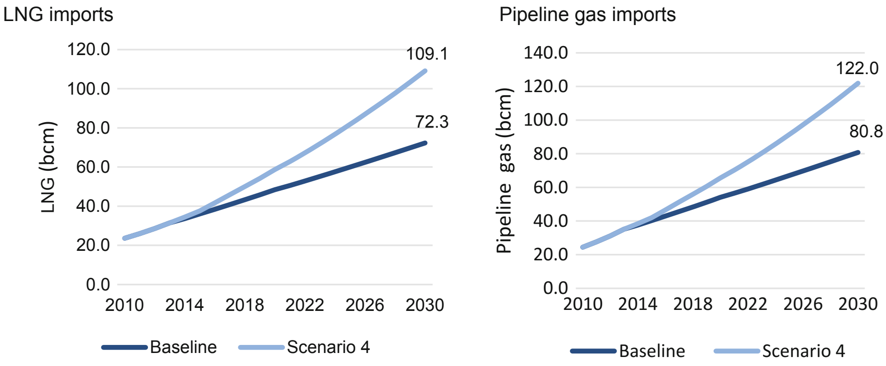

Fig. 3.12 Comparison of natural gas imports in Scenario 4 vs the baseline, 2010–2030. Source: CHINAGEM baseline and policy simulations

3.5 Conclusions

China's economic growth pattern is changing. Using a dynamic computable general equilibrium model of the Chinese economy, in this chapter, we explore the effects of alternative economic growth patterns on China's energy demand, particularly the demand for natural gas. We present the results of five scenarios: the baseline (business-as-usual scenario), Scenario 1 (accelerating economic transition by increasing share of the service sector in the economy), Scenario 2 (capping coal consumption by 2020), Scenario 3 (accelerating unconventional gas production), and Scenario 4 (a composite scenario of Scenarios 1 to 3).

The simulation results show the following:

- Encouraging household consumption and accelerating economic transition from investment-led to service led growth will boost China's economic growth.
- Capping coal consumption without other compensating policies will slightly harm the macro economy. However, capping coal consumption will improve China's energy consumption structure and reduce carbon emission significantly.

- Investment in nonconventional gas will reduce the production cost of domestic natural gas and increase the competition between conventional and nonconventional gas.
- Combining all the three policies together will not only boost China's economic growth but also improve China's energy consumption structure. The model shows that in 2030, the share of coal consumption in the primary energy mix will reduce to 51%, the share of natural gas will increase to 11%, and the share of non-fossil fuels will increase to 20%.
- Natural gas imports will grow faster to meet the increase in natural gas demand, which will cause the import dependency to rise to 38% in 2030.
- China's total carbon emissions will reduce substantially, especially if coal consumption is capped.

These simulations imply that with a well-designed policy, the Chinese government can meet the challenge of strong economic growth, lower carbon emissions, environmental benefits, and energy security. Moreover, the Chinese government's goal of peaking carbon emissions by 2030 is achievable. Accelerating economic transition and capping coal consumption are the keys to achieving these goals.

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Chapter 4
Analysing Policy Impact in Preparation for Post-Hydrocarbon Era of Brunei Darussalam

Tsue Ing Yap, Philip D. Adams, and Janine M. Dixon

Abstract Brunei Darussalam (hereafter Brunei), a small and open economy highly dependent on hydrocarbon revenues, is facing the inevitable fate of the *economic* depletion of its oil and gas resources. With limited success in its diversification efforts for the past decades, Brunei will face a challenging future. In this chapter, using a recursive dynamic, computable general equilibrium (CGE) model called BRUGEM, we attempt to elucidate such a post-hydrocarbon scenario. We also outline an alternative (policy) scenario in which unspecified policy options are put in place to revive economic growth in Brunei through improved productivity performance.

Findings from the policy simulation indicate that in order to add one percentage point to annual growth in real GDP, overall productivity in the economy has to improve by an average of 2.5% per annum relative to the base case. This result may suggest the implementation of microeconomic reforms to improve productivity for economic growth. However, we remain cautious if the pursuit of productivity growth can lead to improved economic welfare in the context of Brunei's economy if this is achieved through the shedding of public sector jobs, which can lead to the collapse of real wage rate under the conditions imposed in the simulation. The key lesson of the modelling is that reforms need to be complemented by labour market measures to address some of the underlying structural issues. We also find that distributing

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some of the hydrocarbon proceeds indirectly to the people may be necessary during the transition period in preparation of the post-hydrocarbon era.

Keywords CGE · Recursive-dynamic model · Resource depletion · Post-hydrocarbon economy · Productivity growth · Brunei

4.1 Introduction

Brunei Darussalam is a small and open economy, with a population of just 459,500 in 2019.[1] Economic growth has been reliant on the hydrocarbon sectors since the first oil export in 1932 and first liquefied natural gas (LNG) export in 1972. Owning 0.1% of the world's proven reserves of oil and 0.1% of natural gas (BP 2018), Brunei has used the income from these resources to provide a welfare state with extensive subsidies. Per capita income is relatively high, at around B$39,989[2] as of 2019. However, per capita income declined nearly 25% between 2014 and 2019.[3]

As of 2018, oil and gas accounted for 94.6%[4] of the total value of Brunei's exports and provided 77.7% of government revenues in the financial year 2017/2018 (Department of Statistics [DOS] 2018). Based on existing levels of proven and recoverable reserves and production rates in 2017, BP plc forecasts that oil reserves will last for 26.6 years while gas will last for 22.4 years (BP 2018). This implies that by early 2040, the oil and gas resources will be depleted[5] assuming no new significant finds and no change to the production rate. In April 2017, it was reported that there was a new discovery of oil and gas amounting to at least 18 million barrels of oil equivalent in the Lumut area.[6] The exact volume was not known but the potential revenue was estimated to be around B$0.9 billion based on the oil and gas prices at that time or around 5.7% of the nominal GDP. This amount is not significant in terms of adding to the existing reserves to prolong the life of oil and gas resources.

Diversification efforts away from oil and gas sectors in Brunei have been slow with limited success despite the various initiatives and National Development Plans in place (Tisdell 1998; Bhaskaran 2010; Lawrey 2010). There are past studies suggesting (Crosby 2007; Bhaskaran 2007) the areas into which Brunei could diversify. Most of the studies are of a qualitative nature and there are limited empirical studies on how these strategies could be carried out and what the economy-wide impacts would be if such policies were implemented.

[1]Source: http://www.deps.gov.bn/SitePages/National%20Statistics.aspx (viewed 27 April 2020).

[2]Average exchange rate for 2019 was US$1 = B$1.36.

[3]Source: http://www.deps.gov.bn/SitePages/National%20Accounts.aspx (viewed 27 April 2020).

[4]Source: http://www.depd.gov.bn/SitePages/International%20Merchandise%20Trade.aspx (viewed 16 August 2019).

[5]Depletion in this context implies that oil and gas reserves are no longer economically extractable based on available technology, and does not necessary mean complete exhaustion physically.

[6]Source: http://borneobulletin.com.bn/bsp-finds-oil-lumut/ (viewed 15 April 2017).

Although there are no known quantitative studies done in terms of the effectiveness of the diversification efforts, it is the aim of this chapter to represent a plausible baseline scenario based on the current policy directions and the government's efforts in channelling resources into specific industrial sectors such as downstream industries to broaden the economic production base. A specific policy simulation to examine the impact of productivity in stimulating the economy is run using BRUGEM, a dynamic Computable General Equilibrium (CGE) model for Brunei Darussalam.

Section 4.2 discusses the modelling approach while Sect. 4.3 lays out the baseline developed. In Sect. 4.4, we analyse the impact of productivity improvement in a policy simulation. Concluding remarks are in Sect. 4.5.

4.2 Modelling Approach

BRUGEM is based on the ORANIG-RD model (Horridge 2002). It contains the key features of the well-documented comparative static ORANI-G model (Dixon et al. 1982; Horridge 2003) and is extended to include the additional equations required to build a recursive dynamic model. BRUGEM has much in common with the dynamic MONASH model (Dixon and Rimmer 2002).

BRUGEM has a forecasting capability that utilises three mechanisms: (1) the stock–flow relation between investment and capital stock with 1-year gestation lag assumed; (2) a positive relation between investment and the rate of return on capital; and (3) a lagged adjustment relationship between wage growth and employment (Horridge 2002). There are five categories of agents: firms, investors, one representative household made up of households, and nonprofit organisations serving these households (NPISH), the government, and a representative foreign agent to which Brunei provides exports, and from which Brunei purchases imports.

The model theory is based on neoclassical assumptions. Firms minimise costs with constant returns to scale production. Households maximise their utility subject to a budget constraint. Investors allocate capital to industries based on the expected rates of return where each unit of capital created is a cost-minimising composite of inputs sourced locally and from abroad. It is assumed that the imported variety is an imperfect substitute for the domestic variety of each commodity. This is known as the Armington assumption. The demand for any export commodity is inversely related to its foreign currency export price. Therefore, any increase in the export price will cause a reduction in demand by foreigners. In general, markets are competitive and prices adjust to ensure supply matches demand.

BRUGEM uses a database that has 74 industries producing 74 commodities. There are three primary factors of production, namely land, labour and capital. The model is solved with the GEMPACK software (Harrison and Pearson 1996) using the Euler solution method for linear approximation, described in more detail by Dixon and Rimmer (2002). The chosen solution method is the Euler-100 steps for a

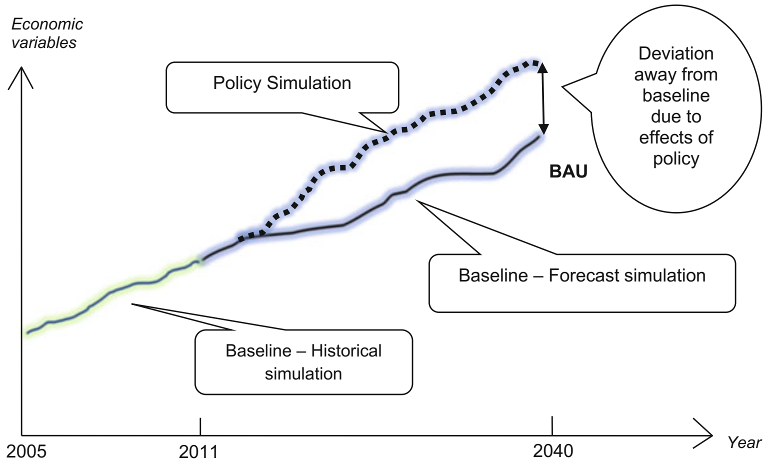

Fig. 4.1 Baseline history, baseline forecast and policy simulation

high degree of accuracy. This is ramped up to 200 steps where there is an unusually large shock, such as in the year 2015 when the oil price plunged by nearly 45%.

Readers who are interested in more details about the underlying model theory may refer to Yap (2015) as well as the documentation on the ORANIG-RD and MONASH models (Horridge 2002; Dixon and Rimmer 2002).

We can represent the BRUGEM model as a system of equations describing the economic activities at year t in vector form:

$$F\,[V(t)] = 0$$

where F is a vector of length m of differentiable functions and $V(t)$ is a vector of length n of prices, quantities, household tastes and other variables for year t. Since there are more variables (n) than the number of equations (m) or $n > m$, we need to define a closure or to specify the combination of values for $n - m$ exogenous variables in order to solve for the remaining m endogenous variables. Dixon and Rimmer (2002) described the four basic choices in choosing the sets of $n - m$ exogenous variables: historical, decomposition, forecasting and policy closures. The choice will depend on the issue to be examined. The applicability of the historical, forecast and policy closures is illustrated in Fig. 4.1 (the decomposition closure is not relevant in this case).

The modelling reported in this chapter is based on data drawn initially from 2005 statistics, updated using the historical simulation method to the year 2011. 2011 is the starting year for the forecasting simulation, which builds a future baseline forecast to be used as the baseline or business-as-usual (BAU) scenario. Impact of the policy simulation is measured as deviations from the BAU case as shown in Fig. 4.1.

4.2.1 Updated Input–Output (IO) Database

The database required for CGE modelling is derived from national input–output (IO) tables. The model database should be as current as practically possible, while also representing a typical year without unusual features such as natural disasters or political upheaval. Brunei's Department of Economic Planning and Development (DEPD) has published two sets of IO tables. One set contains 74 sectors for the year 2005 (DEPD 2011) and another set is the 50-sector IO tables for the year 2010 (DEPD 2014).

The more recent set of published IO tables for the year 2010 has 50 industries and 50 commodities. The oil and gas sectors were merged into one sector while agricultural products were disaggregated. The IO tables of 2010 did not provide sufficient industry detail to address the research questions for this chapter. Furthermore, the tables may not represent a typical year, due to impact of Global Financial Crisis of 2008/2009. The 2010 IO table was deemed unsuitable to be used as a starting point for calibrating the database for BRUGEM. Therefore, the published IO tables for the year 2005 were considered more suitable for calibrating the database for BRUGEM.

Using the historical simulation technique, the IO tables of 2005 were updated to the year 2011, the year for which most key macroeconomic and survey data were available at the time this task was undertaken. In the process of updating, a new infant industry—the methanol and petrochemical industry was created since this was not included in the official IO tables. The rationale for introducing this new industry is that one of the government's initiatives is to develop downstream industries for immediate broadening of the industrial base. The methanol industry, which was set up in 2006, produced its first exports in mid-2010. It has the advantage of pricing its product competitively due to the availability of cheap natural gas, which is one of the key intermediate inputs. A new petrochemical industry is set up on Pulau Muara Besar, a large island off mainland Brunei, where there is ongoing work to set up a mega-port, refinery and aromatic cracker plant to produce petroleum products such as gasoline, diesel, Jet A-1 fuel and petrochemical products such as paraxylene and benzene.[7]

The systematic process in the construction of the full IO database used in BRUGEM and how the database was updated to 2011 are detailed in Yap (2015).

4.3 Developing the Baseline Scenario

The updated IO database for 2011 provides a starting point for our baseline spanning the period 2012–2040. The end point of 2040 is chosen as it includes the forecast period over which oil and gas resources are depleted using BP plc forecasts.

[7]Source: https://www.chemicals-technology.com/projects/zhejiang-hengyi-petrochemicals-refinery-aromatics-cracker/ (viewed 26 August 2019).

In the baseline simulation, we incorporate forecasts from various sources for variables such as the labour force, population and volumes of oil and gas exports. To accommodate these forecasts, the closure is set up by exogenising these variables and endogenising a similar number of naturally exogenous corresponding variables such as the position of domestic export supply curves and macro coefficients such as the average propensity to consume.

In this section, we describe a baseline in which diversification into the production of petrochemicals and other activities occurs against a background of declining reserves of oil and gas. This baseline generates a decline in living standards as indicated by gross domestic product (GDP) and real wages.

4.3.1 Model Closure and Data

The baseline or the reference scenario excludes any policy shock and is created based on current policy directions and growth projections. The structural drivers of economic activity such as productivity and labour force growth, can provide the likely growth trajectories. However, productivity is not readily observable and can be difficult to forecast. Using the forecast closure (Dixon and Rimmer 2002), we can impose values for variables that are observed and allow the model to deduce values for such unobservable drivers. One such example is to use GDP forecast to estimate the underlying overall productivity growth by exogenising GDP and shocking it with the forecast growth rate.

In developing this baseline, actual macroeconomic data is used where available from the DOS of DEPD, Brunei. Wherever possible, we try to draw upon the work of specialist forecasting organisations and use their forecasts as shocks. Using the GDP growth forecast, the underlying total factor productivity (TFP) is estimated for this baseline in the forecast closure.

The GDP forecast for Brunei is derived from several sources including the World Economic Outlook (WEO) report by the International Monetary Fund (IMF), OECD and the Asian Development Bank (ADB). These different published forecasts for economic growth are used to find the range of economy-wide TFP required to build the baseline forecast. Based on this approach as described in Yap (2015), a modest 0.5% per annum of underlying productivity growth was used for the baseline forecast for the Brunei economy for the period 2012–2040.

Population and labour force forecasts are also available for Brunei. In the forecast simulation, population and labour force drive aggregate employment from the supply side of GDP. The population and labour force forecasts for the years 2012–2030 are obtained from the International Labour Organisation (ILO 2013). The labour force is defined as the total number of people who are willing and able to work. The labour force participation rate is the labour force as a percentage of the working age population. The unemployment rate is the percentage of people in the labour force who are not employed. The forecast of employment growth that drives GDP is worked out by using the forecast population, participation rate and unemployment rate. Details of the derivation of the relationships between these variables are discussed in Yap (2015).

From 2031 onwards, in the absence of data, it was assumed that both population and labour force would grow at a constant rate of 0.83% per annum.

Sectoral forecasts are also incorporated, especially those related to oil and gas, the key industries in Brunei. Although the BP forecasts are based on current extraction rates, here it is assumed that annual extraction will slow down from the present rate, prolonging the life of the reserves. An average annual shock to output of oil of negative 10% per annum was computed for the simulation period 2012–2025 followed by 5% per annum for 2026–2040.

The oil and gas price forecasts are obtained from the World Bank Commodity Markets Outlook report (World Bank 2017). For these sectoral forecasts, the corresponding sectoral shift variables are endogenised instead. For example, forecasts of oil and gas prices are incorporated by endogenising the price shifter variable of the export demand schedule in the model.

Corresponding with the gradual depletion in oil and gas reserves, overall aggregate investment in these sectors is also forecast to decline over the long term. Some assumptions are also made pertaining to the government accounts in terms of revenues and expenditures where the decline of revenue relating to the oil and gas exports will affect fiscal capacity. Since Brunei has positive net foreign assets (NFA), in the absence of forecast of rate of return on these assets, a conservative 2% annual return is assumed in the baseline.

The baseline scenario also incorporates the impact of existing industry diversification strategies of the Brunei government through stimulation of new industries such as methanol, petrochemicals, manufacturing, pharmaceutical industries while boosting physical infrastructure and connectivity economy-wide via roads, bridges, expansion of existing airport and port facilities as well as building industrial parks. Since there are no known quantitative studies to track or measure the effects of these efforts, reasonable assumptions are made to produce a baseline forecast.

It is assumed that half of the lost output in dollar values from oil and gas will be eventually replaced by the selected eight industries between 2012 and 2040. Further details on these assumptions are discussed in Yap (2015).

4.3.2 Underlying Assumptions of Baseline Forecast

In the baseline, government spending is exogenous and expands over time to partly offset the decline in general demand brought about by the contraction in oil and gas production. The government is assumed to continue with most of the existing subsidies and expenditure programmes designed to prepare the local workforce for new industries and development of industrial zones. Funds are withdrawn from

Table 4.1 Replacement industries for the lost output from oil and gas sectors

Code	Industry	Annual value added (B$ million)
CokePetroPrd	Manufacture of coke and refined petroleum products	948
ChemPhrmRbrP	Manufacture of chemicals, chemical products, pharmaceuticals, rubber and plastic products	38
BldgConstruc	Construction of buildings	1518
CvlEngConstr	Civil engineering	1138
SpecConstrc	Specialised construction activities	1138
ArcEngTchSrv	Architectural and engineering activities, technical testing and analysis	948
PubAdmDfnSoc	Public administration and defence, compulsory social security	2276
MethanolPChm	Methanol and petrochemicals	1518
	Total	9522

financial reserves to cover shortfalls in government revenue without jeopardising government spending and on-going national development projects.[8]

For the baseline, it is assumed that diversification efforts including stimulating new industries such as methanol, petrochemicals, manufacturing, pharmaceutical industries and also the building up more physical infrastructure will continue. Uniform annual shocks to the output of these industries are implemented by exogenising the inventory demand variable with the shifter for stocks endogenised (to remove the link of stocks to domestic output) to simulate the current efforts. The sector-specific inventory demand variable was used as a proxy to model demand-side factors.

The overall export demand shift variable is also boosted to stimulate export-oriented industries. Under this scenario, it is assumed that the selected industries stimulated would replace half of the lost output from the declining oil and gas sectors as shown in Table 4.1. Based on a decline of 10% per annum in Sect. 4.3.1, the total lost output from the oil and gas sectors is expected to be around B$19.044 billion during the simulation period 2012–2040.

The chosen numeraire is the nominal exchange rate defined as Brunei dollar vis-à-vis a trade-weighted average currency. The economic rationale for this is to reflect that value of the Brunei dollar is exogenously determined with the currency peg[9] to

[8]IMF notes that Brunei has sizable financial assets to help absorb and insulate its economy from negative shocks (IMF 2015). The existence of a sovereign wealth fund (SWF) provides some financial protection. The SWF is managed by the Brunei Investment Agency (BIA) and there is no official published data on the holdings. Brunei's SWF has been estimated to be worth between US$30 and $40 billion (Investment Management Institute 2012) and the Sovereign Wealth Fund Institute stated the current assets under management for BIA is US$60 billion (https://www.swfinstitute.org/profile/598cdaa50124e9fd2d05aadd (viewed 29 April 2019).

[9]Brunei has a currency board system with the Brunei dollar pegged to Singapore dollar at par.

the Singapore dollar in place. In the model context, this numeraire acts as a yardstick to which other price variables can be measured.

Productivity in the baseline is assumed to grow at 0.5% per annum, a similar rate to the long-term average in most developed economies.

4.3.3 Baseline Forecasts

With the above assumptions in place, real GDP declines by an average of 1.8% per annum (Fig. 4.2).

Government consumption expenditure has been stimulated in this baseline as evident in Fig. 4.2. The magnitude of the decline in aggregate exports shown in Fig. 4.2 is high because of the major reduction in oil and gas production over the simulation period. In addition, some oil exports are diverted to stimulate the domestic production of refined petroleum products. Similarly, gas exports are cut back to stimulate the domestic methanol and petrochemicals industry. This is based on the assumption that domestically produced oil and gas will be used in the production of these two categories of commodities since they are readily available. To prevent large increases in the prices of oil and gas arising from the reduction in supply, a small negative shock is also applied to the export demand shift variables for oil and gas.

In the short run, aggregate investment falls as a result of the decline in the oil and gas sectors, which make up a total of 80% of total investment and 80% of total capital stock in the initial (2011) database. Aggregate investment recovers gradually in the long run as shown in Fig. 4.2 led by methanol and petrochemical investment under the assumption of continuous stimulation via diversification.

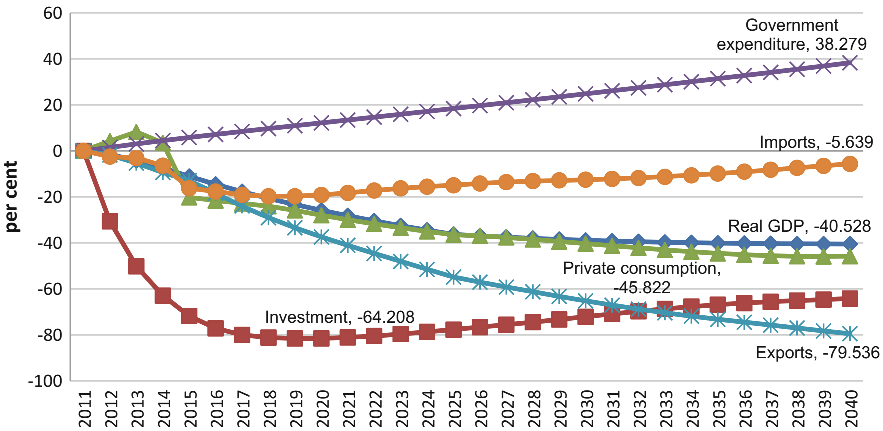

Fig. 4.2 Real GDP and other expenditure components (cumulative growth from 2011, per cent)

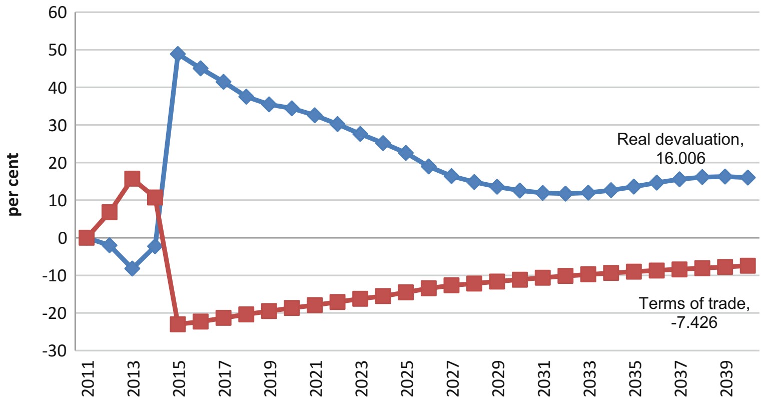

Fig. 4.3 Real devaluation and terms of trade (cumulative change from 2011, per cent)

The temporary increase in private consumption, observed in 2013 (Fig. 4.2), is due to the terms of trade effect, coupled with real appreciation of the domestic currency given the high oil and gas prices observed that year (Fig. 4.3). In Fig. 4.3, real devaluation is defined as the ratio of the import price index at CIF[10]prices to the GDP deflator, which measures the changes in domestic prices in relation to world prices using CIF import prices as a proxy for world prices. Real devaluation indicates that the domestically produced goods are relatively cheaper in the world market, improving the competitiveness of the local economy but reducing the purchasing power of local incomes.

Aggregate employment is tied down by demographic factors and grows steadily throughout the forecast period (see Fig. 4.4). There is a large fall in the real wage between 2011 and 2015, which is connected to the decline in the terms of trade over the same period. After 2015, the real wage recovers, driven by productivity growth and a recovery in terms of trade. The four stimulated industries—building construction, specialised construction activities, architectural engineering activities and public administrative services are also labour intensive and absorb more labour as they expand.

As can be seen in Fig. 4.5, the real devaluation benefits export industries such as methanol and petrochemicals, chemicals and pharmaceutical products. With the fall in real wage, labour-intensive industries such as agriculture, animal products, fishery and aquaculture, food and beverages, architectural engineering industries also experience greater than average growth prospects.

[10]In trade terms, CIF stands for cost, insurance and freight.

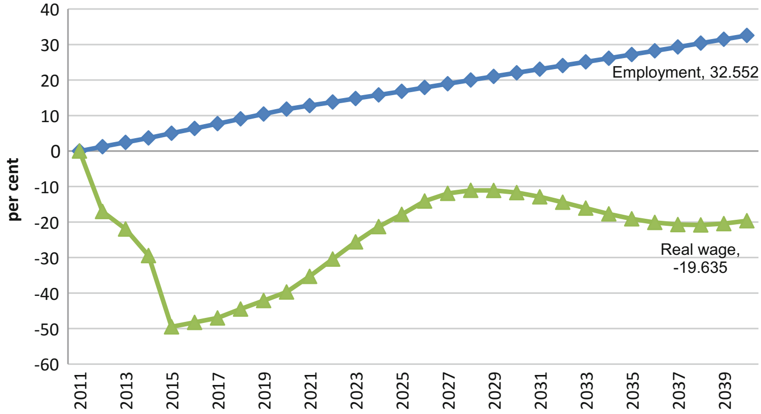

Fig. 4.4 Aggregate employment and real wage (cumulative change from 2011, per cent)

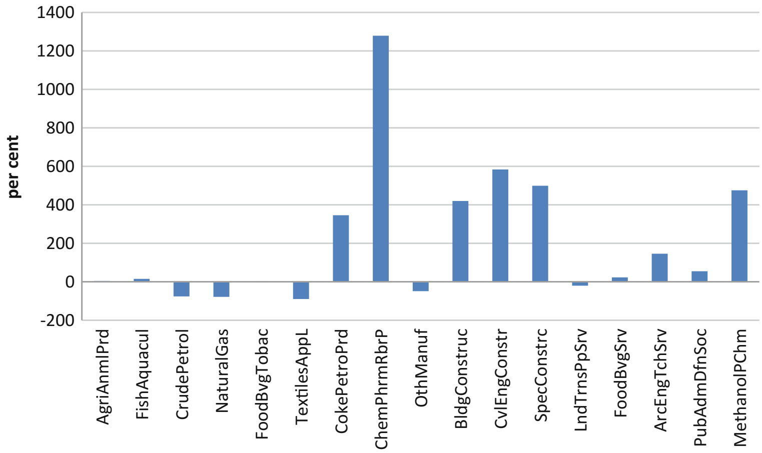

Fig. 4.5 Selected industrial outputs in 2040 (Please refer to Table A.1 in Appendix for the description of industries)

4.4 Policy Simulation of Productivity Improvement

Productivity is widely recognised as one of the key drivers for economic growth in the literature (Jorgenson (1991, p. 21) provides a list of references). The Solow growth model shows that technological progress is necessary for a sustainable increase in material living standards. Therefore, one of the policy options that the government of Brunei is emphasising is productivity enhancement. This intention was explicitly in the Tenth National Development Plan launched in April 2012 (Haji Apong 2013, p. 14).

The government has been working on several initiatives to improve productivity, especially in the non-energy sector (Shahminan 2012; Too 2012). The fibre-to-the-home broadband initiative, one of the largest projects under the Tenth National Development Plan, concluded in April 2019[11] and covers over 5000 homes and businesses nationwide, enabling access to faster Internet connectivity. By having better information and communications technology (ICT) infrastructure, efficiency can be improved. Other initiatives include building better infrastructure such as roads and bridges to contribute to greater connectivity and time efficiency, providing incentives to attract more capital intensive and high value-adding types of industries through foreign direct investment (FDI), investing in human capital and encouraging research activities with high commercial values. There are also general measures to provide an enabling environment for these changes to take place.

One such measure has created technological progress through infrastructure for the financial sector in Brunei. Autoriti Monetari Brunei Darussalam (AMBD), Brunei's monetary authority, has implemented a series of projects to modernise the national Payment and Settlement System (PSS). The first Real Time Gross Settlement System (RTGS) was launched on November 07, 2014, to enable safe and real-time large-value interbank fund transfers to be carried out between financial institutions (AMBD 2014). This system helps to mitigate settlement risk and improve liquidity management. The manual cheque clearing house was automated in 2016 under the Automated Clearing House (ACH) project, which had reduced the time required for cheques to clear from 4 to 3 days (Koo 2014). In March 2017, a cost-effective and efficient way of depositing money by direct credit was introduced to the ACH system. Relative to physical cheques, this offered a safer and faster way for funds to reach the beneficiary's bank account. New electronic payment instruments are expected to be introduced in the near future to encourage more paperless transactions, improving efficiency and hence productivity. A country with a modern, reliable and efficient PSS to cater for the growth of its financial market will be an important consideration to investors in setting up businesses and bringing more FDI to Brunei. More FDI inflows would help boost investment and capital stocks in the domestic economy.

4.4.1 Model Closure

In this simulation, we use a policy closure in which naturally endogenous variables such as macro variables like GDP, aggregate investment, aggregate consumption, are endogenous and are allowed to respond to the policy introduced. Naturally exogenous variables such as average propensity to consume, taste or preference for imports and technical change remain exogenous. In the absence of a policy shock,

[11] See https://borneobulletin.com.bn/telbru-celebrates-5-4k-ftth-milestone/ (viewed 29 April 2019).

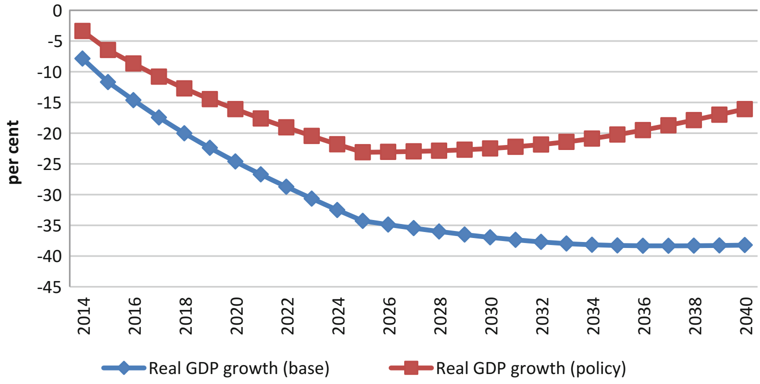

Fig. 4.6 Base case and policy paths of real GDP growth (cumulative growth from 2011, per cent)

the policy simulation generates the same results as the baseline forecast reported in Sect. 4.3.3, although the closures differ. Therefore, any differences in the solutions between the policy simulation and the baseline forecast are due to the additional shocks implemented in the policy simulation.

Since there is no measurement of the expected overall productivity that can be achieved from the ongoing microeconomic reforms, a calibrated all-factor augmenting technological progress shock is implemented to target real GDP growth of an additional 1% per annum to the baseline forecast for the economy. In the baseline, real GDP falls at an average annual rate of 1.8%. Thus, in the policy case where additional 1% real GDP growth is imposed, the real GDP falls at a lower average annual rate of 0.8% for the period from 2014 to 2040. Figure 4.6 shows the improvement brought about by productivity with steadily increasing deviation in real GDP growth from the baseline.

Aggregate employment was assumed to remain at the baseline forecast, by assuming the real wage was sufficiently flexible to enable this. General features of the policy closure as they related to expenditure and income side macroeconomic aggregates are shown in Fig. 4.7. Variables in rectangles are exogenous—unless shocked, their values are set at values in the baseline forecast. Variables in ovals are endogenous—their values are determined by the model and will deviate from baseline values in response to the exogenous shocks imposed. Arrows indicate plausible directions of causality.

From the supply side, GDP is driven by labour (L), capital (K), land (LND) and productivity (A). In this policy simulation, aggregate employment (L) is tied down, by assuming the real wage (RW) is flexible. Capital (K) is also exogenous in this year-on-year closure while the rate of return on capital (ROR) is endogenous. The required rate of return is exogenous and is determined by the world interest rate in the long run. The expected rate of return, which is assumed to vary with the rate of return in the current period, determines investment (I) and capital stocks in the subsequent year. Government expenditure (G) is set exogenously. With real

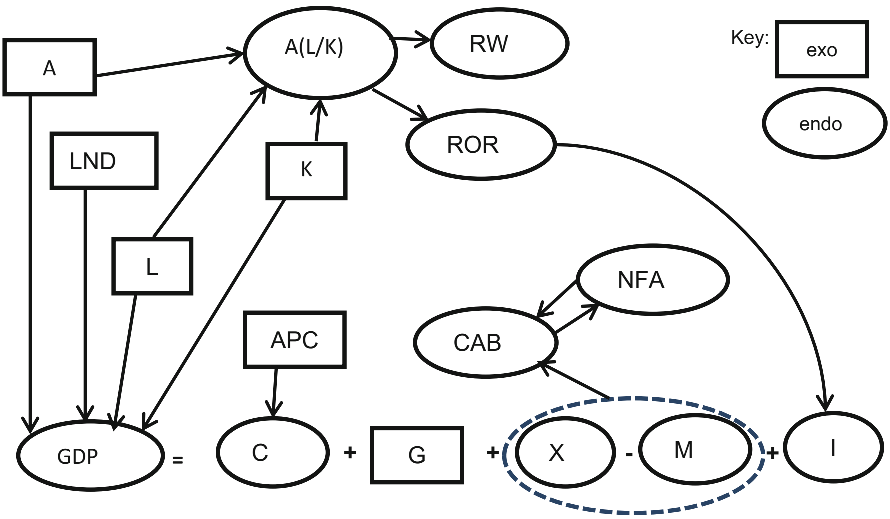

Fig. 4.7 Year-on-year dynamic policy closure for productivity shock

GDP determined from the income side, the trade balance (X-M) is determined as a residual. Most of the export (X) side is tied down due to the specific oil and gas shocks (the main exports). Private consumption (C) is determined by total income and a fixed average propensity to consume (APC). The current account balance (CAB) is driven by the trade balance and interest payments on the stock of NFA at the beginning of each period. The standard stock and flow relationship between the CAB and NFA in the model determines NFA at the end of each period.

4.4.2 Simulation Results

All-factor augmenting productivity improvement stimulates output (Fig. 4.8) where all expenditure components show an increase except for aggregate investment. The fall in aggregate investment and the large gains in exports indicate a fall in real domestic absorption relative to the real GDP, when compared to the baseline values. Investment eventually recovers and returns to baseline in the longer run with more capital built up over time with productivity improvement.

Figure 4.9 shows percentage deviations in the key labour market variables—aggregate employment and the real wage rate. By the end of the period, the real wage rate is down 86% relative to its baseline level, while employment does not change by assumption. Over the period, in the policy simulation the real wage rate falls at an average annual rate of 6.5%. The fall in the real wage rate is an unusual response to an increase in productivity and appears to contradict the uplift in GDP.

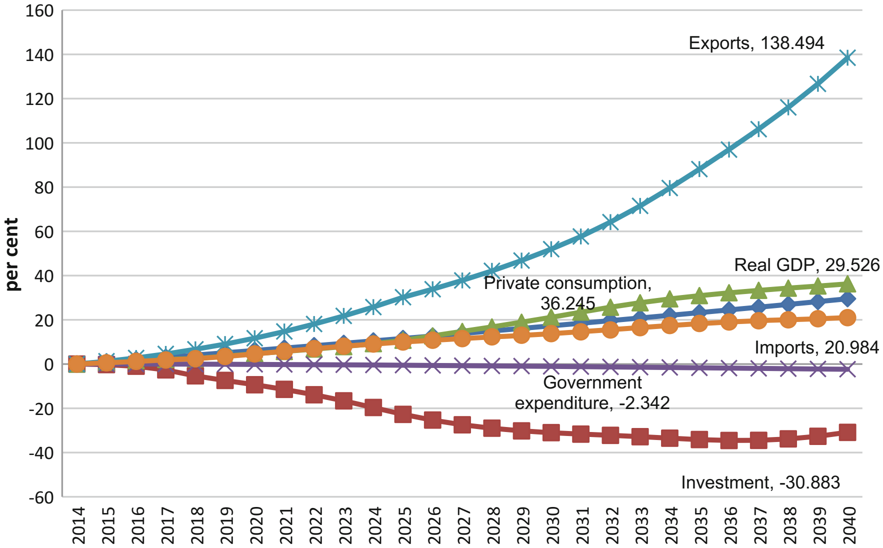

Fig. 4.8 Real GDP and its components (percentage deviation from the baseline forecast)

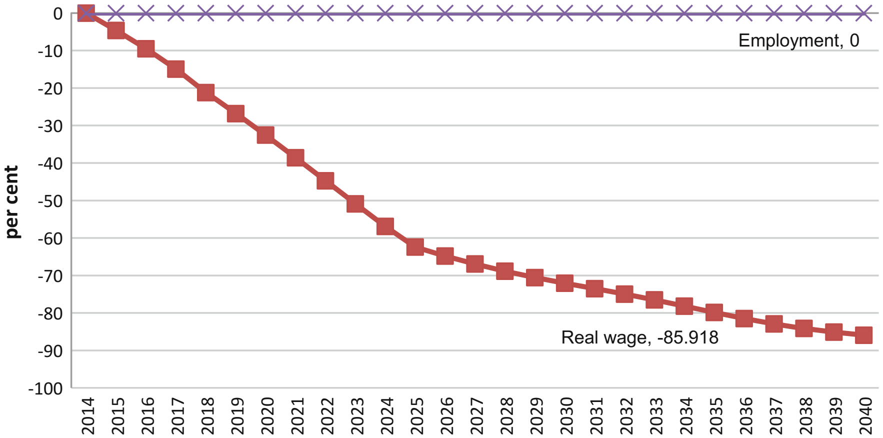

Fig. 4.9 Labour market (percentage deviation from the baseline forecast)

Despite the economy generating more output, the purchasing power of the wages earned by its workers falls.

This result can be explained by looking at the compositional effects that arise from the assumed fixed level of output of the government sector. The government sector employs about 50% of the total labour force according to the IO database. With output of the government sector fixed, the sector is unable to respond to technological change by expanding. Hence, the productivity improvement is absorbed by reducing employment in the sector. Given that aggregate employment is

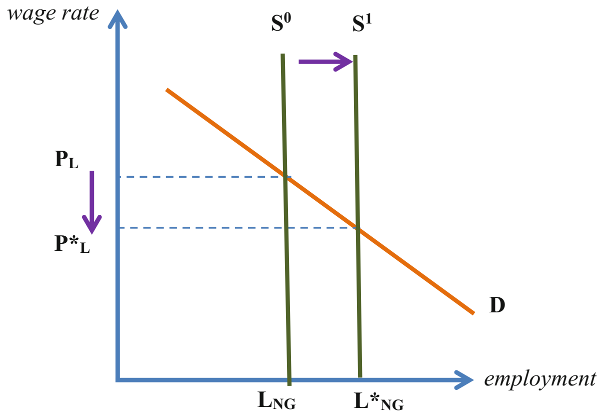

Fig. 4.10 Supply and demand of labour in non-government sector

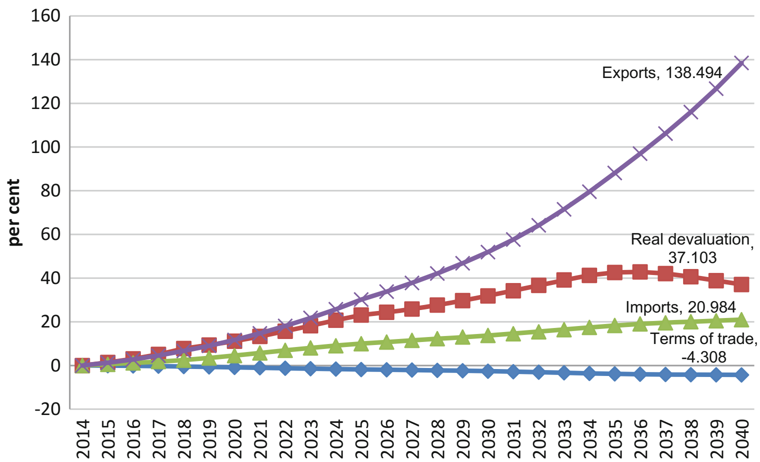

Fig. 4.11 Macro trade variables (percentage deviation from baseline forecast)

assumed to be fixed, labour that is released from the government sector is absorbed by industries other than the government sector or mining sector. To absorb this excess labour into non-governmental sector, the price of labour must fall leading to a decline in real wage (Fig. 4.10). This leads to a significant expansion in relatively labour-intensive industries such as food and beverage, administration and business services agriculture, fisheries and aquaculture and other manufacturing, and real devaluation (Fig. 4.11) can support an increase in exports by some of these sectors.

Figure 4.12 shows percentage deviations in real GDP, employment and capital. By 2040, real GDP is up 29.5% relative to the base case, employment is unchanged and capital is down 19.5%. As can be seen, the only positive contributor to the increase in real GDP is technological progress, which proceeds at a rate necessary

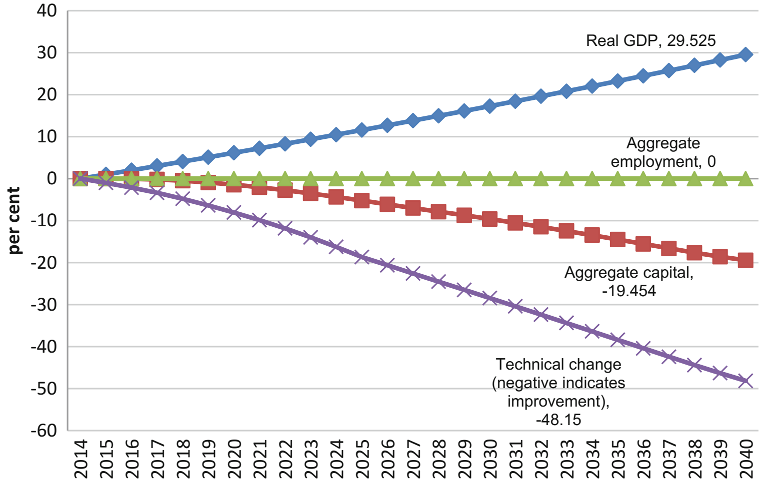

Fig. 4.12 Real GDP and factor inputs (percentage of deviation from the baseline forecast)

to increase annual growth in real GDP by 1% relative to its rate of growth in the baseline.

Figure 4.13 shows a comparison between the baseline and the policy paths for the balance on current account (CAB) and Brunei's stock of foreign assets (NFA). In Fig. 4.14, the same information is provided for the government's fiscal balance. At the time of writing, Brunei has no foreign debt and has a sizeable pool of NFA, excluding SWF. It was assumed that these assets would be well managed to generate a conservative return of 2% per annum. NFA will accumulate over time and help offset the current account deficit brought about by the excess of imports over exports. The current account balance in the policy simulation has improved relative to its baseline value.

In the baseline, as oil and gas deplete, the balance on current account will weaken and NFA will start to fall (see Fig. 4.14). The government will run into budget deficits very quickly as income from oil and gas declines (see Fig. 4.14). With the improvement in productivity, Brunei could continue to enjoy both a current account surplus and the build-up of its NFA, as well as a budget surplus for the government.

At the industry level, in the long run, sectoral outputs increased with productivity improvement (see Fig. 4.15). However, it was found that not all industries would benefit equally, depending on the factor intensity and sale structure. The forecast showed some increased activity levels for the oil and gas industries in 2040, which should be interpreted in the context of the low level of oil and gas output in 2040 in the baseline.

The better performing industries are those that are relatively more labour intensive, such as food and beverage, office administrative activities, agriculture, animal products, fisheries and aquaculture, furniture and other manufacturing industries. These industries are well-positioned to take advantage of labour that is displaced

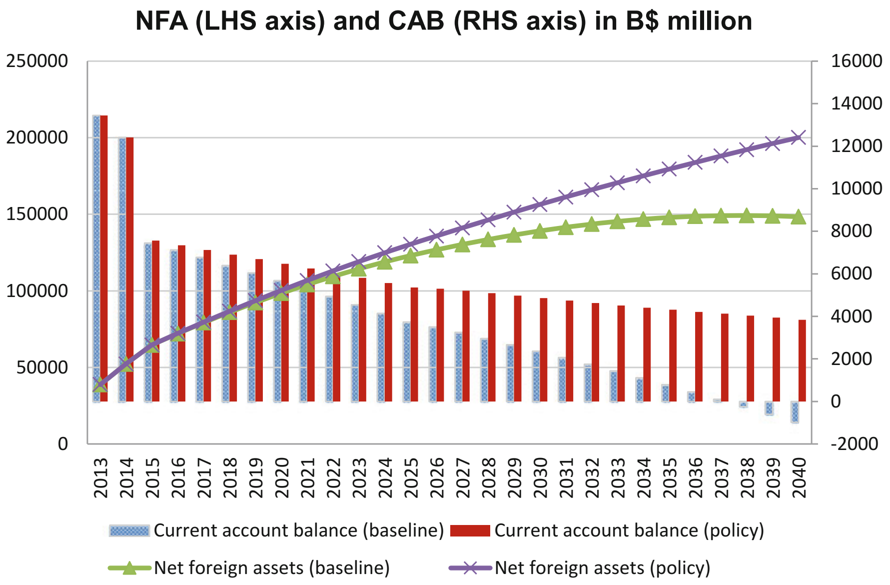

Fig. 4.13 Policy results for current account balance and net foreign assets

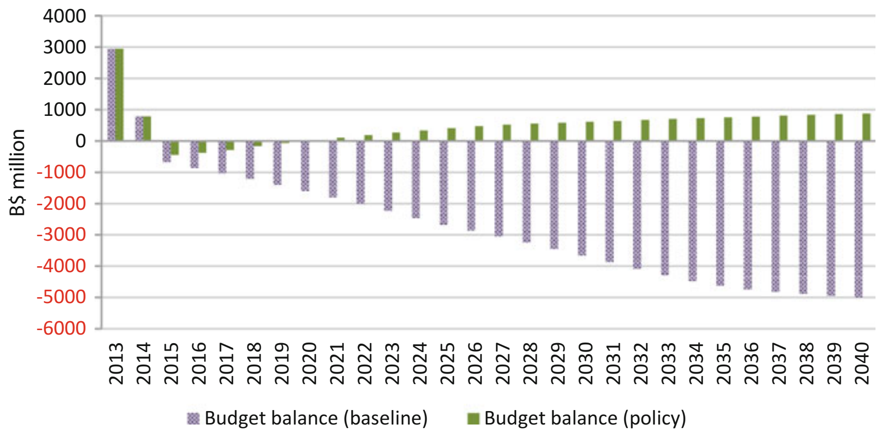

Fig. 4.14 Government budget balance pre-policy and policy scenario with productivity shock

from the government sector. Those who sell mainly to households also benefit, since private consumption (see Fig. 4.8) increases with the productivity improvement.

Industries that are export orientated will benefit from real devaluation of currency. Besides oil and gas, the land transport and transport via pipeline services industry (the fourth largest industry in terms of market sale share), and the methanol industry are amongst the better performers (Fig. 4.15).

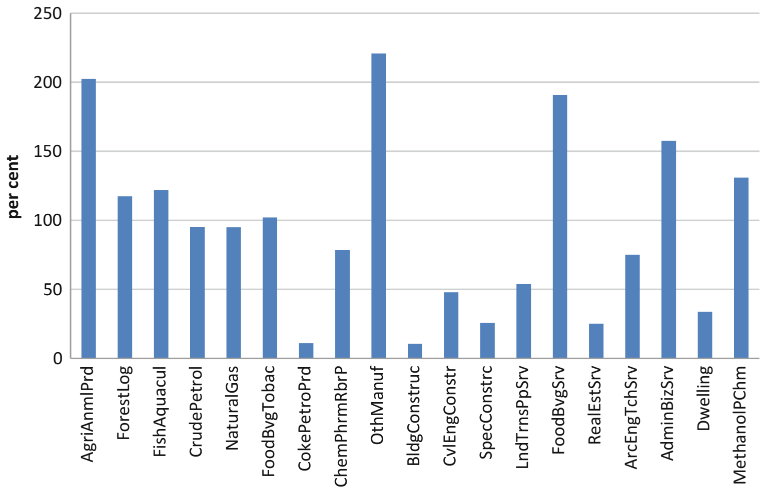

Fig. 4.15 Selected industrial outputs under improved productivity in 2040 (percentage deviation from the baseline forecast)

4.5 Conclusions

With declining reserves of oil and gas and limited diversification, our baseline forecast for Brunei paints a bleak future of declining GDP and investment. Real wages grow after a fall induced by terms-of-trade but do not recover to 2011 levels.

We report a policy simulation that describes an alternative future in which productivity growth is strengthened, moderating the decline in GDP over the forecast period. From the policy simulation results in Sect. 4.4, it is clear that all factor-augmenting technical change can have a positive effect on the economic growth and aggregate consumption. It is found that in order to create 1% of real GDP growth per annum on top of the baseline forecast, 2.5% of additional productivity growth will be required annually.

However, the policy simulation contains some important warnings about pursuing productivity growth as a means to improve economic welfare in the context of Brunei's economy. As illustrated, a sustained period of productivity growth, under the conditions imposed on the simulation, leads to a collapse in real wages. This is because with the output fixed to its baseline levels in Brunei's large government sector, the response to productivity growth is to shed government jobs. With the oil and gas sectors also in the decline, displaced workers have few options in the relatively small private sector and wages must fall significantly to maintain full employment.

The policy simulation also finds that significant real devaluation can support the export markets. However, this may be difficult to achieve in practice as there are many factors influencing the export markets which are not solely driven by the exchange rate. Brunei is not able to compete effectively with other larger economies that can mass produce homogenous goods and it needs to focus on differentiated and high value-added exports that are not as price sensitive. Brunei has successfully exported some premium seafood products[12] to specific markets that value product quality. Overall, Brunei remains a large importer of most goods and some services where a weaker currency may not be desirable. Industries may find that they are unable to expand as quickly as suggested by the simulation due to other factors. Therefore, some creative thinking will be required to innovate the export-orientated industries to absorb more employment in the labour market with increased productivity. Exports can also be service-orientated that require relatively more labour.

We do not suggest that productivity growth will necessarily lead to such an outcome in practice, as it is unlikely that the government would allow a situation as described in our policy simulation to unfold over a period of several decades. While we think that productivity-enhancing reforms should be pursued as a response to declining growth in hydrocarbon production, our simulations show that there are potential risks in such reforms. The largest risk is that if the government responds to productivity growth by shedding workers, this can lead to a collapse in the real wage rate. Productivity reform should be embraced gradually, and the government sector should manage its employment carefully by implementing complementary labour market reforms that prevent wage collapse.

In the policy simulation result with wages rapidly falling, the use of GDP per capita as a measure of welfare must be treated with caution. The simulation highlights that under certain conditions, the benefits of strong GDP growth flow not to the workers through high wage growth, but instead to the owners of capital, including the owners of the hydrocarbon reserves. It is important therefore that Brunei's welfare state based on the proceeds of the hydrocarbon sectors is maintained for as long as possible through the transition to other conduits of growth.

[12]See https://borneobulletin.com.bn/bruneis-blue-shrimp-bound-japanese-market/ (viewed 12 August 2019).

Appendix

Table A.1 New list of industries created from input–output tables 2005

No.	Description of Industries	Code
1	Crop and animal production, hunting and related service activities	AgriAnmlPrd
2	Forestry and logging	ForestLog
3	Fishing and aquaculture	FishAquacul
4	Mining of coal and lignite	CoalMining
5	Extraction of crude petroleum	CrudePetrol
6	Extraction of natural gas	NaturalGas
7	Mining of metal ores	MetalOres
8	Other mining and quarrying	OtherMining
9	Mining support services activities	MiningSptSrv
10	Manufacture of food products, beverages and tobacco products	FoodBvgTobac
11	Manufacture of textiles, wearing apparel, leather and related products	TextilesAppL
12	Manufacture of wood and products of wood and cork, except furniture	WoodPrd
13	Manufacture of paper and paper products	PaperPrd
14	Printing and reproduction of recorded media	PrintRecPrd
15	Manufacture of coke and refined petroleum products	CokePetroPrd
16	Manufacture of chemicals, chemical products, pharmaceuticals, rubber and plastic products	ChemPhrmRbrP
17	Manufacture of other non-metallic mineral products	OthNonMetal
18	Manufacture of basic metals	BasicMetals
19	Manufacture of fabricated metal products, except machinery and equipment	FabMetalPrd
20	Manufacture of computers, electronic and optical products	CompElectOpt
21	Manufacture of electrical equipment	ElectriclEqp
22	Manufacture of machinery and equipment n.e.c.	MachineryEqp
23	Manufacture of motor vehicles, trailers and semi-trailers	MotorVehTrlr
24	Manufacture of other transport equipment	OthTrsprtEqp
25	Manufacture of furniture	Furniture
26	Other manufacturing	OthManuf
27	Repair and installation of machinery and equipment	RprInstlSrv
28	Electricity, gas, steam and air conditioning supply	ElecGasAircn
29	Water collection, treatment and supply	WaterTrmtSup
30	Sewerage, waste collection, treatment and disposal activities; materials recovery; remediation activities, etc.	SwgWstSrv

(continued)

Table A.1 (continued)

No.	Description of Industries	Code
31	Construction of buildings	BldgConstruc
32	Civil engineering	CvlEngConstr
33	Specialised construction activities	SpecConstrc
34	Wholesale and retail trade and repair of motor vehicles and motorcycles	WhReTrdRepMV
35	Wholesale trade, except motor vehicles and motorcycles	WhTrdSrv
36	Retail trade, except motor vehicles and motorcycles	ReTrdSrv
37	Land transport and transport via pipelines	LndTrnsPpSrv
38	Water transport	WaterTrnsSrv
39	Air transport	AirTrnsSrv
40	Warehousing and support activities for transportation	WrhsgSrvTrns
41	Postal and courier activities	PostlCourier
42	Accommodation	AccomSrv
43	Food and beverage service activities	FoodBvgSrv
44	Publishing activities	PublishgSrv
45	Motion picture, video and television programme production, sound recording and music publishing activities	PicSndPrdSrv
46	Broadcasting and programming activities	PrgmBrdctSrv
47	Telecommunication	TelecomSrv
48	Computer programming, consultancy and related activities	ComPrgmCnsIt
49	Information service activities	InfoSrv
50	Financial service activities, except insurance and pension funding	FinSrv
51	Insurance, reinsurance and pension funding, except compulsory social security	InsrnPnsFSrv
52	Other financial activities	OthFinSrv
53	Real estate activities	RealEstSrv
54	Legal and accounting activities	LegalActgSrv
55	Activities of head offices; management consultancy activities	MgtCnsltSrv
56	Architectural and engineering activities; technical testing and analysis	ArcEngTchSrv
57	Scientific research and development; advertising and market research	RnDRschSrv
58	Other professional, scientific and technical activities	OthPrfTchSrv
59	Veterinary activities	VetSrv
60	Rental and leasing activities	RentalLsgSrv

(continued)

Table A.1 (continued)

No.	Description of Industries	Code
61	Employment activities	EmploymtSrv
62	Travel agency, tour operator and other reservation services	TrvlAgtSrv
63	Security and investigation activities	SecuritySrv
64	Services to buildings and landscape activities; office administrative, office support and other business support activities	AdminBizSrv
65	Public administration and defence; compulsory social security	PubAdmDfnSoc
66	Education	Education
67	Human health activities	HealthSrv
68	Residential care activities; social work activities without accommodation	ResCareSWSrv
69	**Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; sports activities and amusement and recreation activities; activities of membership organisations**	**ArtEntSport**
70	Repair of computers and personal and household goods	RepairSrvHH
71	Other personal service activities	OthPrsnlSrv
72	Activities of households as employers of domestic personnel	DomSrvHH
73	**Dwellings**	**Dwelling**
74	**Methanol and petrochemicals**	**MethanolPChm**

Note: Cells with bold emphasis indicate modification from official published input–output tables to fit modelling purposes

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Chapter 5
Assessing the Economic Impacts of Changes in Crop Production Due to Climate Change and Adaptation in Vietnam

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Abstract Vietnam is at risk from diverse climate change impacts, including sea-level rise, extreme weather events, rising temperatures and changes in precipitation. In this chapter, we use a multi-regional dynamic computable general equilibrium model of Vietnam to investigate the effects of changes in crop yields and harvested areas caused by climate change, with and without adaptation measures, under alternative climate change scenarios. We find that reduced crop yields, and reduced crop areas in low-lying regions, cause negative deviations in national and regional GDP, consumption and industrial production. Inequality is projected to rise, primarily due to higher food prices. Adaptation measures improve both crop yields and crop area compared with no-adaptation scenarios. This mitigates some of the adverse macroeconomic effects, while also reducing disparities in climate change impacts across regions and across households distinguished by urban/rural location and expenditure quintile.

Keywords CGE · Climate change · Adaptation measures · Crop yields · Vietnam

JEL Classification: C68, D58, N55, O13, Q54

Abbreviations

AD	Adaptation scenario, when only the benefits of the adaptation measures are taken into account

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ADC	Adaptation scenario, when both benefits and costs of the adaptation measures are taken into account
CGE	Computable general equilibrium
CH	Central Highlands
CSIRO	Climate model of the Commonwealth Scientific and Industrial Research Organisation, Australia
DRY-AD	Dry scenario (IPSL-CM4), with adaptation benefits
DRY-ADC	Dry scenario (IPSL-CM4), with adaptation benefits and costs
DRY-NOA	Dry scenario (IPSL-CM4), no adaptation
EACC	Economics of Adaptation to Climate Change
GCM	General Circulation Models
GISS-ER	GCM projection for SRES A2 emission scenario (by the coupled atmosphere–ocean models, the Goddard Institute for Space Studies, NASA, USA)
GNDI	Gross National Disposable Income
GSO	Vietnam General Statistics Office
IFPRI	International Food Policy Research Institute
ILO	International Labor Organization
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPSL-CM4	GCM projection for SRES A2 (Earth system model, by the Institute Pierre Simon Laplace, France, version 4)
MONASH-VN	A Monash-style CGE model for Vietnam
MONRE	Ministry of Natural Resources and Environment, Vietnam
MONRE-AD	Official Vietnam (MONRE) scenario, with adaptation benefits
MONRE-ADC	Official Vietnam (MONRE) scenario, with adaptation benefits and costs
MONRE-NOA	Official Vietnam (MONRE) scenario, no adaptation
MRD	Mekong River Delta
NCAR	Climate model of the National Centre for Atmospheric Research, USA
NCC	North Central Coast
NE	North East region
NIAPP	National Institute of Agricultural Planning and Projection
NOA	No adaptation scenario
NOCC	No-climate-change baseline
NW	North West region
RRD	Red River Delta
SCC	South Central Coast
SE	South East region
SRES	Special Report on Emissions Scenarios
US$	United State Dollar
VHLSS	Vietnam Household Living Standard Survey
VND	Vietnamese Dong
WET-AD	Wet (GISS-ER) scenario, with adaptation benefits

WET-ADC	Wet (GISS-ER) scenario, with adaptation benefits and costs
WET-NOA	Wet (GISS-ER) scenario, no adaptation

5.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC 2007) ranks Vietnam among countries most likely to be heavily affected by climate change. Key risks to Vietnam are sea-level rise, extreme weather events, rising temperatures and changes in precipitation. Other potential climate change impacts include effects on hydrology and water resources, human health, biodiversity and infrastructure. Among these many potential impacts, our chapter focuses on one: the economic effects of changes in the relative yields and harvested areas of six important Vietnamese crops, namely, paddy rice, sugarcane, coffee, maize, cassava and vegetables. In particular, we assess the impacts on the Vietnamese economy of changes in crop yields, crop area, crop prices and related adaptation measures under alternative climate change scenarios. We do this using MONASH-VN, a large-scale dynamic computable general equilibrium (CGE) model of the Vietnamese economy.

The scenarios input to MONASH-VN were supplied by the International Food Policy Research Institute (hereafter, IFPRI) under the Economics of Adaptation to Climate Change Study (hereafter EACC) by the World Bank (2011).[1] As we discuss further in Sect. 5.2, IFPRI and EACC supplied inputs describing six scenarios, composed of crop- and region-specific yield and area projections, under three climate scenarios, with and without adaptation measures. We also include in our simulation projections by IFPRI (2009) on changes in rice and maize prices in the world market with and without climate change. We assume that these price changes apply to all climate change scenarios for Vietnam.

According to the World Bank (2011, p. 9), the selection of climate scenarios was based on the ranking of General Circulation Models (GCMs) with sufficient geographical detail by the climate moisture index for the IPCC Special Report on Emissions Scenarios (SRES) A2 emission scenarios. The A2 emission scenarios are a family of scenarios characterised by a world of independently operating and self-reliant nations, where there are continuously increasing population and regional oriented economic development.

There are 14 GCMs that met the criteria for consideration. The driest (IPSL-CM4) and wettest (GISS-ER) scenarios are used for what we refer to as the "DRY" and "WET" scenarios in our analysis. But our analysis focuses mainly on the official Vietnam Ministry of Natural Resources and Environment (MONRE)

[1] These inputs were provided in the project "Economics of Adaptation to Climate Change—Macro assessment for Vietnam" that the Centre of Policy Studies, Victoria University, conducted for the World Bank in 2009–2010. The inputs were provided for three points: 2010, 2030 and 2050. For the purpose of this chapter, we use only the inputs up to 2030.

climate projection for the medium scenario, which represents the middle of the distribution of GCMs in terms of the moisture index. Temperature increases and precipitation changes were estimated in all agro-ecological zones for all the three climate change scenarios for 2030 and 2050. According to the World Bank (2011, p. 9), "the DRY scenario is warmer than the WET scenario and both are warmer than the MONRE scenario. However, the largest differences concern the changes in annual precipitation. For most of the country, the DRY scenario projects a significant decline up to 2030, which is partly reversed in the period 2030–2050. On the other hand, the WET scenario shows a substantial increase in annual precipitation, especially in northern Vietnam, but again the rate of change is greater up to 2030 than in the following two decades. In contrast, the MONRE scenario shows much smaller changes in precipitation, so that it lies in between the DRY and WET scenarios". As we shall see in Sect. 5.2, the differences in climate scenarios translate into big differences in crop yield impacts. The adverse impacts of climate change on crop yields are largest in the DRY scenario, followed by the WET scenario. The impacts are smallest under the MONRE scenario.

In this chapter, outcomes of the six scenarios are reported as deviations away from a no climate change baseline described in Sect. 5.4. We use the following shorthand to describe the simulations associated with these scenarios:

For climate change scenarios:	
NOCC	No climate change
DRY	IPSL-CM4 GCM projection for SRES A2 emission scenario (Earth system model, by the Institute Pierre Simon Laplace, France, version 4).
WET	GISS-ER GCM projection for SRES A2 emission scenario (by the coupled atmosphere-ocean models, the Goddard Institute for Space Studies, NASA, USA)
MONRE	Official projection from the Ministry of Natural Resources and Environment, Vietnam.
For adaptation responses:	
NOA	No adaptation.
ADC	With adaptation, taking into account both benefits and costs of adaptation measures.
AD	With adaptation benefits only. These are additional simulations that we find useful in elucidating the benefits and costs of adaptation measures.

Thus, in our notation: "MONRE-NOA" refers to the MONRE climate scenario in the absence of adaptation measures; "MONRE-ADC" refers to the MONRE climate scenario in the presence of adaptation measures; and "MONRE-AD" refers to the MONRE climate scenario, with adaptation measures in place, but without modelling the costs of adaptation.

The remainder of this chapter is structured as follows. Section 5.2 describes IFPRI inputs to our modelling, and the manner in which they have been translated to model-compatible shocks under an appropriate model closure environment. Section 5.3 describes the theoretical structure of MONASH-VN, and developments to the model specific to this chapter. Section 5.4 details our baseline forecast. Section

5.5 describes simulation setup. Section 5.6 reports in detail economic outcomes for Vietnam under the MONRE scenarios. Section 5.7 compares key economic outcomes under three alternative climate change scenarios. Section 5.8 concludes the chapter.

5.2 Inputs to Our Analysis

Inputs to our analysis comprise the following data: (1) crop yields under alternative climate change scenarios with and without adaptation; (2) crop harvested areas with and without adaptation; (3) the costs of adaptation expressed as total US$ capital spending over the forecast period and (4) the differences between the rice and maize prices in the world market with and without climate change in 2030. These data are the basis for the exogenous shocks to MONASH-VN capturing the direct effects of climate change and adaptation spending. We discuss each of the inputs below. We begin with adaptation measures, because they have significant effects on yields and harvested areas under all climate change scenarios.

5.2.1 Adaptation Measures

The adaptation measures considered in this chapter include those planned by government, but not the autonomous adaptation that might be undertaken by farmers to adapt to climate change. According to the World Bank (2011, p. xvi), planned adaptations include (a) increased spending on research, development and extension with the goal of raising crop yields by 13.5% by 2050 relative to the baseline, and (b) extending the area of irrigated land by about 688,000 ha by 2050, roughly half for rice and the remainder mainly for maize and coffee.

IFPRI estimated the cost of planned adaptation measures at US$ 8.8 billion at 2009 prices (without discounting) for the period 2010–2050. The measures comprise agricultural research and extension (US$ 4.05 billion) and irrigation expansion (US$ 4.76 billion). These costs are spread evenly over the period 2010–2050. For the period 2010–2030 in this chapter, the total costs of these adaptation measures are US$ 4.4 billion.

We model implementation of adaptation measures as an increase in final demand for commodities relevant to agricultural research and extension, and irrigation expansion. The commodities include agricultural services, construction, science and technology and education. Our macroeconomic closure implicitly assumes that adaptation spending is financed by foreign borrowing. This is consistent with policymakers matching the time frame of the adaptation financing burden with the lengthy time frame over which the adaptation infrastructure will provide benefits. In our simulations, we link economy-wide consumption spending to national income. Under this closure, the increase in spending associated with adaptation measures moves the balance of trade toward deficit. Over time, this damps the real consumption deviation via accumulation of interest obligations on foreign debt incurred to finance the adaptation measures.

5.2.2 Crop Yields Under Alternative Scenarios

Under the EACC study (World Bank 2011), IFPRI provided us with crop yield data for six agricultural industries in eight regions for seven climate change scenarios. The six crops include paddy rice, coffee beans, sugar cane, maize, cassava and vegetable. The eight regions include Red River Delta (RRD), North East (NE), North West (NW), North Central Coast (NCC), South Central Coast (SCC), Central Highlands (CH), South East (SE) and Mekong River Delta (MRD). The seven climate change scenarios include:

1. No climate change (NOCC)
2. MONRE climate change scenario without adaptation
3. MONRE scenario with adaptation
4. DRY climate change scenario without adaptation
5. DRY climate change scenario with adaptation
6. WET climate change scenario without adaptation
7. WET climate change scenario with adaptation

The yield data were provided in the form of "relative yield", defined as the ratio of actual yield to potential yield in 2010 and 2030. The percentage deviations of the relative yield in 2030 under alternative climate change scenarios away from the no-climate-change scenario are reported in Table 5.1.

To assist our analysis, we have summarised the changes of relative yield by crop and by region as weighted averages of the detailed yield data by crop, region and scenario. For summarising the changes by each crop, the weights are the share of regions in total value added of economy-wide production of the crop in 2010 (Table 5.2). The weighted average changes in crop yield under alternative climate change scenarios are reported in Table 5.3.

For summarising the changes by each region, the weights are shares of crops in aggregate value added to the production of the six crops in the region under examination in 2010 (Table 5.4). The summarised changes in regional yield under alternative climate change scenarios are reported in Table 5.5.

From the yield tables above, and especially from the last rows of Tables 5.3 and 5.5, we can see that without adaptation measures, climate change will cause all crop yields to decline. The decline is largest under the DRY scenario, followed by the WET scenario, and then the MONRE scenario. With adaptation measures, all crop yields improved compared with the no-adaptation scenarios. For the MONRE scenario, adaptation measures (e.g. research, extension and irrigation) improve the yields above the no-climate-change case.

Table 5.1 Changes in relative crop yield in 2030, by crop and region, under alternative climate change scenarios (% change relative to no-climate-change baseline)

	RRD	NE	NW	NCC	SCC	CH	SE	MRD
1. MONRE, no adaptation								
Paddy	−3.5	−3.2	−7.1	−5.1	−5.2	−6.7	−7.2	−7.7
Coffee	−1.8	−2.0	−5.2	−2.5	−4.2	−6.3	−6.6	−5.2
Sugarcane	−1.5	−2.8	−3.9	−3.1	−4.0	−4.9	−5.2	−6.4
Maize	−2.1	−2.6	−3.4	−1.8	−3.3	−4.8	−5.2	−6.4
Cassava	−1.6	−1.8	−4.8	−2.8	−4.5	−5.2	−5.3	−4.8
Vegetable	−3.2	−2.8	−5.8	−4.7	−4.8	−6.5	−7.1	−6.3
2. MONRE, with adaptation								
Paddy	6.7	4.4	0.4	8.7	13.7	3.7	1.2	−1.4
Coffee	8.1	7.0	3.6	8.3	13.3	2.9	3.3	6.3
Sugarcane	6.8	4.9	4.0	5.8	6.7	3.1	3.8	1.9
Maize	11.6	7.0	6.4	7.1	6.6	3.7	4.6	−0.0
Cassava	5.0	4.9	1.7	3.8	2.0	1.3	1.1	1.7
Vegetable	5.2	5.2	2.1	3.6	3.7	2.0	1.3	2.4
3. DRY, no adaptation								
Paddy	−22.8	−42.2	−30.1	−27.6	−25.4	−40.9	1.0	−12.8
Coffee	−19.4	−37.5	−27.5	−18.6	−30.6	−40.5	−2.8	−15.8
Sugarcane	−22.7	−36.9	−26.7	−25.7	−16.2	−30.5	−7.9	−10.0
Maize	−29.4	−37.0	−26.2	−21.9	−12.5	−36.9	−8.6	−8.8
Cassava	−16.7	−33.3	−21.7	−21.4	−31.2	−39.1	−3.1	−11.8
Vegetable	−7.9	−28.0	−17.6	−11.5	−25.2	−40.4	−2.8	−13.0
4. DRY, with adaptation								
Paddy	−13.6	−37.4	−24.1	−15.6	−10.2	−33.9	10.5	−6.8
Coffee	−9.5	−30.5	−19.4	−8.4	−16.6	−34.4	8.1	−4.9
Sugarcane	−15.5	−31.3	−20.0	−18.4	−6.5	−24.3	1.6	−1.9
Maize	−16.3	−29.2	−17.6	−14.5	−3.6	−29.7	2.3	−2.6
Cassava	−11.1	−28.7	−16.4	−16.1	−26.5	−34.9	3.5	−5.8
Vegetable	0.5	−21.6	−10.2	−3.5	−18.4	−34.9	6.2	−4.9
5. WET, no adaptation								
Paddy	−30.9	−33.9	−11.4	−23.7	−8.0	−27.1	2.3	−2.1
Coffee	−23.8	−30.6	−9.2	−33.4	−20.3	−39.1	−17.6	−17.9
Sugarcane	−23.6	−26.8	−12.3	−21.3	−6.6	−22.1	−0.1	−3.2
Maize	−24.0	−27.3	−12.7	−20.0	−5.0	−22.7	−1.5	−3.4
Cassava	−24.3	−31.5	−10.1	−33.3	−20.8	−37.5	−17.6	−17.4
Vegetable	−26.5	−32.1	−10.3	−35.2	−22.5	−39.3	−17.6	−19.1
6. WET, with adaptation								
Paddy	−23.5	−28.7	−4.2	−12.5	10.0	−19.2	11.7	4.5
Coffee	−16.4	−24.4	−0.9	−26.1	−6.1	−33.2	−8.8	−7.9
Sugarcane	−17.3	−21.0	−5.1	−14.1	3.8	−15.5	9.4	5.4
Maize	−13.5	−20.2	−3.8	−12.8	4.4	−15.7	8.8	3.2

(continued)

Table 5.1 (continued)

	RRD	NE	NW	NCC	SCC	CH	SE	MRD
Cassava	−19.1	−26.8	−4.0	−28.7	−15.4	−33.3	−12.0	−11.8
Vegetable	−20.2	−26.5	−2.8	−29.6	−15.6	−33.9	−10.1	−11.5

Source: Calculated from IFPRI data supplied for the World Bank's EACC Project (World Bank 2011)

Table 5.2 Regional shares in crop value added (%)

Crop	RRD	NE	NW	NCC	SCC	CH	SE	MRD	Total
Rice	17.8	7.0	1.6	9.3	5.2	2.2	4.8	52.0	100.0
Coffee	0.1	0.1	0.5	0.9	0.2	92.8	5.1	0.3	100.0
Sugarcane	0.8	3.6	3.6	19.4	14.0	9.2	19.4	29.9	100.0
Maize	9.0	17.3	11.3	14.1	4.1	24.6	14.7	4.9	100.0
Cassava	1.2	9.2	5.8	10.5	13.2	22.5	36.6	0.9	100.0
Vegetables	7.0	10.5	29.6	6.4	10.3	8.0	27.0	1.3	100.0

Source: MONASH-VN database for 2010

Table 5.3 Changes in relative crop yield in 2030, by crop, under various climate change scenarios (% change relative to no-climate-change baseline)

	(1) MONRE		(2) DRY		(3) WET	
Crop	No adaptation	With adaptation	No adaptation	With adaptation	No adaptation	With adaptation
Rice	−6.2	2.5	−18.9	−11.2	−12.3	−4.5
Coffee	−6.2	3.1	−38.2	−31.8	−37.7	−31.6
Sugarcane	−4.8	4.0	−17.0	−8.9	−9.6	−1.3
Maize	−3.7	5.8	−26.3	−17.7	−17.3	−9.1
Cassava	−4.5	2.0	−20.8	−15.4	−25.0	−19.9
Vegetables	−5.5	2.7	−16.2	−8.6	−21.0	−14.1
Average	−5.9	2.7	−20.6	−13.0	−15.9	−8.4

Source: Calculated from IFPRI data supplied for the World Bank's EACC project (World Bank 2011)

Table 5.4 Crop shares in regional production of the six crops (%)

Region	Rice	Coffee	Sugarcane	Maize	Cassava	Vegetables	Total
Red River Delta	88.8	0.1	0.2	4.5	0.4	6.0	100.0
North East	61.8	0.1	1.7	15.1	5.6	15.8	100.0
North West	18.9	0.7	2.3	13.3	4.8	60.1	100.0
North Central Coast	68.1	0.7	7.6	10.2	5.3	8.0	100.0
South Central Coast	57.4	0.2	8.2	4.5	10.1	19.6	100.0
Central Highlands	12.1	56.2	2.7	13.2	8.4	7.4	100.0
South East	32.0	3.8	6.9	9.7	16.9	30.8	100.0
Mekong River Delta	95.6	0.1	2.9	0.9	0.1	0.4	100.0

Source: MONASH-VN database for 2010

Table 5.5 Changes in crop yield in 2030, by region, under alternative climate change scenarios (% change relative to no-climate-change baseline)

Region	(1) MONRE		(2) DRY		(3) WET	
	No adaptation	With adaptation	No adaptation	With adaptation	No adaptation	With adaptation
Red River Delta	−3.4	6.8	−22.3	−13.0	−30.4	−23.0
North East	−3.0	4.9	−38.9	−33.5	−32.5	−27.1
North West	−5.7	2.3	−21.8	−14.7	−10.9	−3.3
North Central Coast	−4.5	7.7	−25.4	−14.8	−24.5	−14.7
South Central Coast	−4.9	10.1	−24.7	−12.6	−11.5	2.4
Central Highlands	−6.1	2.9	−39.8	−33.6	−35.2	−29.1
South East	−6.5	1.8	−2.4	6.7	−8.1	0.2
Mekong River Delta	−7.6	−1.3	−12.7	−6.7	−2.2	4.5
Average	−5.9	2.7	−20.6	−13.0	−15.9	−8.4

Source: Calculated from IFPRI data supplied for the World Bank's EACC project (World Bank 2011)

Table 5.3 shows that coffee yields are projected to be the most severely affected by climate change under all climate change scenarios. The relative impacts of climate change on the yield of the remaining crops differ across climate change scenarios. For example, rice and vegetable are projected to be among the worst affected crops under the MONRE scenario, but not under other climate change scenarios. Under the DRY scenario, maize and cassava are the worst affected after coffee. Maize is projected to be the least affected under the MONRE scenario, but is among those most affected under the DRY and WET scenario.

The impacts of climate change on a region depend on the effects of climate change on the crops and the shares of the crops in cultivation industries in the region. Because coffee is projected to be the most heavily affected crop, and coffee is very important for the Central Highlands region, the average yield decline in the Central Highlands is the largest. As we shall see later, this will cause the Central Highlands economy to suffer the most from the projected climate change impact on crop yields.

The yield data described above are converted into the form required by MONASH-VN in two ways. First, because agricultural yield in MONASH-VN is defined as all-input-using technical efficiency, the relative yield described in Table 5.1 was converted via simple inversion into model-compatible all-input-using efficiency levels corresponding to years 2010 and 2030. Second, MONASH-VN is a year-on-year model, and requires inputs for every year between 2010 and 2030. To construct these inputs, IFPRI data for 2010 and 2030 and 2050 were interpolated using a cubic spline, which has the properties of being smooth with minimal curvature.[2] The same procedure is used to interpolate the harvested area data described below.

5.2.3 Harvested Area

IFPRI provided us with harvested areas for the six crops in eight regions in 2009 and 2030. The 2009 areas represent the areas in the no-climate-change scenarios throughout the simulation period.[3] The 2030 harvested areas are provided for the no-adaptation and with adaptation scenarios, and in each case are assumed to be the same for the three climate change scenarios (MONRE, DRY and WET) (Table 5.6).

Table 5.7 reports estimated changes in harvested land area by crop from 2009 to 2030 with and without climate change. These changes represent the effects of climate change, because, as discussed above, IFPRI assumes that land areas remain unchanged if there were no climate change.

Via Table 5.7, without adaptation, land loss to crop cultivation will be greatest in the RRD, followed by MRD. There are no changes to the cultivation areas in the NCC, SCC and CH regions. Rice area will be reduced, while the areas for maize, sugarcane and cassava will increase. The total harvested area will decline by 0.08% for the six crops by 2030 compared with that in 2009.

With adaptation, areas for rice, some crops in RRD, NE and MRD still decline, but to a lesser extent than without adaptation. The areas for all crops in the remaining regions increase. The total harvested areas for the six crops will increase by 4.65% compared with 2009.

5.2.4 Changes in World Prices for Rice and Maize

IFPRI (2009, pp. 6–7) projects changes in world prices for a range of crops with and without climate change, and with and without CO_2 fertilisation in the NCAR and the CSIRO scenarios.[4] Among these crops, two are relevant to this study, namely rice and maize. Within the limits of this study, we have adopted the projections for

[2] Although our analysis is concerned only with the period 2010–2030, we use IFPRI data for 2050 as well in generating year-on-year changes in crop yields and harvested areas. That is because, as discussed in the Introduction, some climate change scenarios project some reversal of precipitation and other climate conditions in the period 2030–2050 compared with the period 2010–2030. We use the cubic spline to smooth out the transition between these two periods.

[3] That is, IFPRI assumes no-change in harvested areas during the period 2009–2030 under the no-climate-change scenario. However, as will be discussed later, in our no-climate-change baseline we take into account some changes in agricultural land due to conversion to non-agricultural uses.

[4] NCAR is the climate model of the National Centre for Atmospheric Research, USA. CSIRO is the climate model of the Commonwealth Scientific and Industrial Research Organisation,

Table 5.6 Harvested land area by crop in 2009 and 2030, with and without adaptation (thousand ha)

	RRD	NE	NW	NCC	SCC	CH	SE	MRD	Total
A. Land harvested areas, 2009									
Rice	1111.6	552.5	157.7	683.2	375.8	205.0	431.6	3683.6	7201
Coffee	0.0	0.0	3.5	7.0	1.6	458.2	36.1	0.0	506
Sugarcane	2.3	13.4	12.1	63.4	49.8	33.5	49.4	66.9	291
Maize	84.7	236.0	172.0	137.3	42.1	233.4	126.1	36.3	1068
Cassava	7.5	55.4	42.9	58.9	65.3	129.9	130.8	6.3	497
Vegetables	158.6	45.6	45.6	68.5	44.0	49.0	59.6	164.3	635
Total	1364.7	902.9	433.8	1018	578.6	1109	833.6	3957.4	10,198
B. Land harvested areas, 2030, no adaptation									
Rice	946.1	567.7	151.2	683.2	375.8	205.0	636.3	3590.8	7156
Coffee	0.0	0.0	3.5	7.0	1.6	458.2	36.1	0.0	506
Sugarcane	8.2	11.2	13.0	63.4	49.8	33.5	49.4	66.9	295
Maize	75.8	225.4	216.1	137.3	42.1	233.4	126.1	36.3	1092
Cassava	6.7	52.9	53.9	58.9	65.3	129.9	130.8	6.3	505
Vegetables	158.6	45.6	45.6	68.5	44.0	49.0	59.6	164.3	635
Total	1195.3	902.7	483.3	1018.3	578.6	1109.0	1038.3	3864.6	10,190.1
C. Land harvested areas, 2030, with adaptation									
Rice	1037.7	583.2	157.7	803.7	442.1	241.2	657.8	3590.8	7514
Coffee	0.0	0.0	3.9	7.7	1.8	504.4	39.7	0.0	557
Sugarcane	8.3	11.9	13.6	66.6	52.3	35.2	51.9	70.2	310
Maize	77.9	231.3	220.4	140.8	43.2	239.3	129.3	37.2	1119
Cassava	6.7	52.9	53.9	58.9	65.3	129.9	130.8	6.3	505
Vegetables	166.6	47.8	47.8	72.0	46.2	51.5	62.6	172.6	667
Total	1297.2	927.2	497.3	1149.6	650.8	1201.4	1072.1	3877.1	10,672.7

Source: IFPRI, for the World Bank's EACC project (World Bank 2011)

rice and maize prices for the CSIRO with no CO_2 fertilisation scenario.[5] Under this scenario, rice prices are projected to be US$ 307 per metric ton (without climate change) and US$ 406 per metric ton (with climate change). The corresponding projections for maize are US$ 155 per metric ton and US$ 240 per metric ton, respectively. Assuming that these price differences emerge smoothly over the period

Australia. For more information on the climate change scenarios used by IFPRI for the projection of agricultural prices, see IFPRI (2009).

[5]We expect that, compared with those under the adopted scenario, the impacts of changes in international prices of rice and price due to climate change under the NCAR scenarios would be very similar, and the impacts under the 'with CO_2 fertilisation' scenarios would be somewhat smaller. This is because, assuming smooth growth rates of crop prices over 2010-2050 for IFPRI (2009, p. 7) projections, the projected prices under the NCAR scenarios are very similar to those in the CSIRO scenarios, differing only by 1.8% for rice and 1.1% for maize by 2030. And the projected prices under the 'with CO2 fertilisation' are approximately 8.4% lower for rice and 6.1% lower for maize than under the adopted scenario without CO_2 fertilisation by 2030.

Table 5.7 Percentage change in harvested land area by crop from 2009 to 2030, with and without adaptation

	RRD	NE	NW	NCC	SCC	CH	SE	MRD	Total
A. % change by 2030, no adaptation									
Rice	−14.9	2.7	−4.1	0.0	0.0	0.0	47.4	−2.5	−0.62
Coffee	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.00
Sugarcane	254.3	−16.2	7.2	0.0	0.0	0.0	0.0	−0.0	1.56
Maize	−10.5	−4.5	25.6	0.0	0.0	0.0	0.0	0.0	2.30
Cassava	−10.5	−4.5	25.6	0.0	0.0	0.0	0.0	0.0	1.55
Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Total	−12.4	−0.0	11.4	0.0	0.0	0.0	24.6	−2.3	−0.08
B. % change by 2030, with adaptation									
Rice	−6.7	5.6	0.0	17.6	17.6	17.6	52.4	−2.5	4.35
Coffee	0.0	0.0	10.5	10.1	10.1	10.1	10.1	0.0	10.08
Sugarcane	259.4	−11.2	12.3	5.0	5.0	5.0	5.0	5.0	6.60
Maize	−8.0	−2.0	28.2	2.5	2.5	2.5	2.5	2.5	4.82
Cassava	−10.5	−4.5	25.6	0.0	0.0	0.0	0.0	0.0	1.55
Vegetables	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.04
Total	−4.9	2.7	14.7	12.9	12.5	8.3	28.6	−2.0	4.65

Source: Calculated from Table 5.6

2010–2050, the annual average impact on prices due to climate change would be 0.7% for rice, and 1.1% for maize. These differences are used as shocks to both the export and the import prices of rice and maize in the policy case (with climate change) against the baseline (without climate change) scenario.

5.3 Methodology

5.3.1 Theoretical Structure of the MONASH-VN Model

The analysis in this chapter is based on simulations with the MONASH-VN model, a Vietnamese implementation of the well-known large-scale dynamic CGE model MONASH. Details of the structure of MONASH are documented in Dixon and Rimmer (2002). Giesecke and Tran (2008a, b) document the model's Vietnam implementation, and applications of the model to Vietnamese policy issues include Giesecke and Tran (2010) and Giesecke et al. (2013). We provide an overview of the model below.

Optimising behaviour governs decision-making by industries and households. Each industry minimises unit costs subject to given input prices and a nested constant returns to scale production function. Three primary factors are identified (labour, capital and land) with labour further distinguished by skill. The model has ten households, distinguished by urban/rural areas and five expenditure quintiles. Households are modelled as constrained maximises of Klein-Rubin utility functions. Units of new industry-specific capital are cost-minimising combinations of Vietnamese and foreign commodities. For all commodity users, imperfect substitutability between imported and domestic varieties of each commodity is modelled using the Armington constant elasticity of substitution assumption.

The export demand for any given Vietnamese commodity is inversely related to its foreign-currency price. The model recognises consumption of commodities by government, and the details of direct and indirect taxation instruments. All sectors are assumed to be competitive and all goods markets clear. Purchasers' prices differ from producer prices by the value of indirect taxes and trade and transport margins.

The model recognises three dynamic mechanisms: capital accumulation, net liability accumulation and lagged adjustments. Capital accumulation is industry-specific, and linked to industry-specific net investment. Annual changes in the net liability positions of the private and public sectors are related to their annual investment/savings imbalances. In policy simulations, the model provides the option of allowing the labour market to follow a lagged adjustment path. With this option activated, short-run real consumer wages are sticky. Hence, short-run labour market pressures mostly manifest as changes in employment. In the long-run, employment returns to baseline, with labour market pressures reflected in changes in real wages.

To elucidate the distributional impacts of climate change and associated adaptation, we add to MONASH-VN a multi-household top-down income/expenditure extension.[6] The income/expenditure model is implemented with data from the 2004 Vietnam Household Living Standard Survey (VHLSS). Details of the income/expenditure model are in Giesecke and Tran (2010).

The regional consequences of climate change and adaptation for eight agro-ecological regions are generated using the top-down regional theory described in Dixon et al. (1982). In Sect. 5.2.2, we describe how MONASH-VN models activity by individual crop industry distinguished by region. Hence, while the regional model is top-down, we note that a significant proportion of regional activity is essentially modelled in a bottom-up manner. The model is solved with the GEMPACK economic modelling software (Harrison and Pearson 1996).

5.3.2 The MONASH-VN Database

MONASH-VN is calibrated to 2005 Vietnamese input–output data. These data are based on the input–output table for 2000 (General Statistics Office (GSO) 2003), updated using data from Enterprise Surveys 2002–2005 and the VHLSS 2004 available at GSO website. The MONASH-VN database begins with 113 sectors.

[6]Such a model is described in Dixon and Rimmer (2002, pp. 286–289). They conjecture that the obvious potential limitation of the top-down approach—the absence of feedback effects influencing the structure of production in the CGE core—is unimportant in practice.

Of these, six relate to crop production. For this chapter, we expand the database to: (1) distinguish more agricultural sectors; (2) distinguish land by agro-ecological region and (3) include multiple households. We expand below.

EACC and IFPRI identify the six crops most important in Vietnam and most likely to be affected by climate change. These are paddy, sugarcane, coffee, maize, cassava and vegetables. Paddy, vegetables and maize cover 60% of Vietnam's total cultivated area and are grown by 79% of landholders. Coffee is a major cash crop. To model the economics of adaptation to climate change in Vietnam, these crops must be individually identified in our model.

Of the six crops, three (paddy rice, sugarcane and coffee) were already separately identified in our original input–output data. The remaining crops (maize, cassava and vegetables) were aggregated in a sector named 'other crops'. Our first data task was to disaggregate the 'other crops' sector into four new sectors, namely maize, cassava, vegetables and a new miscellaneous other crops sector (see Columns 1 and 2, Table 5.8).

In disaggregating crop production costs, we used land and output shares to split the cost structure of the original 'other crop' industry. The land shares for the four new sectors were calculated using data from the GSO website on Agriculture, Forestry and Fishery. These land shares were used to split 'other crops' land rental value across the four new sectors. The output shares in value terms were calculated from the VHLSS 2004. These output shares were used to split all remaining cost components for the production of these crops.

In disaggregating crop sales, we used information from VHLSS 2004 on the amount of each of the four crops used for self-consumption, livestock feeding, and other sales, in order to calculate the shares of each of these destinations in each crop's total sales. We then used these shares to split the commodity row of the 'other crops' product in the existing input–output table into four new rows relating to our four additional crops.

Table 5.8 The concordance between old and new crop sectors in MONASH-VN

1. Old crop sectors	2. New crop commodities	3. New crop industries
1. Paddy rice	1. Paddy rice	Paddy rice × 8 regions
2. Raw rubber	2. Raw rubber	Raw rubber
3. Coffee bean	3. Coffee bean	Coffee bean × 8 regions
4. Sugarcane	4. Sugarcane	Sugarcane × 8 regions
5. Raw tea	5. Raw tea	Raw tea
6. Other crops	6. Maize	Maize × 8 regions
	7. Cassava	Cassava × 8 regions
	8. Vegetable	Vegetable × 8 regions
	9. Other crops	Other crops

After this procedure, the number of crop commodities in MONASH-VN increases from six to nine (Column 2, Table 5.8).

Next, we further disaggregated crop production industries by agro-ecological region. The regions are (1) Red River Delta, (2) North East, (3) North West, (4) North Central Coast, (5) South Central Coast, (6) Central Highlands, (7) South East and (8) Mekong River Delta. These regions were chosen to correspond to the regional dimension of IFPRI's yield data. For example, we split the Paddy rice sector into Paddy rice in RRD, Paddy rice in NE, Paddy rice in NW, and so on. Data for region-specific crop output and land cultivation areas are sourced from the GSO's website on Agriculture, Forestry and Fishery. In total, after disaggregation, MONASH-VN expands to 116 commodities and 158 industries. Of these, 48 industries and six commodities cover the six crops that are the focus of this study. For this study, we retained the crop industries and commodities, but aggregated the non-crop sectors from 79 to 32. Hence, the final database for simulations in this study comprises 80 industries and 38 commodities.

To investigate the regional consequences of climate change and adaptation policies, we added to MONASH-VN the regional extension described in Dixon et al. (1982) and developed further in Horridge (2003). The regional extension required regional shares in production, investment, consumption, imports and exports. We calculated these from Vietnamese regional input–output tables reported in Bui (2008).

To investigate the distributional consequences of climate change and adaptation policies, we added to MONASH-VN the multi-household income/expenditure extension described in Giesecke and Tran (2010). This extension used results for commodity prices, factor employment, factor prices and government transfers from the CGE core, to generate real consumption outcomes for urban and rural households distinguished by expenditure quintile.[7]

[7]Our income/expenditure model is based on the VHLSS 2004 (GSO 2006). The VHLSS 2004 surveys 9300 households on detailed expenditure and income characteristics. Using appropriate survey weights, GSO (2006) uses these survey results to calculate detailed expenditure and income data for the Vietnamese population classified by ten expenditure groups. These expenditure groups are identified by region of residence (urban/rural) and expenditure quintile. Our income/expenditure model recognises, for each of ten households distinguished by expenditure quintile and region of residence: (1) labour income from six qualifications cross-classified by 158 industries; (2) capital income from 158 industries; (3) land income from 66 agriculture and mining industries; (4) government benefit payments; (5) foreign interest payments; (6) interest income on domestically issued government debt; (7) foreign transfer income and (8) expenditure on 116 commodities cross-classified by two sources of supply. With this detail, the model captures impacts on real household expenditures arising from changes in factor income (whether via factor prices or employment), transfer payments and commodity prices.

5.4 Baseline Forecast

5.4.1 Introduction

Policy analysis with a model like MONASH-VN requires two broad steps. First, the model must generate a baseline forecast, that is a forecast excluding the policy or other external shock (like climate change) under investigation (Line A in Fig. 5.1). Second, the model must generate a second forecast that incorporates all exogenous features of the baseline forecast, but with the addition of relevant policy or other external shocks under investigation (Line B in Fig. 5.1). The economic implications of the policy are reported as deviations in values for model variables between the policy and forecast simulations.

In generating a baseline scenario with MONASH-VN, we use independent forecasts for as many variables as practical (Dixon and Rimmer 2002, pp. 261–268). Sources for such forecasts include international organizations, government agencies and research institutions.

Many of the variables for which such forecasts are available (e.g. real GDP) are naturally endogenous in a model like MONASH-VN. To impose an independent forecast for such a variable, it must be determined exogenously, and a corresponding variable describing economic structure (e.g. primary factor technical change in the case of real GDP) must be determined endogenously. In the remaining subsections below, we describe the independent forecasts used to build the baseline scenario for this study, the economic environment under which we allow MONASH-VN to track these independent forecasts, and the key features of the resulting development of the Vietnamese economy under the baseline simulation.

Recall that the initial database for the MONASH-VN is the input–output tables for 2005. In the baseline forecast, we first update the database to 2011, using available observed data for population, employment, land and GDP expenditure

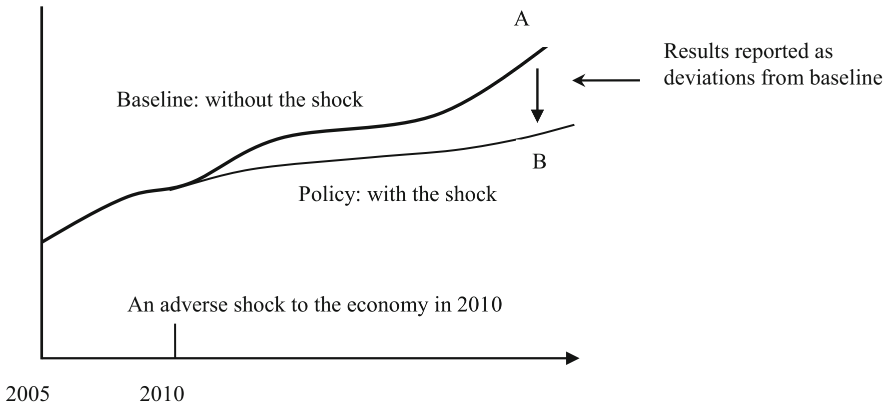

Fig. 5.1 Policy analysis with MONASH-VN

components. We then use independent forecasts for the period 2012–2030 to generate the baseline forecast for the period.

5.4.2 Baseline Forecast Data and Assumptions

5.4.2.1 GDP, Employment, Population and Agricultural Land

In the baseline forecast simulation, we impose the projections for real GDP, employment, agricultural land and population on the model. Real GDP and employment are normally endogenous in the model. To impose the extraneous data on those variables, we endogenise economy-wide primary factor technical change and the real wage.

The growth rates used in our baseline projections of population, employment and real GDP are reported in Table 5.9. We obtain our baseline projections for

Table 5.9 Actual and projected changes in population, employment, GDP and agricultural land, 2006–2030 (%)

Year	1. Population (a)	2. Employment (b)	3. Real GDP (c)	4. Agri land (d)
2006	1.10	1.82	8.23	−0.43
2007	1.11	1.99	8.46	−0.38
2008	1.11	2.16	6.31	−0.34
2009	1.10	2.07	5.32	−0.30
2010	1.09	1.94	6.78	−0.55
2011	1.07	1.88	5.89	−0.55
2012	1.06	1.83	5.11	−0.55
2013	1.03	1.77	5.88	−0.55
2014	1.00	1.71	6.42	−0.55
2015	0.96	1.65	6.76	−0.55
2016	0.92	1.60	7.20	−0.55
2017	0.88	1.54	7.50	−0.55
2018	0.83	1.48	7.46	−0.55
2019	0.79	1.43	7.43	−0.55
2020	0.74	1.37	7.39	−0.55
2030	0.74	0.74	7.00	−0.55
Annual average 2006–2011	1.10	2.76	7.05	−0.36
Annual average 2012–2030	0.82	1.65	7.0	−0.55

Source: (a) ILO (2011) for 2006–2020, and assumption of the same growth rate from 2020–2030; (b) Actual data from GSO for 2006–2011, calculated data from ILO (2011) labour force data for 2012–2020 using the assumption that the unemployment rate remains at 3.5% for the period 2012–2030; (c) Actual growth rate of for 2006–2011 from GSO, and IMF (2012a, b) afterwards and (d) Actual data from GSO for 2006–2009, NIAPP (2010) for 2010–2030 real GDP from the World Economic Outlook (International Monetary Fund (IMF) 2012a) and the IMF's Debt Sustainability Analysis (2012b). The projections for population and labour force up to the year 2020 are obtained from the International Labour Organization (ILO 2011). We assume that the growth rates of population and labour force remain unchanged after the year 2020. The projections for employment are generated from ILO's labour force projections with the assumption that the unemployment rate stays at 3.5%—the average unemployment rate over the period 2005–2011.

Projections for agricultural land are based on data from National Institute of Agricultural Planning and Projection (NIAPP), which projects that agricultural land will decline from 9598.8 thousand ha in 2009 to 8998.8 thousand ha in 2020 and 8548.8 thousand ha in 2030 due to conversion to non-agricultural uses (NIAPP 2010). This implies a decline of 0.55% p.a. over 2009–2030.

Even without climate change, IFPRI projected that crop yield will change, although the change will be very small. In our baseline forecast simulation, we impose these projections on the model for the six crops in eight regions, on top of changes in economy-wide primary factor technical change, which, as discussed above, is calculated endogenously by the model to accommodate exogenous changes in real GDP and employment.

5.4.2.2 Other Inputs and Assumptions

The IMF forecasts a GDP growth rate for Vietnam of about 7% p.a. over 2012–2030. This implies that, ceteris paribus, Vietnamese export volumes will grow. In the absence of expansion in foreign demand for Vietnam's exports, growth in Vietnam's export volumes will cause Vietnam's terms of trade to decline. Trade is a high share of Vietnamese GDP, so movements in the terms of trade have important consequences for national income and real consumption. We assume that foreign demand for Vietnamese exports will expand enough to cause the terms of trade to stay unchanged over the forecast period.[8] In the baseline simulation, we implement this by holding the terms of trade unchanged via endogenous determination of a commodity-wide export demand shift. Under this environment, as the Vietnamese economy grows, foreign demand schedules for Vietnamese exports shift outwards, thus accommodating expansion in Vietnamese exports at given foreign currency export prices. Over the forecast period, we assume that both household consumption and government consumption move with Gross National Disposable Income (GNDI).

[8]We think this is a realistic assumption, for three reasons. First, as Vietnam grows, other economies will also grow, shifting outwards demand curves for Vietnamese exports. Second, as Vietnam develops, we expect Vietnamese trade negotiators will have growing success in accessing foreign markets and countering protectionist reactions to export expansion. Thirdly, Vietnamese entrepreneurs will have success in developing new products and niche markets for their exports.

For the consumption of rice, we adopt the assumption of Centre for Agricultural Policy that per capita rice consumption will fall by 1% p.a., from 135 kg in 2010 to 110 kg by 2030.[9] We assume that as households reduce rice consumption of rice, they increase the consumption of other food items.

5.4.3 Some Features of the Baseline Forecast

At the macro level, the projected annual GDP growth is high, averaging 7% over 2011–2030. Wage bill weighted employment grows at a slower pace, at 2.1% p.a. The capital stock grows at an annual average rate of about 6.5%. Land declines at about 0.37% p.a.[10] Returns to labour, capital and land comprise approximately 44, 34 and 8% of GDP, respectively. Taken together, movements in these factors can explain around three percentage points of the IMF's annual GDP growth ($0.44 \times 2.1 + 0.34 \times 6.53–0.08 \times 0.37 = 3.11$). The remainder of GDP growth comes from technical progress (3% p.a.) and indirect tax movements.

As the economy grows, so too do all sectors, but at different rates. Agricultural output has the lowest growth rate, averaging 4.8% over 2011–2030. The average growth rates of the outputs of industry (mining, manufacturing, utilities and construction) and services over the same period are 7.7 and 8.1%, respectively. The low growth rate for agriculture reflects our assumption of declining agricultural land, which constrains agriculture's growth.

5.5 Simulation Setup

5.5.1 Shocks

We use as shocks in our simulations the inputs discussed in Sect. 5.2, namely:

1. Annual percentage changes in all-input-using technology for the six crops in eight regions, which is calculated from changes in the yields of the crops under the three climate change scenarios (MONRE, DRY and WET) with and without adaptation measures.
2. Annual percentage changes in harvested areas for the six crops in eight regions in the above climate change scenarios.

[9]Centre for Agricultural Policy, under the Institute of Policy and Strategy for Agriculture and Rural Development, Vietnam Ministry of Agriculture and Rural Development, *Rice domestic demand*, Presentation at the 'Food security and rice value chain research consortium: Taking stock of work in progress' workshop, Can Tho 19–20 October 2010.

[10]Although agricultural land decline at the 0.55% p.a., we assume that the subsoil assets (e.g. minerals) are unchanged. Hence, the aggregate land and natural resources decline only at 0.37% p.a.

3. The costs of adaptation expenditures, which include agricultural research and extension (US$ 98.84 m. p.a.), and spending on irrigation expansion (US$ 116.05 m. p.a.).
4. Annual changes in the world prices of rice and maize with and without climate change. We assume that these changes affect both Vietnam's import and export prices for these crops.

5.5.2 Closure Assumptions

In the policy simulations, we assume that the ratio of nominal consumption spending (private and public) to nominal GNDI is endogenous, adjusting to ensure that real (investment price deflated) national savings remain on its baseline path. As discussed in Giesecke and Tran (2010), this assumption facilitates the interpretation of the economy-wide real consumption deviation as a welfare measure by ensuring that movements in real national income are expressed as movements in real consumption, and by minimising the impact on real consumption of movements in the price of investment relative to the price of consumption.

In terms of the basic mechanics of macroeconomic causation, the main effect of this closure is to ensure that economy-wide consumption moves with national income. We also assume that real government consumption moves with private consumption. Investment in each industry is a positive function of the rate of return on capital in the industry, and the balance of trade is endogenous. Note, however, that much of the scope for deviations from baseline in the balance of trade to GNDI ratio is constrained by our assumption that real consumption adjusts in each year of the policy simulation so as to keep real national savings on its baseline path. We also assume that the gradual effects of climate change do not affect the unemployment rate; that is the unemployment rate stays at the baseline level.

5.6 Simulation Results for the MONRE Scenario

We have run simulations for all three climate change scenarios, with and without adaptation. For reporting, we first focus on the results from the MONRE scenario, which is Vietnam's official climate change scenario. In the next section, we will compare the key results between the MONRE and other climate change scenarios.

5.6.1 Macro Results

Figure 5.2 reports percentage deviations (away from the NOCC base-case) in real GDP under our three MONRE climate scenario simulations: (1) climate change without adaptation (MONRE-NOA), (2) climate change with adaptation, exclusive of adaptation costs (MONRE-AD), and (3) climate change with adaptation, inclusive of adaptation costs (MONRE-ADC). Figure 5.2 shows that the deviations in real GDP remain increasingly negative throughout the simulation period in the no-adaptation scenario. By 2030, real GDP is 0.84% lower than the baseline.

As can be seen from Tables 5.3 and 5.7, Sect. 5.2, adaptation generates an improvement in crop yields and crop areas. Not only does average crop yield improve relative to the MONRE-NOA case, but it also improves relative to the NOCC base-case. Average yield in the crops sector rises steadily relative to the NOCC base-case throughout the MONRE-AD simulation. By 2030, the deviation in average crop yield is 2.7% above the NOCC level. Adaptation also increases crop harvested areas. By 2030, the aggregate crop area under the MONRE-ADC scenario is 4.7% higher than that under the NOCC scenario. This explains the higher level of real GDP in the adaptation cases compared with the no-adaptation case in Fig. 5.2.

Note that the inclusion of the costs of constructing adaptation measures has little effect on the adaptation-inclusive real GDP deviation, with the MONRE-ADC and MONRE-AD lines tracking closely in Fig. 5.2. As discussed in Sect. 5.2.1, we model the process of undertaking adaptation measures as an expansion in the final demand for commodities used in agricultural capital formation (such as construction) and agricultural extension services (such as agricultural services and scientific research). This expenditure affects the composition of real GDP, but has little direct effect on the level of real GDP since it does not directly affect productivity or factor supplies. Rather, the gross returns from adaptation measures are manifested in Fig. 5.2 as the difference between the real GDP deviations under the MONRE-NOA and MONRE-AD simulations. As we shall see below, the gross costs of securing these returns are manifested as a greater

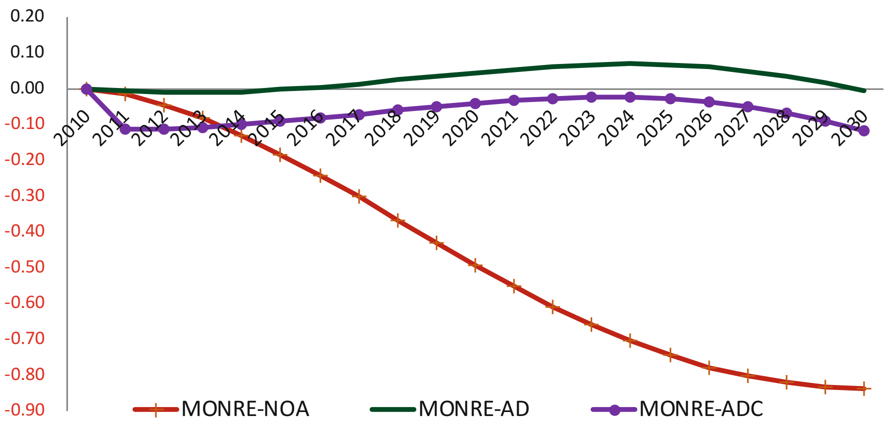

Fig. 5.2 Real GDP under alternative MONRE climate scenarios (percentage deviation from NOCC baseline)

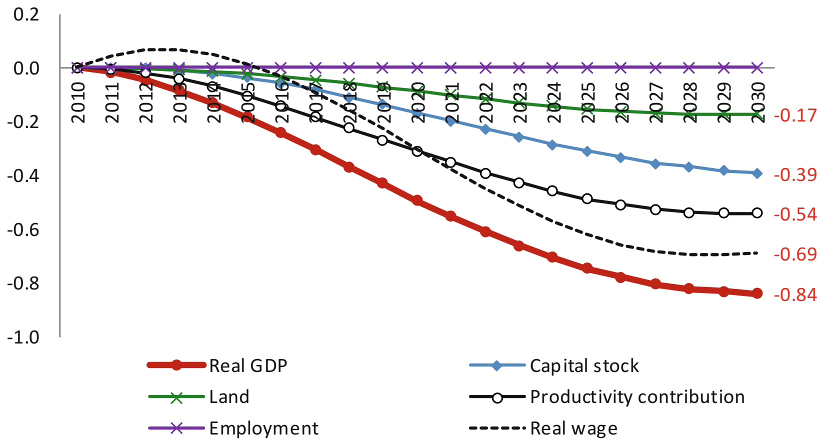

Fig. 5.3 Real GDP income components in the MONRE-NOA scenario (percentage deviation from baseline)

negative consumption deviation in the MONRE-ADC simulation compared with the MONRE-AD simulation.

In order to understand the real GDP results for all three MONRE scenarios, we will first explain the real GDP results for the MONRE-NOA case. The real GDP results for the remaining scenarios (MONRE-AD and MONRE-ADC) can then be similarly explained from the differences in their crop yield and crop area changes compared with the MONRE-NOA case.

We can see from Fig. 5.3 that the deviation path for real GDP is largely determined by the path of climate change-related agricultural productivity movements implicit in the IFPRI yield projections. As discussed in Sect. 5.2.2, without adaptation, the average yield in the crops sector deteriorates. By 2030, average crop yield is 5.9% below its NOCC base-case level, which translates into the deterioration of all-input-using technology in MONASH-VN by 6.23%.[11] Changes in crop productivity contribute to changes in real GDP both directly via a lower efficiency of the use of inputs to crop production, and indirectly via changes in the capital stock, which will be discussed below. The direct contribution made by crop productivity changes to the real GDP deviation can be estimated as the product of the changes in productivity and changes in the share of crops in GDP. In the baseline, the share of agriculture in Vietnam's GDP declines steadily. As such, the share of crop output in Vietnam's real GDP also declines steadily, from 11.5% in 2010 to 8.7% in 2030. Hence, in 2030, the direct contribution to the real GDP deviation made by technical deterioration in the crops sector is −0.54% (=−6.23% × 0.087).

[11] As discussed in Sect. 3.2, MONASH-VN all-input-using technology in crop production is the inverse of crop yields. Therefore, changes in technology have the opposite sign, and close, but not exact absolute value as changes in yields.

This explains about two-third of the MONRE-NOA real GDP deviation of −0.84% for 2030.

The remaining contributors to the real GDP deviation are changes in cropland, labour and capital stocks. Table 5.7 shows that, without adaptation, there is a 0.08% decrease in crop area compared with the no-climate-change case.[12] But the value of land rentals declines even more, at −0.17% by 2030, because of lower land productivity. The lower productivity also affects capital and labour payments because it lowers the marginal products of capital and labour. The lower marginal product of capital lowers the rate of return on capital. This leads to lower level of investment, and hence a lower level of capital stock. The level of employment does not deviate from baseline, but with lower productivity, the marginal product of labour falls, and thus the real wage falls. By 2030, labour payment and capital stock fall by 0.27 and 0.39%, respectively.

In 2030, labour, capital and land contribute 42.1, 32.5 and 11.9%, respectively, to real GDP. Together, changes in productivity and factor payments explain 0.8 percentage points of the 0.84% decline in real GDP.[13] The remaining 4 percentage points are attributable to allocative efficiency effects arising from changes in the structure of the economy across sectors with different rates of indirect taxation.

Figure 5.4 reports deviations in real consumption (private and public) under alternative MONRE climate scenarios. Our macroeconomic closure links movements in consumption to movements in GNDI (see Sect. 5.5.2). Movements in real GDP are the dominant (but not sole) determinant of movements in real GNDI. Hence, the paths of the real consumption deviations under the MONRE-NOA and MONRE-AD scenarios closely track the paths of the real GDP deviations under the MONRE-NOA and MONRE-AD scenarios, respectively (compare Figs. 5.2 and 5.4). Since the real GDP deviation under the MONRE-AD scenario lies above the real GDP deviation under the MONRE-NOA scenario, the real consumption deviation under MONRE-AD exceeds the real consumption deviation under MONRE-NOA. However, the MONRE-AD simulation does not model costs associated with the adaptation measures responsible for the real GDP increase evident in the comparison of the MONRE-NOA and MONRE-AD simulations. In the MONRE-ADC simulation, expenditure on adaptation measures causes net foreign liabilities to rise relative to the MONRE-AD simulation to pay for the adaptation costs. Over the first half of the simulation period, the MONRE-ADC real consumption deviation is slightly higher than the MONRE-AD real consumption deviation. This is because spending on adaptation measures moves the balance of trade in the MONRE-ADC simulation towards deficit relative to the MONRE-AD simulation. The resulting negative deviation in export volumes generates terms of

[12] In the discussion of results, to avoid long sentences, we often use the words 'increase' and 'decrease' to mean 'have a positive deviation from the baseline' and 'have a negative deviation from the baseline', respectively.

[13] $-0.80 = -0.54$ (technology contribution) $- 0.27\% \times 0.421$ (labour contribution) $-$ $0.39\% \times 0.325$ (capital contribution) $- 0.17\% \times 0.119$ (land contribution).

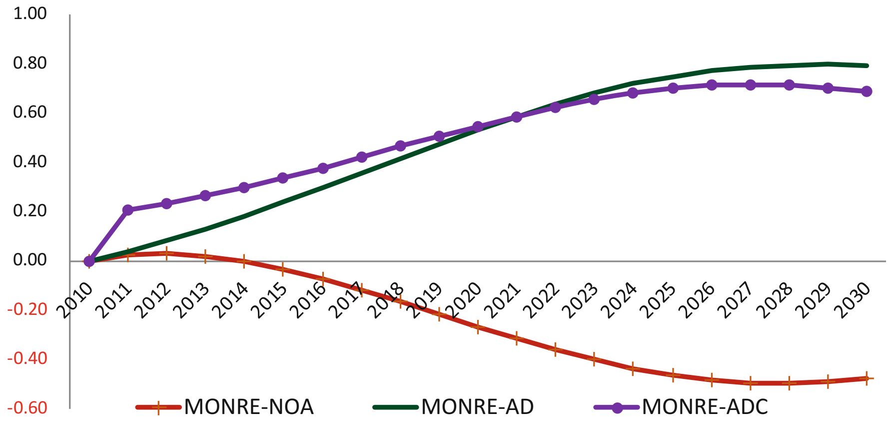

Fig. 5.4 Real consumption under alternative MONRE climate scenarios (percentage deviation from NOCC baseline)

trade gain. This lifts national income in the MONRE-ADC simulation relative to the MONRE-AD simulation, and hence the higher consumption level in MONRE-ADC simulation. In the longer run, interest payments on net foreign liabilities exert a growing damping influence on the MONRE-ADC real consumption deviation relative to the MONRE-AD real consumption deviation.

Recall that the consumption deviations reported in Fig. 5.4 are in terms of movements away from the NOCC base-case. To make more explicit the benefits of adaptation, Fig. 5.5 translates the consumption results reported in Fig. 5.4 to deviations from the no-adaptation MONRE climate change scenario (MONRE-NOA), expressed in terms of constant US$ billions denominated in 2010 prices. The net benefit of adaptation over the simulation period is given by the area under the MONRE-ADC line in Fig. 5.5. The undiscounted sum of the net consumption benefit between 2010 and 2030 under the MONRE-ADC scenario is US$ 21.87 billion. Discounted at a rate of 5%, the difference between the real consumption streams under the MONRE-ADC and MONRE-NOA simulations has a present value of US$ 10.42 billion. This is the present value of the net benefits of adaptation under the MONRE climate scenario.

5.6.2 *Sectoral Results*

In Fig. 5.6 we aggregate output results for the model's 80 industries to outcomes for three broad sectors: Agriculture, Industry and Services. Figure 5.6 reports results for these sectors under the MONRE-NOA and MONRE-AD simulations. Sectoral

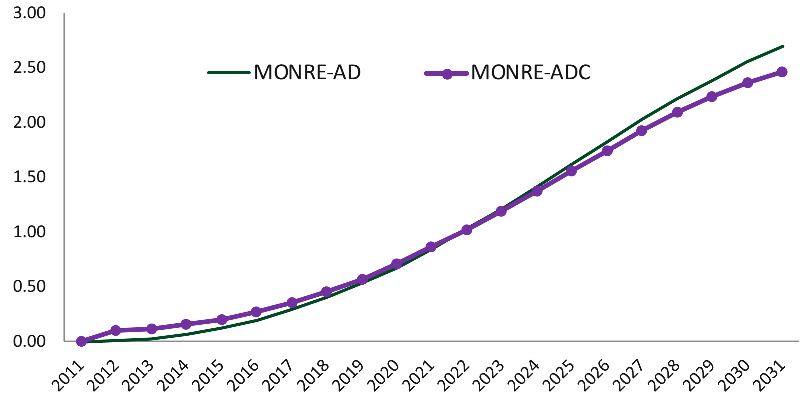

Fig. 5.5 Real consumption under alternative MONRE climate adaptation scenarios (real (2010 prices) US$ billion deviation from MONRE-NOA scenario)

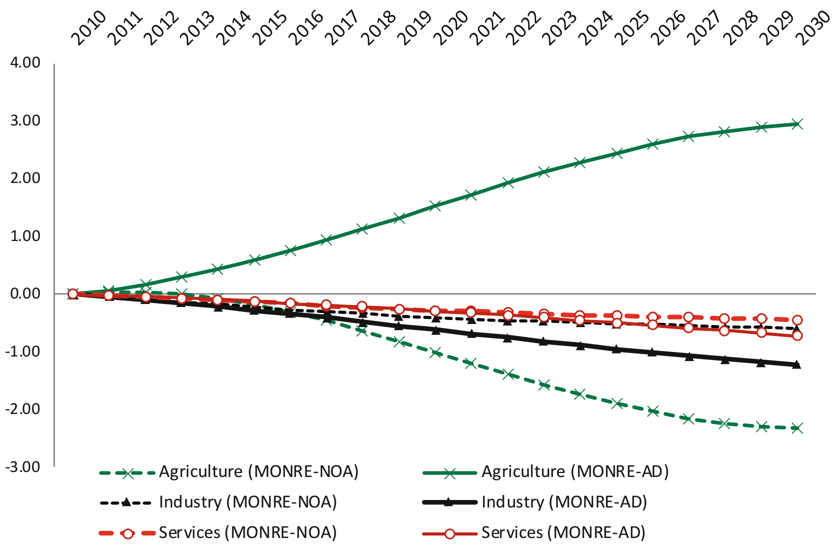

Fig. 5.6 Real output of three broad sectors under alternative MONRE climate scenarios (percentage deviation from NOCC baseline)

output results for the MONRE-ADC simulation are similar to those of the MONRE-AD simulation, and as such, are not reported.

In Fig. 5.6 we see that the sectoral effects of agricultural productivity and land changes under the MONRE climate scenario are mainly experienced by the agricultural sector itself. Without adaptation, crop yields decline relative to the NOCC base-case. This accounts for the negative deviation in the output of agriculture under the MONRE-NOA scenario. The deviation in average crop yields is positive and growing under the MONRE-AD scenario. This accounts for the growing positive deviation in the output of agriculture under the MONRE-AD scenario.

Both the Industry and Services sectors experience small negative deviations in the NOCC base-case under both adaptation and no-adaptation scenarios. This is mainly due to the rise in rice and maize prices caused by climate change, which causes an increase in production, and hence employment, in paddy, rice and maize production. With aggregate employment unchanged compared with baseline, the increase in agricultural employment reduces labour available to manufacturing and services, causing production in these sectors to fall.

As discussed earlier, our climate change productivity shocks are crop-specific. Figure 5.7 elucidates the crop-specific consequences of our productivity shocks by reporting 2030 crop output deviations. For coffee, sugarcane, cassava and vegetables, the deviations in crop production closely mirror the MONRE climate crop-specific productivity shocks reported in Table 5.3. The production of rice and maize is higher than that expected from these crops' productivity deviations. The reason is the projected higher level of world price for these crops, which promotes the exports, and hence the production of these crops.

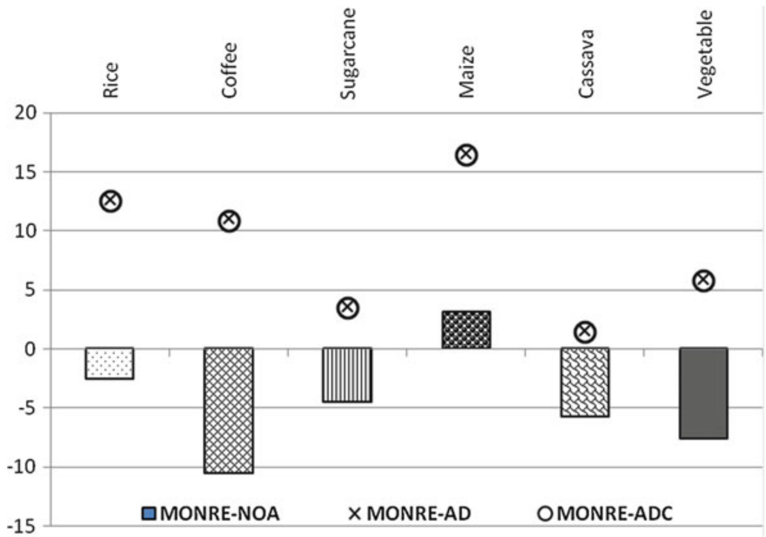

Fig. 5.7 Real output by crop sector under alternative MONRE climate scenarios (percentage deviation from NOCC baseline in 2030)

5.6.3 Distributional Consequences of the MONRE Climate Scenarios

Figure 5.8 reports the change in Vietnam's expenditure-based Gini coefficient under alternative MONRE climate scenarios. Under the MONRE-NOA scenario, Gini-measured inequality rises throughout the simulation period. By 2030, Vietnam's expenditure-based Gini coefficient has increased 11.7 percentage points compared with that in the NOCC case. The MONRE-AD and MONRE-ADC scenarios generate steady improvement in Gini-measured inequality, relative to the NOCC base-case. By 2030, the Gini coefficient is 17.8 and 22.6 percentage points below the NOCC base-case. To understand these results, we must examine the impacts of climate change and adaptation measures on the ten household types distinguished by rural/urban area and expenditure quintile.

Table 5.10 reports real consumption deviations for ten household types. Consistent with the outcome for the MONRE-NOA Gini coefficient reported above, we see in column 1 of Table 5.10 that the impacts of climate change are felt hardest by the poorest urban and rural households. By 2030, households ranked in the lowest quintile of the urban expenditure distribution (that is, UQ1) experience a real consumption decline, relative to the NOCC base-case, of 0.74% under the MONRE-NOA scenario. Households ranked in the lowest quintile of the rural expenditure distribution (that is, RQ1) are projected to experience a real consumption decline of 0.85% by 2030 under the MONRE-NOA scenario. The consumption impacts of the MONRE climate scenario attenuate as we move to households more highly ranked in terms of annual household expenditure. The results in columns 1 of Table 5.10 also display a pattern of rural households being more adversely affected than urban households under the MONRE-NOA scenario.

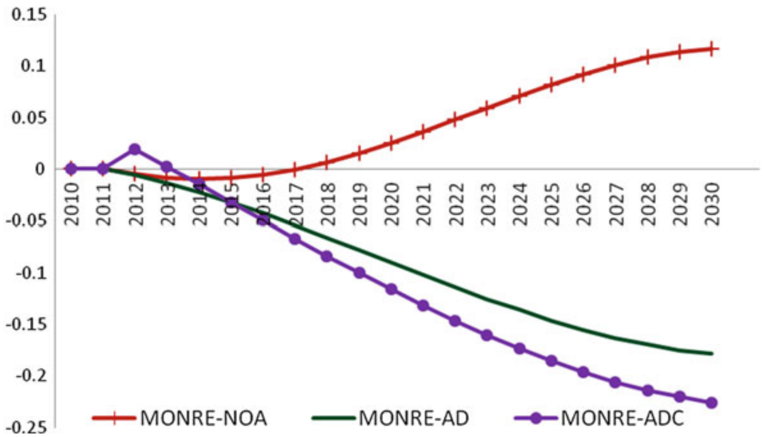

Fig. 5.8 Gini coefficient under alternative MONRE climate scenario (change from NOCC baseline)

Table 5.10 Household real consumption deviation under alternative MONRE climate change scenario by 2030 (percentage deviation from NOCC baseline, unless otherwise stated)

	1. MONRE-NOA	2. MONRE-AD	3. MONRE-ADC	4. MONRE-ADC versus MONRE-NOA in 2030 (%)
Urban households				
Quintile 1 (UQ1)—poorest	−0.74	1.10	1.20	1.96
Quintile 2 (UQ2)	−0.55	0.83	0.88	1.44
Quintile 3 (UQ3)	−0.67	0.33	0.32	1.00
Quintile 4 (UQ4)	−0.67	0.13	0.04	0.72
Quintile 5 (UQ5)—richest	−0.51	0.09	−0.12	0.39
Rural households				
Quintile 1 (RQ1)—poorest	−0.85	1.76	1.84	2.72
Quintile 2 (RQ2)	−0.66	1.43	1.50	2.17
Quintile 3 (RQ3)	−0.53	1.18	1.21	1.75
Quintile 4 (RQ4)	−0.40	0.93	0.89	1.30
Quintile 5 (RQ5)—richest	−0.00	1.39	1.20	1.20

The pattern of increasing adverse impacts, both as we move down the ranking of households by expenditure quintile, and as we move between urban and rural households, reflects differences across households in both food budget shares and labour income shares.

Differences in food budget shares across household types exert an influence on the distributional consequences of the MONRE-NOA scenario because Agriculture is the sector most adversely affected under this scenario (see Sect. 5.6.2). Contraction of agriculture causes food prices to rise. Food budget shares increase, both as we move down the ranking of households by expenditure quintile, and as we move between urban and rural households.

Differences in labour income shares across different household types exert an influence on the distributional consequences of the MONRE-NOA scenario because the real wage declines under this scenario (see Fig. 5.3). Vietnamese households that are low-ranked in terms of household expenditure obtain higher shares of their income from labour than do those households more highly ranked in terms of expenditure. Hence, households low-ranked in terms of household expenditure are more adversely affected by the negative deviations in the real wage generated by the no-adaptation MONRE climate scenario.

Consistent with the Gini coefficient deviations under the MONRE-AD and MONRE-ADC scenarios reported in Fig. 5.8, in Table 5.10 we see that the largest consumption gains from adaptation are experienced by households low-ranked in terms of expenditure quintile, and rural households. This pattern is clearest in

Column 4, which calculates deviations in household real consumption under the MONRE-ADC simulation away from their MONRE-NOA values. This reflects the fact that the gains from adaptation take the form of increased crop productivity in the MONRE-ADC scenario relative to the MONRE-NOA scenario. This increases crop output in the MONRE-ADC scenario relative to the MONRE-NOA scenario, assisting households with high food expenditure shares. The increase in productivity in the MONRE-ADC scenario relative to the MONRE-NOA scenario also lifts the real wage. This assists poor households, since they obtain an above-average share of their household income from labour.

5.6.4 Regional Economic Consequences of the MONRE Climate Scenarios

The deviations in real GDP of each region are the weighted average of the deviations in the output of each region's industries, the weights being industry shares in regional value added. Figure 5.9 reports 2030 regional real GDP deviations under alternative MONRE climate scenarios.

Without adaptation, all regions experience negative deviations in GDP, because all sectors experience negative output deviations (Fig. 5.6). CH, MRD and RRD experience the largest negative GDP deviations throughout the simulation period. This mainly reflects the IFPRI crop- and region-specific yield and area projections. Under the MONRE-NOA scenario, the falls in weighted crop yields are largest for the MRD, SE, CH and NW regions (Table 5.5). We would expect crop production to fall the most for all of these regions. However, crop areas increase for NW and

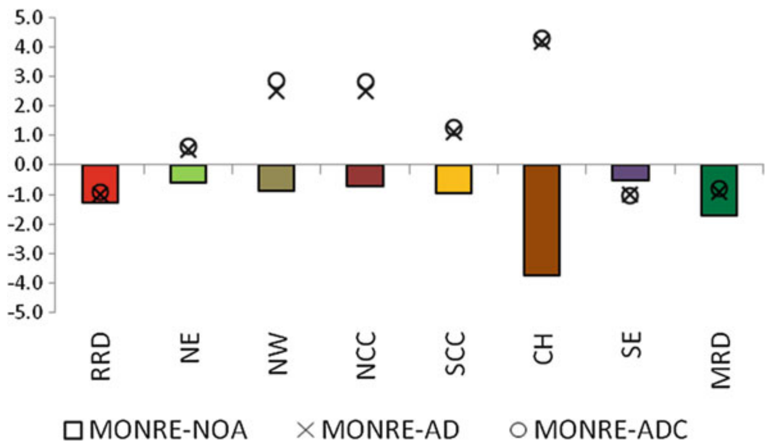

Fig. 5.9 Regional real GDP deviations for 2030 under alternative MONRE climate scenarios (percentage deviations from NOCC baseline)

SE regions (see the last row of Table 5.7, no-adaptation case), and hence crop production in these regions does not fall as much. The falls in crop area are largest for RRD and MRD. Together with the fall in crop yields in these regions, we would expect their production to fall even more than CH. But, RRD and MRD gain from the increase in world prices of rice and maize. The combined effect of all shocks sees the GDP of these regions falling by less than in CH.

From Fig. 5.6, we can see that adaptation measures cause positive deviations for agriculture production, but manufacturing and services still experience negative deviations. The impacts of sectoral outcomes on regional GDP depend on the importance of each sector in each region. Other than SE, all regions experience improvements in real GDP relative to the no-adaptation case. This is because these regions benefit more from adaptation (compare the 'no adaptation' and 'with adaptation' columns for the MONRE scenario in Tables 5.5 and 5.7). They also have relatively high shares of agriculture in GDP.

Compared with other regions, the SE experiences relatively smaller gains in crop yields and crop areas due to adaptation, and hence its agricultural production experiences smaller positive deviations than those in other regions. In the SE, industry and services are important. The negative deviations in these sectors are more than offset by the positive deviation in the region's agriculture. This results in a negative deviation for the SE even in the adaptation case. Industry and services are also important for RRD, causing its real GDP deviations to remain negative in the adaptation case. MRD experiences the smallest increase in both crop yields and crop area due to adaptation. This causes the average prices of crops produced in MRD to rise relative to crop prices in other regions. This causes some substitution in crop demand away from MRD, damping the output deviations of this region in the MONRE-AD simulation relative to the MONRE-NOA simulation.

5.7 Simulation Results Under Alternative Climate Change Scenarios

In this section we compare the impacts of climate change under the three alternative climate change scenarios: MONRE, DRY and WET, with and without adaptation. In the adaptation case, we focus on the simulations where adaptation costs are taken into account.

Figure 5.10 shows real GDP deviations from baseline under the three climate change scenarios with and without adaptation. *Without adaptation*, the loss of productivity is largest under the DRY scenario, followed by the WET scenario, and then the MONRE scenario (see Sect. 5.2). Accordingly, the negative deviations of real GDP are largest under the DRY scenario, followed by the WET scenario. The negative deviations are significantly smaller in the MONRE scenario. *With adaptation*, real GDP improves for all three scenarios, but the deviations are still

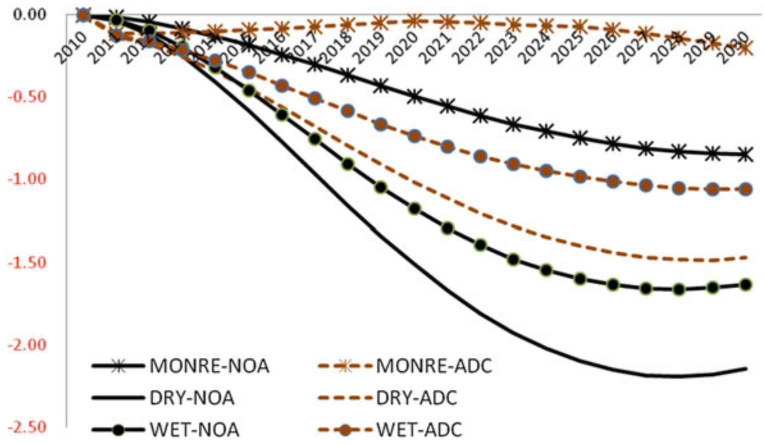

Fig. 5.10 Real GDP under alternative climate change scenarios (percentage deviation from baseline)

negative. The deviations are still largest under the DRY scenario, followed by the WET, and then the MONRE scenarios.

Table 5.11 summarises the key inputs and key results from our simulations for the year 2030. We report deviations in macro, sectoral, regional and household economic variables from the no-climate-change scenario.

Without adaptation, climate change has adverse impacts on Vietnam's economic activity (see Panel 1, Table 5.3). These impacts are largely determined by the impacts of climate change on crop productivity. Row 1, Table 5.11, shows that crop productivity is most negatively affected under the DRY and WET scenario, and less under the MONRE scenario. Accordingly, the negative deviations in economic variables in Table 5.11 are largest under the DRY scenario, followed by the WET scenario. The negative deviations are smaller under the MONRE scenario.

At the macro level, climate change reduces real GDP and real consumption. The negative deviations from the no-climate-change scenario in real GDP and real consumption are largest under the DRY and WET scenarios (Rows 3 and 4, Table 5.11). Row 6 shows the annual average deviation and the present value of consumption losses under the three climate scenarios. Without adaptation, on average, household consumption is lower by US$ 0.4 b., 2.2 b. and 1.6 b. under the MONRE, DRY and WET scenarios, respectively, compared with the no-climate-change baseline. This is equivalent to annual per household losses of approximately VND 0.35 m., 1.94 m. and 1.4 m. under these scenarios respectively.[14] The present values of consumption losses for the period 2011–2030 are VND −3.2 m., −18.3 m. and − 13.2 m. per household.

[14] Assuming the exchange rate of 20,000 VND/US$, and the number of households at 22,628,000 (based on the Population Census 2009).

Table 5.11 Key results for alternative climate change scenarios (% change in 2030 compared with no-climate-change baseline)

	(1) No adaptation			(2) With adaptation			(3) Benefit of adaptation		
	MONRE	DRY	WET	MONRE	DRY	WET	MONRE	DRY	WET
Impacts of climate change on crops									
1. Crop yield	−5.9	−20.7	−16.0	2.7	−13.1	−8.5	8.6	7.5	7.5
2. Crop area	−0.08	−0.08	−0.08	4.65	4.65	4.65	4.73	4.73	4.73
Macro variables									
3. Real GDP	−0.8	−2.1	−1.6	−0.1	−1.5	−1.0	0.7	0.7	0.6
4. Real consumption	−0.5	−2.3	−1.7	0.7	−1.3	−0.7	1.2	1.0	1.0
Deviations of real consumption from baseline (in US$ billion, at 2010 prices)									
5. Annual average	−0.4	−2.2	−1.6	0.7	−1.2	−0.6	1.1	1.0	1.0
6. Present value	−3.6	−20.7	−15.0	6.8	−10.6	−5.4	10.4	10.1	9.6
Sectoral variables									
7. Agriculture	−2.3	−9.6	−7.5	3.0	−4.9	−2.9	5.3	4.7	4.5
8. Industry	−0.6	0.3	0.1	−1.2	−0.3	−0.4	−0.6	−0.6	−0.5
9. Services	−0.4	−0.1	−0.2	−0.7	−0.5	−0.4	−0.3	−0.3	−0.3
Regional GDP									
10. Red River Delta	−1.5	−1.5	−2.1	−1.3	−1.1	−1.9	0.2	0.4	0.2
11. North East	−5.9	−5.9	−4.9	−0.6	−4.9	−3.9	5.3	1.0	1.0
12. North West	−6.3	−6.3	−2.3	−0.9	−2.7	1.4	5.4	3.6	3.7
13. North Central Coast	−4.3	−4.3	−4.2	−0.7	−1.0	−1.1	3.6	3.3	3.1
14. South Central Coast	−2.9	−2.9	−1.5	−1.0	−0.9	0.8	2.0	2.0	2.3
15. Central Highlands	−24.2	−24.2	−21.7	−3.7	−19.2	−16.6	20.5	5.0	5.0
16. South East	0.7	0.7	0.3	−0.5	0.3	−0.1	−1.2	−0.4	−0.4
17. Mekong River Delta	−2.1	−2.1	−0.0	−1.7	−1.1	1.0	0.4	1.0	1.1
Household income									
Urban households									
18. Quintile 1 (UQ1)	−0.7	−3.0	−2.3	1.2	−1.2	−0.6	1.9	1.8	1.7
19. Quintile 2 (UQ2)	−0.6	−2.2	−1.7	0.9	−0.9	−0.4	1.4	1.3	1.3
20. Quintile 3 (UQ3)	−0.7	−2.0	−1.5	0.3	−1.0	−0.6	1.0	0.9	0.9
21. Quintile 4 (UQ4)	−0.7	−1.7	−1.3	0.0	−1.1	−0.7	0.7	0.7	0.6
22. Quintile 5 (UQ5)	−0.5	−1.3	−1.0	−0.1	−1.0	−0.7	0.4	0.3	0.3

(continued)

Table 5.11 (continued)

	(1) No adaptation			(2) With adaptation			(3) Benefit of adaptation		
	MONRE	DRY	WET	MONRE	DRY	WET	MONRE	DRY	WET
Rural households									
23. Quintile 1 (RQ1)	−0.9	−4.3	−3.2	1.8	−1.9	−0.8	2.7	2.4	2.4
24. Quintile 2 (RQ2)	−0.7	−3.5	−2.5	1.5	−1.5	−0.6	2.2	1.9	1.9
25. Quintile 3 (RQ3)	−0.5	−2.9	−2.1	1.2	−1.4	−0.6	1.7	1.6	1.5
26. Quintile 4 (RQ4)	−0.4	−2.5	−1.7	0.9	−1.3	−0.6	1.3	1.2	1.1
27. Quintile 5 (RQ5)	−0.0	−2.3	−1.5	1.2	−1.3	−0.5	1.2	1.0	1.0

At the sectoral level, agriculture output is negatively affected under all climate scenarios. Again, the negative impacts are largest under the DRY and WET scenario, and much smaller under the MONRE scenario. The impacts on industry and services are small.

CH is the region most affected by climate change under all scenarios. This is because among the crops under study, coffee production experiences the largest reduction in its productivity, and coffee production contributes the highest proportion to CH's regional economy. Most other regions also experience the adverse impacts of climate change. The SE region gains slightly from the dry climate scenario, because crops comprise a small share in the region's GDP, and the region gains from some expansion in industrial activities (see Row 8, Panel 1, Table 5.11).

Climate change increases income inequality (see Rows 18–27, Panel 1, Table 5.11). By reducing crop production, climate change causes food prices to rise and income from agricultural labour to fall. Poorer households, especially those in rural areas, spend a large proportion of their income on food items, and derive their income largely from labour, and thus experience the largest negative impacts of climate change.

Adaptation measures reduce the adverse impacts on Vietnam's economy of climate change for all macro, sectoral, regional and income distribution variables. Panel 3, Table 5.11 reports the benefits of adaptation, calculated as the differences in deviations of economic variables under the adaptation and no-adaptation scenarios, i.e. the differences between Panels 2 and 1, Table 5.11.

We measure the net benefit of adaptation in terms of real consumption deviations under the adaptation scenario relative to the no-adaptation scenario. The net benefit of adaptation is largest under the MONRE scenario, followed by the DRY and WET scenarios, respectively. The present value of the net gains in real consumption due to adaptation is US$ 10.4 b., US$ 10.1 b. and US$ 9.6 b. under the DRY, WET and MONRE scenarios, respectively. These gains depend not only on changes in crop productivity by 2030, but also on the path of these changes. As can be seen from

Sect. 5.2.2, total productivity gains due to adaptation are smallest under the WET scenario. Hence, the net consumption gain under the WET scenario is smallest. But net consumption gains in all scenarios are higher than the US$ 4.4 b. of adaptation expenditure, the present value of which is US$ 2.47 b. (at a 5% discount rate).

Panel 3, Table 5.11 shows that (1) adaptation benefits are larger for the regions most affected by climate change, such as CH, NE and NW; (2) adaptation benefits are larger for poorer households than for richer households under all climate change scenarios and (3) adaptation benefits are larger for rural households than for urban households of the same quintile level.

5.8 Concluding Remarks

This chapter has assessed the impacts of climate change shocks and adaptation measures for the Vietnamese economy over the period 2011–2030, examining in particular: (1) changes in crop yields and crop areas due to climate change for the six most important crops in Vietnam (paddy rice, sugarcane, coffee, maize, cassava and vegetables); (2) changes in world rice and maize prices due to climate change and (3) changes in crop yields and crop areas due to adaptation measures, namely increased research and development, increased agricultural extension, and improved irrigation. These shocks were examined under three climate change scenarios: (1) Vietnam's official scenario projected by the Ministry of Natural Resources and Environment (MONRE); (2) the DRY (or IPSL-CM4) scenario and (3) the WET (or GISS-ER) scenario.

Overall, it is projected that climate change will reduce yields for all crops, and crop areas in low land regions, such as RRD and MRD. Without adaptation, there will be negative deviations in national and regional GDP, consumption and industrial production. Income inequality is projected to rise, as poorer households are adversely affected by higher food prices.

Adaptation measures improve both crop yield and crop areas compared with the no-adaptation scenarios, causing an improvement in all economic indicators. Compared with the no-adaptation scenarios, adaption measures not only improve overall welfare, but also improve equality between households distinguished by urban/rural location and expenditure quintile. Poorer households gain more from adaptation than richer households. Adaptation measures also make more equal the impacts of climate change across Vietnam's eight agro-ecological regions.

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Chapter 6
Climate Change Impacts on Agriculture and Internal Migration in Brazil

Joaquim Bento de Souza Ferreira Filho and Mark Horridge

Abstract Recent internal migration flows in Brazil differ from historical patterns observed since the seventies. In the past, internal migration typically flowed from states in Northeast Brazil and Minas Gerais toward the richer Southeast states of São Paulo and Rio de Janeiro. Since the eighties, a succession of economic crises and expansion of the agricultural frontiers have changed the picture. During the nineties, emigration from the Northeast region slowed down and the region has actually become a net recipient of the population in recent years. At the same time, the Southeast states of São Paulo and Rio de Janeiro have recently lost population. Some of the migrants leaving the Southeast return to the Northeast, but many go to the expanding agricultural Center-west regions. Yet precisely these regions may be harmed by climate change, which might reduce their agricultural productivity and useable land. This is likely to cause new changes in migration patterns. We investigate this using a detailed Computable General Equilibrium (CGE) model of Brazil. We find that climate change may induce a new pattern of migration, redirecting unskilled agricultural workers toward São Paulo and Rio de Janeiro, as happened in the seventies.

Keywords Computable general equilibrium · Climate change impacts · Internal migration

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6.1 Introduction

Recent internal migration flows in Brazil differ from historical patterns observed since the seventies. In the past internal migration typically flowed from states in Northeast Brazil and Minas Gerais toward the richer states of São Paulo and Rio de Janeiro. According to Brito and Carvalho (2006) between 1960 and 1990 about 8.1 million people left the Northeast and 3.8 million left Minas Gerais.

This was the "normal" internal migration pattern in Brazil until the eighties, when, according to Brito and Carvalho (2006), a succession of economic crises and expansion of the agricultural frontiers changed the picture. During the nineties, emigration from the Northeast region slowed down considerably and the region actually has become a net recipient of population in recent years. At the same time, the Southeast states of São Paulo and Rio de Janeiro, the main destination for migrants until the end of the eighties, have recently lost population. Some of the migrants leaving the Southeast return to the Northeast, but many go to the dynamic new agricultural Center-west regions.

6.2 Objective

The objective of this chapter is to assess the potential impacts on internal migration in Brazil of different climate change scenarios that impact agriculture. Of particular interest in the analysis will be the effects on labor demand, both in the agricultural sector and in the whole economy, and its role in the inter-regional patterns of population flows. The analysis will be conducted with the aid of a dynamic general equilibrium model of Brazil, the TERM-MIG model, described below.

6.3 Internal Migration in Brazil: Recent Patterns

The Pesquisa Nacional por Amostra de Domicílios—PNAD (National Household Survey) provides the migration data in this study. The PNADs have been available since the 1970s, and are a comprehensive household survey, usually regarded as being of very good quality, and the main data source for many different studies. Among the many questions surveyed by PNAD are the person's region of origin, and where each person was living in previous years. These questions allow us to identify migrants.

There is no established definition of a migrant in the literature, with different authors using different definitions, depending on their interest. For the sake of describing the migration flows and analyzing the influence that different definitions can have on them, migration flows were collected according to different definitions for the period 2001–2007, from PNAD micro data.

Table 6.1 Total internal migration in Brazil, different definitions

Number of years living in the region	2001	2002	2003	2004	2005	2006	2007
2	1,183,171	1,528,940	1,425,925	1,433,473	1,502,439	1,384,481	1,466,653
3	1,169,798	1,322,344	1,478,194	1,386,877	1,505,782	1,412,310	1,493,893
5	1,251,173	1,411,385	1,362,150	1,219,948	1,555,577	1,407,262	996,058

The criterion to define each person's migration status was initially to compare the actual region where the person is living with the region of birth. The second step was to check if the period for which the person is living in a different region would be sufficient to define him as a "migrant." Many different criteria were used, and the total number of migrants according to each definition can be seen in Table 6.1. In the table the criteria used to define a migrant were: a person living in a region other than the region of birth for 2 years, 3 years, or 5 years.

Table 6.1 shows that the number of migrants is fairly stable across different definitions. The Brazilian literature on migration usually utilizes a 5-year time span as the main criterion in defining migration [see, for example, Braga (2006); and Brito and Carvalho (2006)]. We will also use this criterion, since it excludes those moving temporarily, like students. The net regional flows[1] (in-migration minus out-migration) according to that criterion can be seen in Table 6.2. There, negative numbers mean population outflows, and positive numbers mean population inflows. The same information is also presented in Fig. 6.1.

Table 6.2 and Fig. 6.1 illustrate the above-mentioned recent reversal of internal migration flows. The important Southeastern states of São Paulo and Rio de Janeiro, which were poles of attraction in the past, now face population outflow. The same happens to the Brazilian Federal District, to the Pará state (in the Amazon region), and to the Southern states with the exception of Santa Catarina. Two scantily populated Northern states, Roraima and Amapá, are consistently gaining population. However, Northeast Brazil, which, together with Minas Gerais, was the main supplier of migrants now shows mixed behavior. Ceará state in this region is consistently gaining population, and the same seems to be happening to the smaller states of Piaui and Rio Grande do Norte. And, finally, Minas Gerais gains population every year shown except 2007.

The locations of the Brazilian states are shown in Fig. 6.2, grouped by the official macro regions:

- North region: States of Acre, Amazonas, Roraima, Amapá, Pará, and Tocantins
- Northeast region: Maranhão, Ceará, Piaui, Rio Grande do Norte, Paraíba, Alagoas, Sergipe, and Bahia
- Southeast region: Espírito Santo, Rio de Janeiro, Minas Gerais, and São Paulo

[1]The model database includes a full bilateral table of migration flows, for each year, region, and labor type.

Table 6.2 Net migration flows in Brazil, by region. Number of people

NETFLOW	Y2001	Y2002	Y2003	Y2004	Y2005	Y2006	Y2007
1 Rondonia	−7655	−11, 319	4210	3054	−13,470	−2455	−7045
2 Acre	4467	−4658	1329	3060	−185	3204	−2147
3 Amazonas	917	5662	4199	4763	−736	2823	9449
4 Roraima	9192	−541	6500	1886	6027	9363	10,166
5 Para	−30,329	−30,750	−26,249	−16,099	−26,218	−5178	−14,963
6 Amapa	−1016	5401	4932	−3118	5794	1339	1831
7 Tocantins	−3786	−5299	−5402	4901	−16,399	−8312	10,412
8 Maranhao	300	−14,029	5693	−6387	24,701	−17,745	−757
9 Piaui	−20,005	9698	4708	6656	888	12,062	−1033
10 Ceara	39,182	−3052	23,404	16,112	6004	17,996	14,810
11 RGNorte	−3620	1977	11,709	3190	17,922	−2972	−7551
12 Paraiba	−10,000	−21,442	−4206	−4769	−1794	6262	−11,018
13 Pernambuco	−22,765	−13,156	−33,868	−5171	4218	−13,901	1180
14 Alagoas	−20,798	−35,465	−7607	−20,607	−5650	−16,691	−2774
15 Sergipe	−6097	−14,782	−7419	3614	−7826	−6973	1051
16 Bahia	−70,554	−10,753	−21,421	−9667	−489	4989	−16,417
17 MinasG	40,878	5319	25,060	19,523	23,432	48,284	−21,769
18 EspSanto	1285	5521	−10,552	7078	−6177	18,447	4768
19 RioJaneiro	−20,825	4328	−3520	9501	−11,512	−30,143	−9074
20 SaoPaulo	81,767	87,059	−11,967	−35,696	−49,215	−79,661	−19,294
21 Parana	−17,712	27,792	16,161	−4461	−3880	7285	−9495
22 StaCatari	12,142	−8121	−5939	3825	14,398	27,871	46,939
23 RGSul	−5384	3134	4886	−6913	15,578	−2618	−11,613
24 MtGrSul	−4213	−14,450	−1154	7292	−5733	−7019	341
25 MtGrosso	17,597	18,240	11,349	12,520	9309	11,793	2854
26 Goias	44,324	32,256	34,947	35,175	46,915	38,843	10,945
27 DF	−7292	−18,570	−19,783	−29,262	−25,902	−16,893	20,204

Note: Migrant defined as someone living in a region different from its origin for 5 years

- South region: Paraná, Santa Catarina, and Rio Grande do Sul
- Center-west region: Mato Grosso, Mato Grosso do Sul, Goiás and Brasilia (the Federal District)

As may be seen from the data, the population flows in Brazil presently follow a completely different pattern than was observed in the seventies and eighties, when there was an intense flow from the Northeast region toward the Southeast region. During that time Brazil's manufacturing focused model of economic development entailed a transfer of population from rural areas to the cities, and from the Northeast regions to the Southeast, mainly São Paulo and Rio de Janeiro, as noted by Brito and Carvalho (2006).

However, more recent data show that São Paulo and Rio de Janeiro are the most important source of population movement to other states. The Federal District

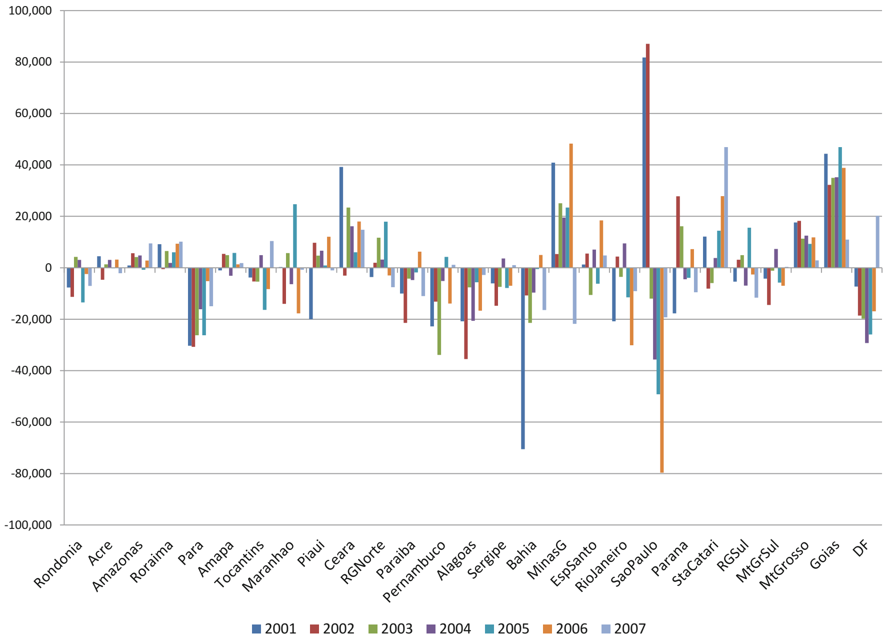

Fig. 6.1 Net migration flows in Brazil, by region. Number of people

(DF—basically Brasilia, the capital) is also losing population, with a net migration outflow from 2001 (Table 6.2); yet this outflow is less in 2007, probably due to the recent strong increase in federal spending. Maranhão, a poor state in the Northeast, also shows negative population flows until 2007, when positive figures were registered.

Some poor Northeast states have consistently received positive migration flows since 2001, such as Ceara, Rio Grande do Norte (RGNorte), Paraiba, and Pernambuco. This reverses the migration flows of the seventies. Possible reasons include congestion in the main cities (São Paulo and Rio de Janeiro), new investments in Northeast Brazil, and the greater incidence of the Bolsa Familia Program[2] in the northeast region.

The Center-west region (Mato Grosso, Mato Grosso do Sul, and Goias) is also attracting population. The economies of these states are driven by soybean, corn, and livestock production. The abundant grain supply and more reliable electric power have also fostered growth in the food industry.

The data suggest that population has been flowing consistently from the richer Southeast Brazil toward the Northeast and the Center-west regions. Those destinations are, however, more likely to be hit by the effects of climate change on

[2]The Bolsa Familia is the major direct income transfer program from the Brazilian Federal Government.

Fig. 6.2 Brazilian states and macro regions

agriculture, as some recent scenarios analyzed by Embrapa (the Brazilian Federal Agricultural Research Institution) show. An eventual reversal of those flows would bring important policy implications for the regional governments in the Southeast regions.

Brazil's vast inland is thinly-peopled, so current migration patterns imply a beneficial decentralization of population—which may be threatened by the effects of climate change on agriculture. Pinto and Assad (2008) and Deconto (2008) provide a translation for Brazil of several IPCC scenarios for climate change in agriculture. These scenarios include estimates of losses in both agricultural productivity and useable land for various Brazilian regions and crops. In general, the scenarios point to a loss in productivity and agricultural land availability in the regions which are currently net population recipients, *potentially reversing current internal migration flows*. These are the scenarios to be simulated in this chapter, as described below.

6.4 Methodology

This chapter explores in more detail the implications of climate change and its impacts on agriculture for internal migration flows in Brazil, with the aid of TERM-MIG, a detailed dynamic General Equilibrium Model of Brazil, based on previous work of Ferreira Filho and Horridge 2006, 2010). It is an inter-regional, bottom-up, annual recursive dynamic model with detailed regional representation, distinguishing up to 27 Brazilian regions, 38 sectors, 10 household types and 10 labor grades, and has a migration module which models gross bilateral regional migration flows. The model is formulated and solved using GEMPACK (Horridge et al. 2018). The core database is based on the 2005 Brazilian Input–Output data, as presented in Ferreira Filho (2011). The migration database is based on the 2005 Brazilian Household Survey (PNAD).

The recursive dynamics included in the model consist basically of three mechanisms: (1) a stock–flow relation between investment and capital stock, which assumes a 1-year gestation lag; (2) a positive relation between investment and the rate of profit; and (3) a relation between wage growth and regional labor supply.

Inter-regional labor migration M_{sdo} is modeled via an equation:

$$M_{\mathrm{sdo}} = K_{\mathrm{o}} A_{\mathrm{sdo}} [R_{\mathrm{do}} / R_{\mathrm{so}}]^{\alpha}$$

where s is the source region, d the destination and o the labor type. R_{do} is the real wage in region d of labor type o. A_{sdo} is a constant reflecting historical PNAD data, and K_{o} adjusts to keep national employment of labor type 0 at exogenous levels.

With these three mechanisms, we can construct a plausible base forecast for the future, and a second, policy, forecast—different only in that some policy instruments are shocked to different values from the base (e.g., the climate change scenarios). The difference in results can be interpreted as the effect of the policy change. The model is run with the aid of RunDynam, a program to solve recursive-dynamic CGE models.[3]

Two scenarios will be analyzed: the IPCC A2 scenario for 2020, and the B2 scenario for 2070. The A2 scenario is the worst scenario for 2020, while the B2 scenario is the best scenario for 2070, meaning by "best" a scenario that allows enough time for adaptation measures. The shocks were based on the work of Moraes (2010), which used a detailed geographical information system production map at the county level in Brazil and on the agricultural productivity and land losses provided by Pinto and Assad (2008) and Deconto (2008) to calculate the state-level agricultural productivity and land loss shocks. Our shocks are described in detail below.

The use of a dynamic model involves two prior steps: an initial historical run, where the model is forced to reproduce the known behavior of some aggregated

[3]RunDynam is described at: http://www.copsmodels.com/gprdyn.htm

Table 6.3 Historical simulation shocks, percentage changes

Variable	Observed annual average rate of growth (%)
Population	Regional values by IBGE
Land productivity	1.0
Real government spending	2.9
Real GDP	4.6
Real household consumption	5.8
Real exports	4.9
Real investment	9.7
GDP deflator	7.0

Table 6.4 Baseline projections, percentage change

Variable	Projected annual average rate of growth (%)
Export demand shifter	3.0
Population	Regional values by IBGE
Labor productivity increase	1.5
Land productivity	1.0
Real government expenditures	3.0
GDP deflator	5.0

variables over a set of previous years, and the definition of a reference path for the economy in the future, in relation to which the policy scenarios will be reported. The historical simulation updates the original 2005 database with recent developments in the economy. In this chapter, the historical simulation forced the model to reproduce macro trends for the period 2005 to 2008 (last available year of the Brazilian National Accounts) for the variables described in Table 6.3.

For the reference scenario, the regional population was updated with information from Instituto Brasileiro de Geografia e Estatística (IBGE), giving observed regional population growth until the present, and projections of regional population growth until 2030. The regional growth rate of population in 2030 was used for the subsequent annual projections until 2070. This information can be seen in the Appendix.

The baseline path was created by projecting the economy forward until 2070, roughly following the observed pattern for some important economic variables, as shown in Table 6.4. The shocks were applied, and the remaining variables adjusted endogenously to accommodate the proposed shocks, creating a reference baseline until 2070, in relation to which the results will be reported. The policy shocks, then, will generate deviations in relation to the proposed baseline.

Although the original model database distinguishes 27 regions of Brazil, we aggregated these to 13 broader zones, to ease presentation and reduce computing

Table 6.5 Regional aggregation

Original region	Aggregated region	Original region	Aggregated region
Rondonia (N)	RestNO	Sergipe (NE)	RestNE
Acre (N)	RestNO	Bahia (NE)	Bahia
Amazonas (N)	RestNO	MinasG (SE)	MinasG
Roraima (N)	RorAmap	EspSanto (SE)	RioJEspS
Para (N)	RestNO	RioJaneiro (SE)	RioJEspS
Amapa (N)	RorAmap	SaoPaulo (SE)	SaoPaulo
Tocantins (N)	RestNO	Parana (S)	Parana
Maranhao (N)	MarPiaui	StaCatari (S)	SCatRioS
Piaui (NE)	MarPiaui	RGSul (S)	SCatRioS
Ceara (NE)	RestNE	MtGrSul (CW)	MatoGSul
RGNorte (NE)	RestNE	MtGrosso (CW)	RestCO
Paraiba (NE)	RestNE	Goias (CW)	RestCO
Pernambuco (NE)	PernAlag	DF (CW)	RestCO
Alagoas (NE)	PernAlag		

Macro regions: *N* North, *NE* Northeast, *SE* Southeast, *S* South, *CW* Center West

time.[4] The regions were aggregated according to similarity, in terms of both general economic aspects and recent migration characteristics, while trying to keep enough regional detail. The mapping from original to new regions is shown in Table 6.5.

6.5 The Scenarios to Be Simulated

As stated before, two scenarios will be simulated in this chapter: the IPCC A2 (worse) scenario for 2020 and the B2 (best) scenario for 2070 (Moraes 2010). The shocks to be applied to the model are described in Tables 6.6, 6.7, 6.8, and 6.9.

The shocks in the tables are percentage changes in production and land availability, by each agricultural product and by region. The values are the total (cumulative) percent variation up to the respective year. To apply the shocks to the dynamic model, the cumulative changes were converted into annual changes, such that the desired accumulated change in either 2020 or 2070 was achieved. The shocks for the 2020 scenario were applied from 2015 until 2025, while the shocks for the 2070 scenario were applied from 2026 until 2065. The shocks, of course, were calculated so that the total final shock at 2070 is the aggregation of the year shocks.

This mixing of two scenarios was necessary in order to try to describe a path of adjustment, based on the resulting scenario in the final years of each period. This is important since some activities change their behavior in passing from one

[4] Yamamoto (2004) estimates that a 10% increase in the number of regions results in a 29% increase in simulation time and uses 14% more memory.

Table 6.6 Shocks to production, year 2020 (% variation)

Region	Rice	Corn	Sugarcane	Soybean	Cassava	Cotton	Coffee	Other ag
1 RorAmap	0	0	0	0	−49.4	0	0	0
2 RestNO	−4.2	−1.7	0.4	−17.2	−1.9	0	−80	−0.1
3 MarPiaui	−39.3	−30.8	−1.1	−80	−2.5	−4.4	−80	−11.3
4 PernAlag	−80	−67.7	−5	−79.4	−63.4	−62.2	−80	−7
5 Bahia	−3.5	−13.4	−5	−0.4	−18	0	−80	−5.4
6 RestNE	−80	−60.7	−4.3	−79.4	−22.1	−80	−80	−18.6
7 MinasG	−4	−1.4	5	−3.2	−11.6	−7	−3.5	−2
8 RioJEspS	0	−0.8	2.3	0	0	0	−4.3	−0.8
9 SaoPaulo	0	−2	5.5	−7	0	0	−19.2	−0.2
10 Parana	0	0	7	−45.3	−4.9	0	0	0
11 SCatRioS	0	0	0	−30.6	−20.2	0	0	0
12 MatoGSul	0	−14.6	6	−60	0	0	−80	0
13 RestCO	−1.9	−2.6	6	−25.2	0	0	−80	−0.4

Table 6.7 Shock to land availability, year 2020 (% variation)

Shock	Rice	Corn	Soybean	Cassava	Cotton	Coffee	Other ag
1 RorAmap	0	0	0	−49.4	0	0	0
2 RestNO	−5.6	−2	−17.1	−1.8	0	−80	−0.1
3 MarPiaui	−40.4	−34.9	−80	−2.8	−14.7	−80	−9
4 PernAlag	−80	−68.5	−79.4	−61.5	−62.2	−80	−7.5
5 Bahia	−2.9	−32.3	−0.4	−19.3	0	−80	−4.6
6 RestNE	−80	−60.7	−79.4	−21.1	−80	−80	−22.4
7 MinasG	−4.9	−3.9	−3.1	−8.7	−16.6	−2	−3.1
8 RioJEspS	0	−1	0	0	0	−6.4	−0.7
9 SaoPaulo	0	−2	−7.4	0	0	−27	−0.1
10 Parana	0	0	−36.8	−5.8	0	2.4	0
11 SCatRioS	0	0	−36.2	−23.5	0	0	0
12 MatoGSul	0	−14.6	−64.2	0	0	−80	0
13 RestCO	−1.9	−3.3	−23.3	0	0	−80	−0.6

scenario to another. This is the case for sugar cane, where there is an increase in productivity in the first (A2, 2020) scenario, due to the increase in temperature and CO_2 concentration, which would be beneficial for the crop. This effect vanishes in the longer run, when temperatures and CO_2 concentration continue to increase, exceeding the optimal level for sugar cane production. The model would be missing this effect if only a year shock based on the final 2070 scenario was used. The same effect happens with land availability for Coffee in Parana under the 2020 scenario.

And, finally, it is important to put the size of those production shocks into perspective. The share of agriculture in each state regional GDP is very different across Brazilian states, which combines with the size of the particular shocks to imply different regional importance. This relative importance can be inferred from Fig. 6.3.

Table 6.8 Shocks to production, year 2070 (% variation)

Shock	Rice	Corn	Sugarcane	Soybean	Cassava	Cotton	Coffee	Other ag
1 RorAmap	0	0	0	0	−49.4	0	0	0
2 RestNO	−5.2	−3.3	−0.2	−20.2	−0.6	0	−80	−0.2
3 MarPiaui	−47.4	−50.3	−2.1	−80	−2.5	−14.2	−80	−23.6
4 PernAlag	−80	−71.3	−10	−79.4	−63.4	−62.2	−80	−9.4
5 Bahia	−3.5	−36.2	−10	−0.4	−19.6	0	−80	−6.3
6 RestNE	−80	−68.5	−8.6	−79.4	−22.1	−80	−80	−18.6
7 MinasG	−4	−1.4	−2	−33	−1.1	−7	−16.6	−2.6
8 RioJEspS	0	−1.6	−3.6	0	0	0	−66.6	−1.1
9 SaoPaulo	0	−7.2	−3.5	−32.1	0	0	−72.2	−0.3
10 Parana	0	0	−4	−76.3	−6.8	0	−14.7	0
11 SCatRioS	0	0	6	−64.7	−3.8	0	0	0
12 MatoGSul	0	−17	−1.5	−61.5	0	0	−80	0
13 RestCO	−1.9	−2.6	−1.5	−26.8	0	0	−80	−0.6

Table 6.9 Shocks to land availability, year 2070 (% variation)

Shock	Rice	Corn	Soybean	Cassava	Cotton	Coffee	Other ag
1 RorAmap	0	0	0	−49.4	0	0	0
2 RestNO	−7.3	−4.1	−18.1	−1.6	0	−80	−0.2
3 MarPiaui	−47	−47	−80	−2.8	−14.7	−80	−23.4
4 PernAlag	−80	−80	−79.4	−61.5	−62.2	−80	−11.1
5 Bahia	−2.9	−74.4	−0.4	−21	0	−80	−5.6
6 RestNE	−80	−68.8	−79.4	−21.1	−80	−80	−22.4
7 MinasG	−4.9	−3.9	−30.7	−0.8	−16.6	−14.5	−3.2
8 RioJEspS	0	−1.8	0	0	0	−67	−0.9
9 SaoPaulo	0	−8	−35.9	0	0	−73.1	−0.3
10 Parana	0	0	−77.1	−8.1	0	−15.1	0
11 SCatRioS	0	0	−67.1	−5.5	0	0	0
12 MatoGSul	0	−17.5	−65.8	0	0	−80	0
13 RestCO	−1.9	−3.3	−24.9	0	0	−80	−1.1

Figure 6.3 shows the share of agricultural lost production (in the 2070 scenario) in total regional value of production in the base year database. The losses are not expected to be very high, even in the worst cases: MarPiaui (Northeast region) and MatoGSul (Center-west) regions. The losses amount to a 2.5% fall in total value of production in MarPiaui and around 3% for MatoGSul. So, these shocks do not involve a large share of production value, when considering the direct impact only. The total effects, of course, are different, due to the economic linkages between primary agriculture and the rest of the economy, especially the food industry.

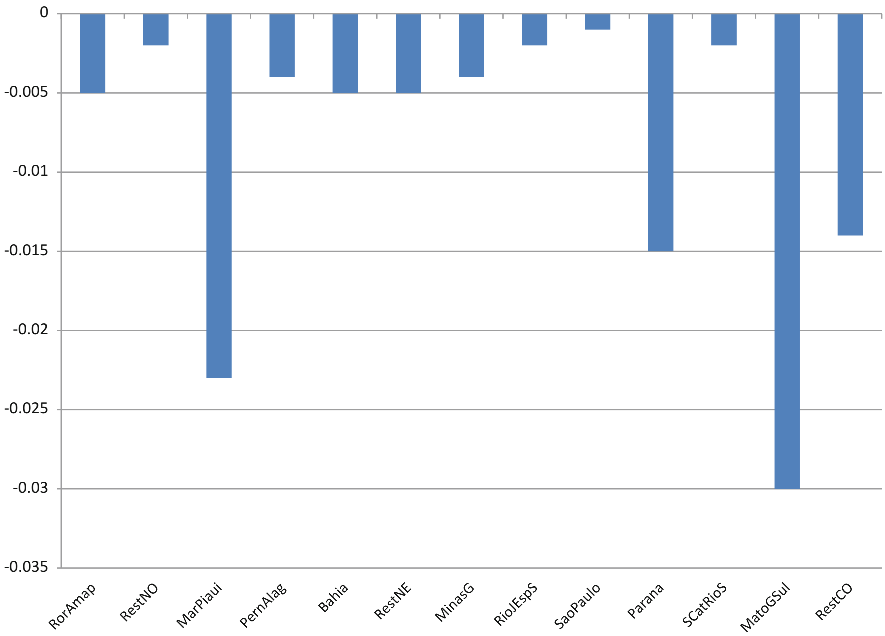

Fig. 6.3 Share of lost agricultural production in total regional value of production

6.6 General Results

Considering the 65 years involved in the analysis, we favor a graphical presentation of results, starting from the macro results of Fig. 6.4.

The data in Fig. 6.4 show the percentage differences until 2070 between the projected economy baseline and the policy simulation. It can be seen that the main macro variables fall, but the effects are not very strong. The accumulated fall in real GDP in 2070 would amount to 0.78%. Real investment in the economy would fall by around 0.46%, a result that oscillates during the adjustment period. Aggregated exports (volume) experience a stronger fall, around 1.04%. This is not surprising if one takes into account the relatively large share of food in total exports. These results, however, are strongly concentrated in coffee and soybeans, as will be discussed later.

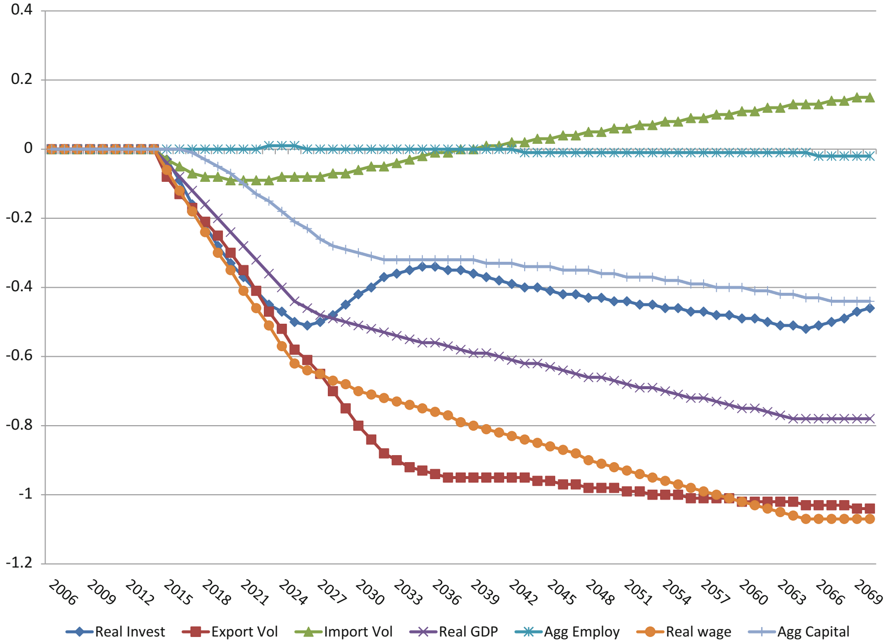

Fig. 6.4 Macro results. Deviation from the baseline (percentage change, accumulated)

The model predicts only a slight fall in total employment[5] (compared to the baseline). The results of the climate change scenarios on the agricultural activities directly affected by the scenarios can be seen in Fig. 6.5. As discussed earlier, sugarcane (and related activities, like ethanol) benefit from small increases in temperature and CO_2 in the 2020 scenario—the effect lasts until 2047. Sugarcane production would increase by around 4.7% compared to the baseline in 2025.

Figure 6.5 shows too that soybean and coffee would be the two activities most affected by the scenarios. This is what causes the fall in exports mentioned before—these are important export crops. These crops are regionally concentrated in Brazil, leading to differentiated regional results.

The regional variation in real GDP can be seen in Fig. 6.6. The state which is worst affected is Mato Grosso do Sul (−4.08%), a state in the Center-West region which relies heavily on soybean production (4.6% of the total value of production in the state), and in which the predicted shocks to soybean productivity are particularly

[5]Essentially, national employment is exogenous, and the same in both policy and base simulations. Regional employment varies through time through (a) natural population growth and (b) wage-driven inter-regional migration. Of course (b) washes out, nationally. However, there is a tiny and subtle effect on national workforce size: fecundity varies by region, and we assume that the migrating worker becomes as fruitful as his new neighbors. So if a fertile region attracts more workers, national employment will rise.

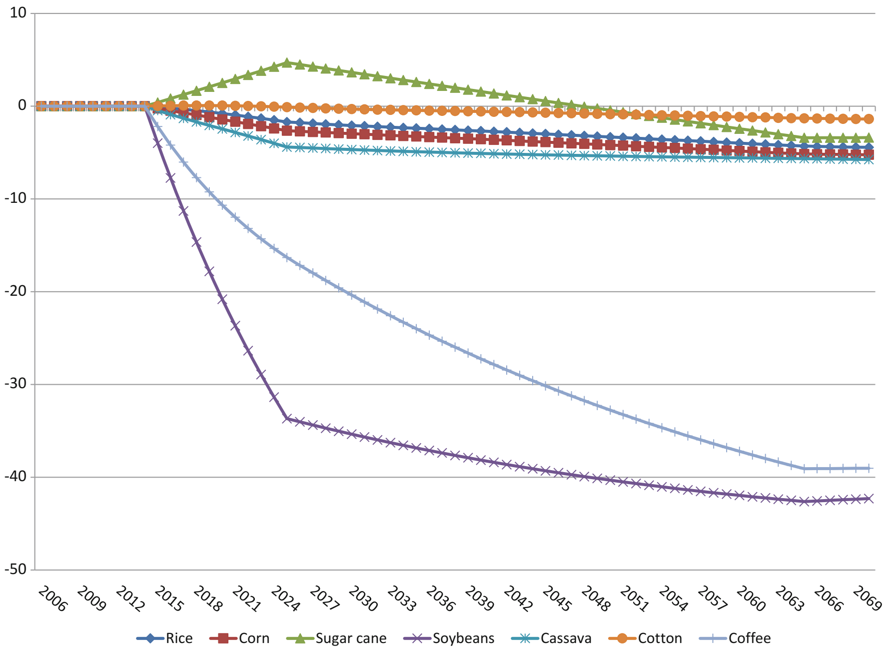

Fig. 6.5 Agricultural production variation (deviation from baseline, %)

severe (−60%). As shown in Table 6.6, the shock to soybean productivity in the state would be −60% for the 2020 scenario. The other Center-west regions (RestCO) where soybean production is even more important (representing 4.9% of total regional production) would face a much smaller productivity shock (−25.2%), with a consequent smaller fall in GDP (−3.12% at the end of the period).

The above-mentioned result is very interesting, since the Northeast region is usually regarded as the one to lose the most from climate change in Brazil. This region, of course, would also be affected by the scenarios, but results are mixed among the region's states. The region comprising Maranhão and Piaui states (MarPiaui) would be the most affected, losing about 2.4% of its real GDP in the long run. The other Northeast regions (PernAlag, Bahia, and RestNE) would be less affected, losing around 1.4% of real GDP.

It can be seen again that São Paulo state tends to benefit during the first-period scenario, due to the increase in output of sugar cane and related products (ethanol and sugar). This is only a slight effect, though, which would peak in 2025 with a 0.11% in state GDP in relation to the baseline. The RioJEspS (Rio de Janeiro and Espirito Santo) region would also gain slightly in this period. And finally, the states in the North region (RorAmap, and RestNO, which includes Amazon) also face a small GDP decrease.

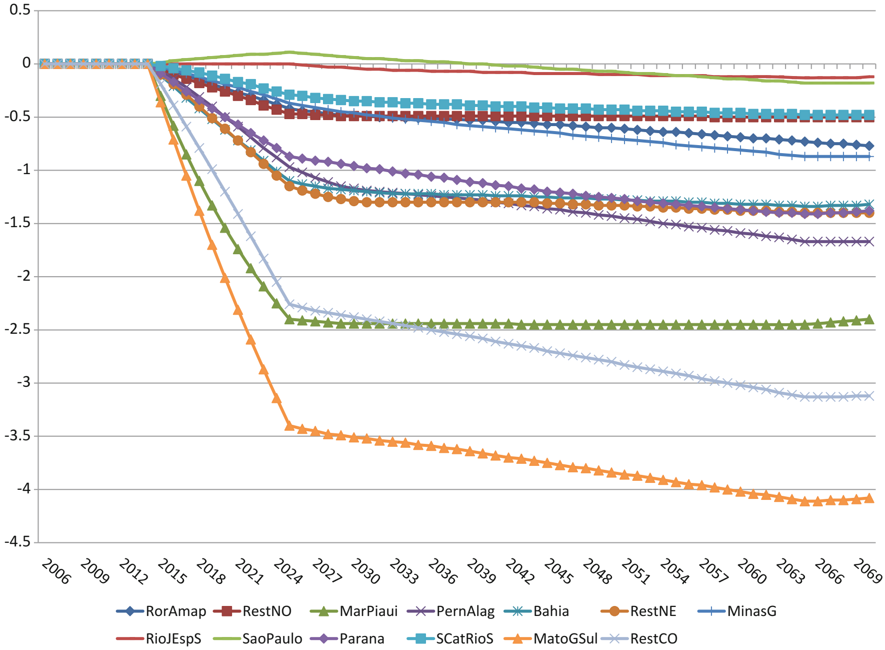

Fig. 6.6 Regional real GDP variation (deviation from baseline, %)

The change in regional employment does not necessarily follow GDP, since the regional production composition is different, and so is the labor demand by different activities in different regions. This can be seen in Fig. 6.7.

It was seen before that Mato Grosso do Sul and MarPiaui would lose the most, in terms of GDP, from the implemented scenarios. This is still the case in terms of employment: model results points to a 0.69% loss of employment in Mato Grosso do Sul and a 0.74% loss in MarPiaui. The other regions in Center-west Brazil show only a slight decline in employment. São Paulo shows a continuous increase in total employment even after 2025, when the sugarcane effect peaked. The most interesting result here, however, is the increase in employment for the Northern regions (RorAmap and RestNO). These states faced GDP losses, but gain in employment. This has to do with migration flows, to be discussed later, and could have important policy implications.

6.7 Migration Results

The general results presented above are the background against which the migration results, the main objective of this chapter, should be interpreted. In the model, migration is driven by the change in regional real wages: the labor force tends to move toward the regions where real wages are increasing, and vice versa.

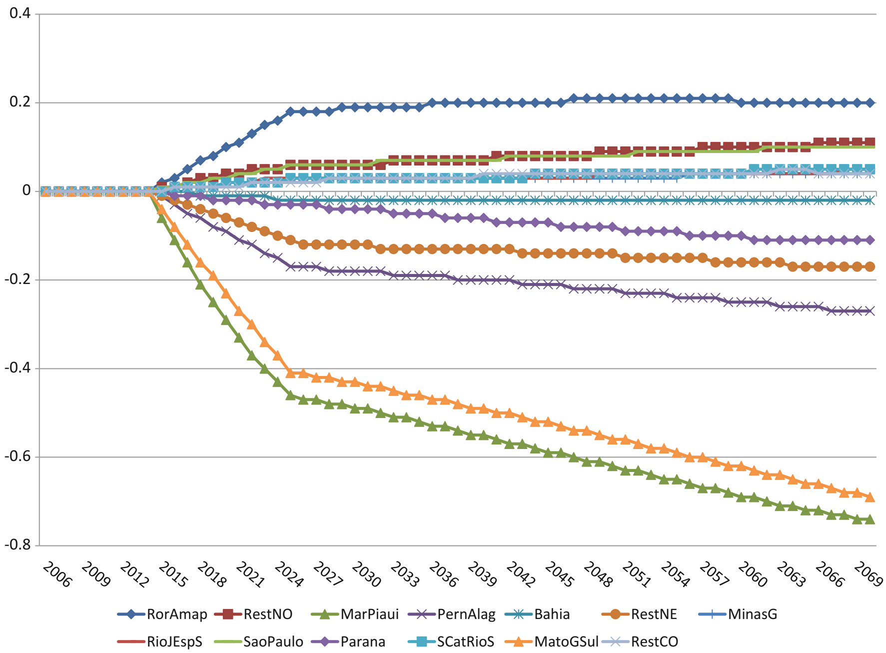

Fig. 6.7 Regional employment variation (deviation from baseline, %)

The model distinguishes ten different occupations or labor types, each with region-specific wage rates. Employment of each occupation is supposed to increase in the baseline at the same rate as regional population, for which official estimates of the Brazilian Statistical Agency (IBGE) were used, as explained before. The demand for those different worker types, however, will depend on the labor mix used in production, which varies by sector and region. In what follows, the movement of total labor across regions is presented, and later the occupational composition will be discussed.

It was seen before that net inter-regional migration in Brazil flows presently from the richer Southeast region to the Center-west, some Northeast and some Northern states. Our climate change scenario, however, falls heavily on the Northeast, as seen above. The model results for the effects on migration of these impacts can be seen in Fig. 6.8, which shows the variation in migration, by region of origin, caused by the policy scenario.

Model results presented in Fig. 6.8 show an interesting picture of the possible effects of the simulated climate change scenarios. The first thing to be noticed is that the MarPiaui (Maranhão and Piaui states in Northeast) and MatoGSul (Mato Grosso do Sul state, in Center-west) regions are those which show the strongest increase in migration outflows, compared to the baseline. The accumulated final result for MarPiaui is a 7% increase in population outflows, and for MatGSul a 4.42% increase, compared to the baseline. However, the bulk of this effect happens during

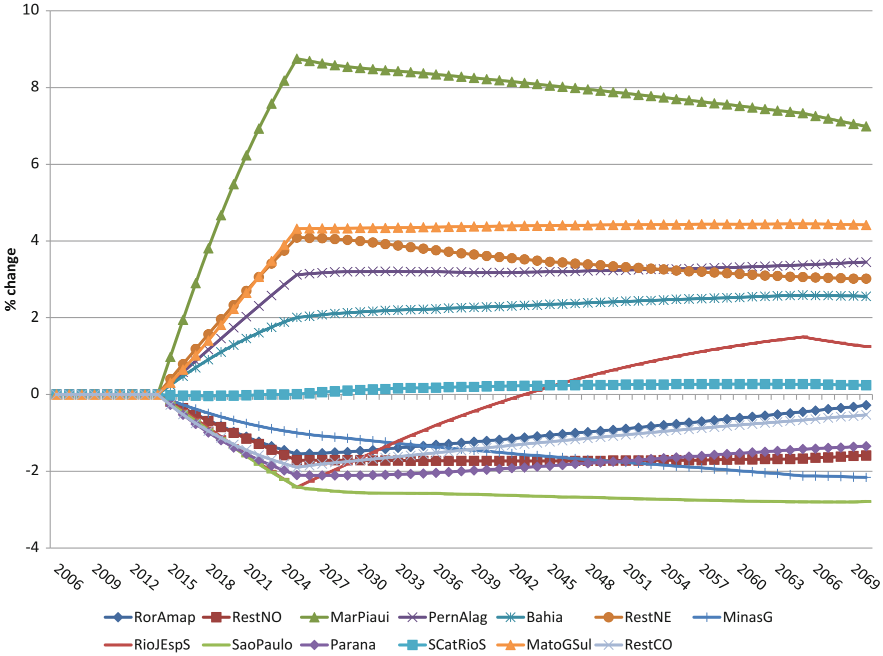

Fig. 6.8 Model results. Inter-regional migration variation, by the origin of migrants (%)

the first-period scenario (2020/A2), when adaptation is not considered.[6] In 2025, the accumulated population outflow would increase by 8.75% for MarPiaui and 4.45% for MatGSul. The same pattern of migration evolution applies to the RestNE and PernAlagoas regions inside the Northeast macro region, although at smaller rates then MarPiaui. Again, the bulk of the effect in these regions also happens at the end of the first-period scenario. After that the annual rate of population outflow falls, causing the migration path to dip, but never return to baseline values.

Bahia, the largest state in Northeast Brazil fares differently. Its outmigration flow increases continually, reaching its maximum at 2070, with an accumulated rate of 2.56% above the baseline. Despite this, the final observed result for this state is smaller than that of MarPiaui, around 7%.

Other regions of the Southeast, South, and Center-west (except MatoGSul, as seen before) would generally reduce their outmigration rates compared to the trend. The noticeable exception here is the RioJEspS subregion, which combines the states of Rio de Janeiro and Espirito Santo in the Southeast macro region. Figure 6.8 shows that this region would reduce its outmigration rate in the first period. From 2026 on

[6]This chapter does not deal directly with adaptation measures, which are included in the scenarios generated by EMBRAPA.

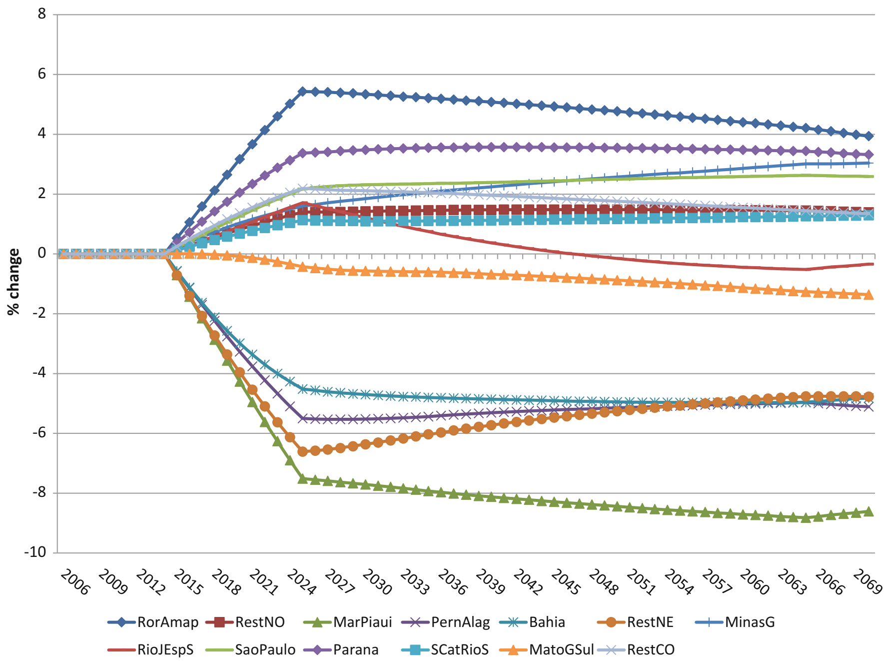

Fig. 6.9 Regional migration in Brazil, by destination (%)

the yearly rate of outmigration would start to increase, causing the accumulated outmigration to become positive by 2038.

Another possible way to analyze the results is to look at migration by destination as shown in Fig. 6.9.[7] Note that the RorAmapa (Roraima and Amapa states, in North macro region) is the region whither migration increases the most (in percentage terms), and there are increases too for the other states inside the North region (RestNO subregion). This has important economic and social implications, since the occupation of the Amazon region is presently an issue of great concern for public policy.

The increase in migration to the north, caused by climate change, would reproduce the trend of the seventies, when the Brazilian (military) government deliberately stimulated population migration from the Northeast to the North, under the slogan "landless people for a land without people," a policy aimed at the occupation of the vast Amazon region, which included the construction of the TransAmazônica road. The intensification of population flows toward the North, of course, will depend on other possible effects of climate change on the region, not included in this chapter, such as the intensification of tropical diseases. The results

[7]Notice that the numbers here are not just the opposite as those seen before in Fig. 6.8, since migration by destination computes the totals from different origins.

presented here, however, point to an increase in the pressure over the region's natural resources, arising from an increase in population.

Model results show that the states in the Southeast and South macro regions would generally start to gain (relative to base) population due to the climate change scenarios. The rate of increase is not too big, reaching 2.6% for São Paulo, 3.32 for Parana and around 1.3% for StaCatRioS (Santa Catarina and Rio Grande do Sul). This is, however, an inversion of the migration trend observed since the beginning of the last decade, as discussed before. Again RioJEspS is an exception. This region would gain population until 2025 (the end of the first scenario period), and would start to lose population from then, with a negative final result of around 0.34% fewer immigrants arriving in the subregion compared to the baseline in 2070.

However, the absolute numbers of migrants involved are not very large. Figure 6.10 shows model results for the estimates of migration.

It can be seen from Fig. 6.10 that São Paulo, for example, the state that would receive the larger absolute number of migrants, would receive in the final period (2070) 36.457 more people than it would receive in the baseline, while MarPiaui, the subregion that would lose more population, would lose 43.827 more people than in the baseline.

Another important point to be noticed here is the labor type composition of migration flows. The most negatively affected regions in the simulated scenarios

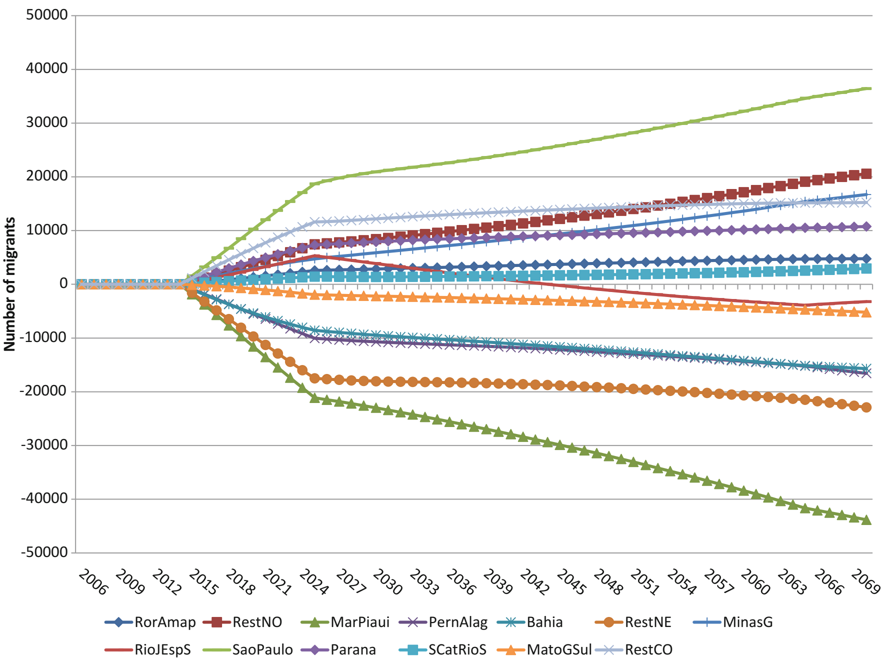

Fig. 6.10 Net number of migrants, by destination

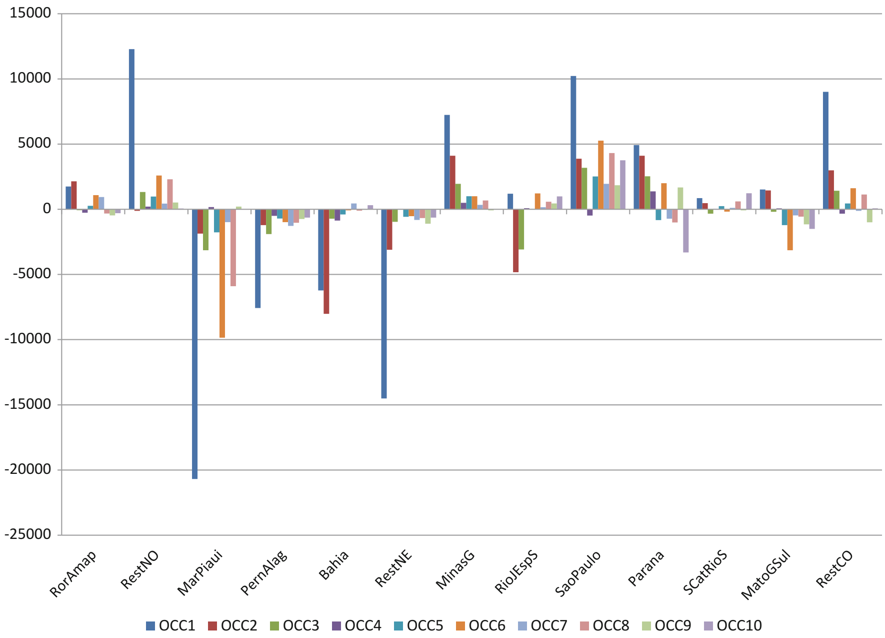

Fig. 6.11 Migration by occupation and destination (accumulated, 2070, % change from baseline)

are regions in Northeast Brazil, as well as in the Center-west. The structure of labor demand and different composition of agriculture in those regions will generate particular migration flows, when analyzed according to the type of labor group classification. Since is difficult to show time, skill and regional dimensions in a single diagram, we have chosen to present the accumulated result in the last year of the period. This can be seen in Fig. 6.11. It shows that the regions receiving most of the migration flows (RorAmapa, MinasG, Sao Paulo, Parana, StaCatRioS and RestCO) all receive a higher share of the relatively unskilled workers, or those classified in occupation 1 to 3 (OCC1 to OCC3). This means that most of the migration flows would occur among the less qualified workers, which again echoes the migration patterns observed in the past.[8] The rapid increase in the migration of unskilled workers toward the big cities in Southeast Brazil caused the surge in the "favelas" (slums), still a very serious problem in the main cities. Again, the results here presented point to a movement in internal migration similar to what was observed in the past.

Figure 6.11 shows too that MatoGSul state which would be losing population in aggregate terms, would actually be receiving a positive inflow of less-skilled

[8]Note that our elasticity governing the response of migration to relative wages is the same for different skills. Whether unskilled workers have more or less difficulty to migrate than skilled workers is an empirical issue, which will have to be considered for future work.

workers (OCC1 and OCC2). This result is strongly related to the projected increase in cassava production in the state. Inspection of labor demand composition for this crop in the database reveals that about 60% of total labor payments in cassava go to workers in the first two occupational groups. The other states where cassava tends to increase production (Sao Paulo, RioJEspS, and RestCO) have a much smaller share of unskilled workers in cassava production.

We should now point out that the migration concept used in this study involves only the personal (worker) dimension. Migration, however, is a complex phenomenon, and frequently involves the whole family, which may sooner or later follow the migrant worker. Indeed, Oliveira and Jannuzzi (2004) analyzed the reasons for migration in Brazil. According to those authors, based on a special supplementary survey in the PNAD 2001, the "search for jobs" is the most common reason for migration, especially among men: 34% of men and 11.8% of women have selected that as the main reason for migration. Altogether, 23% of the surveyed persons declared that their main reason for migration was the search for jobs.[9] The answer "accompanying the family," on the other hand, accounted for 51.5% of the answers for the main reasons for migration (63% among women), and many different factors for the rest. This is, of course, due to the presence in the sample of children and teenagers below 14 years.

Our study's migration database included only persons above 15 years old. According to the same above- mentioned authors, the youngest (around 20 years old) would be more prone to migrate than any other age group, and this would be strongly correlated to movements in the labor market. In this way, the high concentration of young people among migrants would be explained by their "sensibility" to bids in the job market, as well as for their higher adaptability to new situations (Oliveira and Jannuzzi, 2004).

Thus, it is not absurd to suppose that each migrant would bring two other relatives in his/her wake, at least in the medium run, which might triple the numbers observed in Fig. 6.11. This is a point that deserves further elaboration in future studies.

6.8 Final Remarks

The climate change scenarios simulated in this chapter point to a reversal of the current pattern of internal migration in Brazil. The severe climate-induced effects on some Northeast states would cause a new pressure for migrants to leave those regions. Model results presented here point to the MarPiaui subregion (Maranhao and Piaui states) as the most adversely affected in terms of agricultural production, increasing emigration from that region. Perhaps more surprisingly, the same would happen to Mato Grosso do Sul state, in the Center-west region. The Southeast and

[9] In the 20 to 54 years old people, the "search for work" answer varies between 33.1% and 40.1% of answers.

South regions would be the recipient regions, a movement that reverses current flows.

Perhaps even more worrying is the conclusion that the less-skilled workers would be the larger part of migrants. This suggests that a new surge in the population movement toward the already large slums in the Southeast cities could start to appear again in the near future. These low-wage workers, which belong to the most socially vulnerable groups, would be left with no option but migration, if adaptation measures are not put into action.

Another interesting point to be observed from the results presented here is the increase in migration toward the North regions. Even though, as observed before, the forecasted numbers are not very big, they may raise policy concerns. Increased migration toward the Amazon would increase the pressure over natural resources in that region—already a matter of great concern for the Brazilian government.[10]

And, finally, a limitation of this study is that the results should be regarded as floor estimates, since they only refer to workers, and not families. The decision to migrate is a complex one; very often the family comes to join the main migrant later. We hope to analyze this aspect of the problem in future work.

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[10]This was written before Temer or Bolsonaro took power!

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Chapter 7
Closing the Yield Gap in Livestock Production in Brazil: New Results and Emissions Insights

Leandro Stocco, Joaquim Bento de Souza Ferreira Filho, and Mark Horridge

Abstract We analyze the impacts of partially closing the livestock yield gap in Brazil, with a focus on a reduction in deforestation and emissions, using a computable general equilibrium model of Brazil, the TERM-BR model, tailored for land use and emissions analyses. We use satellite imagery information generated by LAPIG (Images Processing and Geoprocessing Laboratory, University of Goias, Brasil) for the year 2014, at municipal level (5570 observations) to calculate the yield gap, using the Tukey method to identify measurement errors in the data. In our calculation, we selected the 10% most productive municipalities in Brazil in livestock production, to calculate the average productivity of this quantile, as an estimate of the attainable regional productivity. The yield gap is expressed as the difference between the average of the 10% quantile and the general average in each region. We further weigh this measure by the share of land with high and very high suitability for pastures, by state. In GHG accounting, we introduce the accounting of carbon storage in soils. With that, we take into account three emissions effects in livestock intensification: a natural forest sparing effect, an emissions in the herd effect, and the carbon storage in soils effect. We undertake GHG emissions calculations in livestock in two alternative ways: in the first way fixed coefficients in relation to livestock activity are used; and in the second alternative way, carbon storage in soils is included. Our results show that the increase in emissions associated with the growing herd size would outweigh the emissions reduction generated by the forest sparing effect, if carbon storage in soils is not taken into account. We conclude that this third effect of carbon storage in soils

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is very important in avoiding the wrong inference when analyzing climate policies involving livestock intensification.

Keywords CGE · Dynamic modeling · Climate change policy · Land use · Technological change · GHG emissions · Brazil

7.1 Introduction and Background

Deforestation control has been key to Brazilian environmental policy. Past command-and-control policies helped reduce deforestation in the Amazon from a high of 2.9 million hectares (Mha) in 1995 to a low of 0.46 Mha in 2012. Recently, deforestation increased again to reach 0.8 Mha in 2018. Brazil's commitment to the Paris agreement relies heavily on curbing deforestation (Ferreira Filho et al. 2016).

These efforts conflict with Brazil's position as an important world food producer and exporter, since they constrain agricultural land supply increase. Yet most of Brazil's agricultural land (170 Mha) is low productivity beef pasture. Reduction of pasture area could maintain crop area while curbing deforestation.

The idea that increased livestock productivity could release pasture land for crops is an important part of Brazil's plans to meet the Paris Agreement, which includes the restoration of 15 million hectares of degraded pasture by 2030 (Brasil 2015). Together with deforestation reduction and the Brazilian Forest Code, degraded pastures recovery is central for emission reductions and is one of the explicit goals of the ABC Program (Low Carbon Agriculture Program, in the Portuguese acronym), an ambitious rural credit program aimed to support the GHG reduction targets in agriculture[1] (Banco Central do Brasil 2016).

While the importance of deforestation reduction and the Brazilian Forest Code has been already assessed by several economic studies (Ferreira Filho et al. 2015, 2017; Ferreira Filho and Horridge 2016), the role of pasture intensification remains largely unexplored in a comprehensive economic framework. This chapter is a contribution to the field: we analyze the implications of a significant closing of the yield gap between actual and potential livestock productivity. We focus on pastures for beef livestock, the vast majority of pasture use in Brazil, where extensive grazing is the main production system.

This study contributes in four ways to the existing literature on the role of livestock and pasture intensification for reducing both deforestation and GHG emissions. First, we do a detailed assessment of beef pastures productivity in Brazil, based on municipal data, to calculate the livestock yield gap at regional level. Second, this data is combined with a classification of land according to its aptitude for livestock production, obtained from satellite imagery, in order to create a weight to classify land according to the possibility of yield gap closing. Third, we

[1]The ABC Program is part of the ABC Plan, and has as one of its objectives the restoration of 15 Mha of degraded pastures. For a recent evaluation of the ABC Program, see Gianetti (2017).

assess the economy-wide effects of livestock intensification through a computable general equilibrium (CGE) model, which allows analysis of both socioeconomic and environmental implications of the policy. Fourth, we present new findings related to the increasing soil carbon stock in pasture when pasture productivity increases. To the best of our knowledge, this is the first chapter to incorporate this last feature of pasture intensification in a CGE simulation of Brazil.

We argue that this is an important addition to the discussion. Increased pasture productivity allows increased livestock production, but emissions need not be proportional to output: improved pastures can store more carbon in the soil, according to new Brazilian research (Silva et al. 2016). This must be taken into account when analyzing pasture intensification policies such as the ABC Program.

Throughout this chapter, the term "livestock" refers to beef livestock. Occasional references to milk livestock, or pastures for raw milk production will be made explicitly.

7.2 Livestock Productivity in Brazil

The Brazilian livestock herd increased from 102 million in 1975 to 207 million in 2005, a 102% increase,[2] with the North and Center-west regions increasing the most, by 1683% and 189%, respectively. Those regions increased their share of the national herd, from 2.1% and 24.3%, respectively, in 1975 to 19.0% and 32.4% in 2007 (Valentim and Andrade 2009). The same authors show that the total pasture areas in Brazil increased only by 4% between 1975 and 2006, from 165.5 Mha to 172.3 Mha. The North region was the only one to show significant increases in pasture areas, while the other regions increased very little (Northeast region, 7%) or decreased (all the others, Table 7.1).

Table 7.1 Pasture area dynamics in Brazil, 1975–2005. Millions of hectares

	1975		1985		1996		2006		Var. 1975–2006
Region	Hectares	%	Hectares	%	Hectares	%	Hectares	%	%
North	5.28	3.2%	20.88	11.7%	24.39	13.7%	32.63	18.9%	518%
Northeast	30.62	18.5%	35.15	19.6%	32.08	18.1%	32.65	18.9%	7%
Southeast	47.28	28.5%	42.49	23.7%	37.78	21.3%	32.07	18.6%	−32%
South	21.16	12.8%	21.43	12.0%	20.70	11.6%	18.15	10.5%	−14%
Center-west	61.31	37.0%	59.24	33.1%	62.76	35.3%	56.84	33.0%	−7%
Brazil	165.65	100.0%	179.19	100.0%	177.70	100.0%	172.33	100.0%	4%
Legal Amazon	20.33	12.3%	42.73	23.8%	51.15	28.8%	61.60	35.7%	203%

Source: IBGE (2009, 2019), Valentim and Andrade (2009)

[2]The more recent 2017 Brazilian Agricultural Census (preliminary results) show that the herd size reduced from 2005, to approximately 172 million in 2017.

Table 7.2 Livestock stocking rate evolution in Brazil

	1975	1985	1996	2006	Variation 1975–2006
Region	UA/ha				%
North	0.34	0.35	0.55	0.97	187
Northeast	0.60	0.62	0.68	0.81	35
Southeast	0.57	0.66	0.73	0.94	64
South	0.88	0.96	1.01	1.18	34
Center-west	0.30	0.45	0.59	0.91	201
Brazil	0.51	0.58	0.68	0.94	83
Legal Amazon	0.30	0.36	0.54	0.91	203

Source: IBGE (2009, 2019), Valentim and Andrade (2009)

Another important indicator of the evolution of livestock is the stocking rate, defined as the number of animals by unit area (the herd/pasture area ratio), which is an indicator of production efficiency. According to Valentim and Andrade (2009), the stocking rate increased by 83% between 1975 and 2006, from 0.51 animal units per hectare (UA/ha) to 0.94 UA in the period (Table 7.2).

Table 7.2 shows that the stocking rate is consistently increasing in Brazil, although remaining at a very low level on average: According to Cohn et al. (2014), the introduction of new management techniques could increase current stocking rates by 2.5 times.

The idea that an increase in livestock productivity can save natural forests from clearing is controversial in the literature, and is the basis for the Borlaug vs Jevons effects argument (Borlaug 2007; CGIAR 2012; Hertel 2012; Martha et al. 2012; Cohn et al. 2014; Silva et al. 2017). The Borlaug idea is that with fixed beef demand, increased livestock productivity reduces land demand, deforestation, and the LUC emissions arising from deforestation. But from the Jevons point of view, increased livestock productivity would also reduce the cost of beef, leading to increased demand, a larger herd size, and so more production-linked emissions. These extra emissions may outweigh the reduction in LUC emissions. This was the approach used by Silva et al. (2017), Ferreira Filho et al. (2015, 2018) Ferreira Filho and Horridge (2016, 2017).

In all those studies, emissions per area or per unit of production are constant. A recent strand in the literature, however, is showing that pasture intensification can lead to a reduction in emissions intensity, or emissions per unit of production. For example, the studies by Oliveira et al. (2017) and Silva et al. (2016) for Brazil show that pasture productivity increases lead to an increase in carbon storage in the soil.

Although the fixed emissions coefficients accounting in pasture is appropriate for increases in extensive pasture area, it is clearly insufficient to deal with the intensification hypothesis. Livestock productivity increases can happen due to many different factors, including improvement in herd quality, management practices, and pasture productivity. The point is that when pasture productivity increases, soil carbon storage also increases. In this chapter, we will examine the effects of pasture intensification in Brazil, extending the analysis to include the carbon storage effect.

7.3 The Yield Gap Concept

The yield gap is a concept frequently used at farm level, or defined using experimental plots (Van Der Linden et al. 2015; Sikkema 2017), in reference to the concept of "potential productivity." It usually refers to land productivity, or production per unit of area. Fischer et al. (2014) present an extensive discussion about the many concepts involved in the definition, based on previous studies by Byerlee (1992), Evans (1993), Evans and Fischer (1999), and Connor et al. (2011).

In this chapter, we use the concept of "attainable productivity" as the reference for our analysis. According to Fischer et al. (2014), this concept reflects the economic aspects of both the region and the type of agricultural activity; experience shows that attainable productivity is normally between 20% and 30% below the potential. The yield gap concept we use here, then, takes as reference the attainable productivity, measured from Brazilian municipal level data. In the next section, we present in detail the methodology used for the yield gap estimation.

7.4 Methodology

Our approach involves several steps. We first identify the yield gap in livestock in Brazil, and then use this information to perform a simulation using a detailed CGE model. The next sections describe in more detail the procedures.

7.4.1 Identifying the Yield Gap in Brazil: Outliers and General Results[3]

We used satellite imagery information generated by LAPIG (Images Processing and Geoprocessing Laboratory, University of Goias, Brasil) for the year 2014. Due to the nature of the information, a previous important step for the calculations is to identify measurement errors in the data, notably extreme values, since these can strongly affect the yield gap measurement. We tested different methods and chose the Tukey method to identify measurement errors in the data. After identification and treatment of the extreme values in the data, we performed the yield gap calculation.

In our calculation, we select the 10% most productive municipalities, to calculate the average productivity of this decile. The yield gap is expressed by reference to this top productivity average, by region:

$$H_r = \frac{\alpha_{r10} - \beta_r}{\beta_r}, \tag{7.1}$$

[3]This section is based in Stocco (2018).

Table 7.3 Productivity yield gap in Brazilian livestock

Region	Average productivity	Top 10% average productivity	Weights	Weighted yield gap
AcreRond (N)	1.96	2.73	0.66	0.51
AmazRor (N)	1.38	4.66	0.41	1.36
ParaAmap (N)	1.47	5.38	0.51	2.00
Tocantins (N)	1.08	1.81	0.33	0.24
Maranhao (NE)	0.95	2.08	0.14	0.16
RestNe (NE)	0.89	3.38	0.19	0.46
Bahia (NE)	0.60	2.03	0.23	0.32
MinasG (SE)	0.81	1.59	0.42	0.33
RestSE (SE)	1.17	3.76	0.35	0.91
SaoPaulo (SE)	1.07	2.73	0.71	1.18
Sul (S)	0.79	4.31	0.40	1.28
MtGrSul (CW)	1.07	1.68	0.48	0.29
MtGrosso (CW)	1.22	1.88	0.50	0.33
GoiasDF (CW)	1.44	2.52	0.41	0.45

Source: Author's own elaboration with data from LAPIG (2017). Regions: *N* North, *NE* Northeast, *SE* Southeast, *S* South, *CW* Center-west

Where

H_r is the livestock yield gap in region r
β_r is the total regional average productivity in region r
α_{r10} is the average productivity of the top 10% municipalities in region r

The above calculation gives the regional yield gap in livestock, or the distance between the average regional productivity and the top 10%. However, it would be unrealistic to simulate the closing of this yield gap estimate over the whole pasture area. The top 10% productivity farms are generally located in the best agricultural areas, in terms of soil quality, precipitation, and other physical characteristics. To deal with this problem, we used information on land aptitude for pasture, by region,[4] to create a weighting system for our yield gap measure. The weight consists of the share of land with very high and high aptitude (net of areas with already high productivity) for pastures in the total pasture area, by region. We weigh the yield gap by this ratio, by region, creating the weighted yield gap used in the simulations (Table 7.3).

We used the above information on yield gap to simulate the economy-wide consequences for Brazil of gap reduction, using a CGE model described below. We will analyze the impacts of closing 50% of the calculated yield gap in Brazil.

[4]The information was obtained from IMAFLORA and GEOLAB (ESALQ/USP), using the method proposed by Sparovek et al. (2018).

7.4.2 The TERM-BR Model

The TERM-BR model is a recursive, bottom-up, dynamic computable general equilibrium model that includes a detailed regional representation of Brazil, with 27 regions (26 states plus the Federal District), 110 products, and 110 productive activities, 10 types of families (classified by family income bracket) and 10 types of labor (classified by salary range).

The model computes solutions for annual periods, guided by a dynamic process that consists of four mechanisms:

- A stock–flow relationship between investment in a given period and capital stock in the following period.
- A positive relationship between sectoral investment and the respective rate of profit.
- A positive relationship between real wage variation and regional labor supply.
- A positive relationship between deforestation in a given period and the available land stock for agriculture and livestock in the following period.

These and other mechanisms allow us to design a baseline (an inertial or business-as-usual growth trajectory), which may be compared to a second, policy, trajectory, which differs from the first only in terms of the economic policy to be implemented. The difference between the two trajectories is the effect of the policy under analysis. The policy scenarios in this study entail various alternative deforestation patterns.

The TERM-BR model has a land-use module and an associated GHG emissions module, described in more detail below.

7.4.3 The Land Use and GHG Emissions in the TERM-BR Model

The land-use module is based on transition matrices. These matrices (one for each state and biome) derive from satellite images for land-use changes observed between 1994 and 2002 (Brazil, 2010). This information was processed to distinguish three major types of land use, Crops (CROP), Pastures (PASTURE) and Forestry (planted forests, FORESTRY), and a residual type identified in the model as UNUSED, which refers to native forests. These transition matrices are detailed by state and, within each state, by six distinct biomes: Amazonia, Cerrado, Caatinga, Atlantic Forest, Pampa, and Pantanal.

The transition matrix shows, for example, how many hectares of the Cerrado biome in the state of Mato Grosso, which was natural vegetation in 1994, became Crops or Pasture in 2002, or remained as natural vegetation. The model has, therefore, for each biome in every state, a complete transition matrix. The data observed in the period mentioned above was processed to show the probability that each hectare under given use in a certain year will be in another use the following year.

These transitions are also price influenced. Transition from pastures or forests to crops, for example, accelerates with the growth of the relative prices of agricultural products. Moreover, the model is flexible enough to allow exogenous projections of the level of deforestation according to desired patterns, as in the case of this study. In this case, the Transition Matrix ensures information consistency, that is, the increase of pasture, crop, and forestry area in a given year must respect the increase in the available area given by deforestation in the previous year.

The transition matrices, then, determine the total land available for each broad land-use group (Crops, Pasture, Forestry and Unused). Once the amount of each aggregate category is determined, the model will allocate land among the activities within each category. Crop area, for example, will be allocated among the eleven agricultural activities of the model, through a CET (Constant Elasticity of Transformation) function, based on the relative prices of the products of these activities.

The model has two main emissions matrices, which together track all emissions. The first matrix tracks emissions in all activities except deforestation and other land-use change (LUC). These emissions are linked to each productive sector and to final demand, and can be of two broad types (sources): emissions from fuel combustion and "Activity" emissions associated with the level of activity of each sector (like fugitive emissions in mining, or CH4 emissions in livestock,[5] for example). Emissions of the several GHG gases are transformed into CO_2 equivalents using the Global Potential Warming for 100 years (GPW-100) coefficients from the IPCC Second Assessment Report–SAR (IPCC 1996).

All the above-mentioned emissions are directly proportional either to fuel use or to sector activity. In the case of livestock, however, we have also modeled emissions in an alternative way, so that emissions vary with pasture productivity. This is discussed further in the next section.

The second emissions matrix accounts for emissions from LUC, and is linked to the LUC Transition Matrix discussed above. This matrix shows observed emissions from LUC transitions, by state and biome. This allows a detailed accounting of emissions from land-use transitions, and the computation of sinks from forest restoration.

In the model, emissions are driven by results for fuel use, sector outputs, and LUC. But Brazilian emissions do not affect the economy. Hence, we can experiment with different ways to calculate emissions, without affecting results for economic variables.

7.4.4 Livestock Productivity Increases and Carbon Intensity Changes

As mentioned previously, the model accounts for emissions in pastures in two ways: using fixed coefficients and alternatively using coefficients that vary with

[5]Of particular interest for this chapter is emissions in "Activity" source in the livestock sector. In this case, emissions in both the herd and the pastures are aggregated together.

productivity. For the second method, we use information from Silva et al. (2016), who measured the change in emissions at different pasture productivity levels. Note that in our model, emissions from livestock and from pastures are combined in the "Activity" source. Emissions from livestock should increase under pasture intensification, due to the increase in herd size, but emissions in pasture transitioning from low productivity to high productivity should reduce, due to higher carbon storage in the soil. According to Silva et al. (2016), the balance is a net reduction in emissions with intensification,[6] when computing emissions from only those two sources.[7] We have adapted the changes observed by the authors from two different pasture types and their emissions, to calculate an emissions/land productivity elasticity[8] of value −0.0043, meaning that a 1% increase in land productivity (production/hectare) in livestock production would cause a 0.0043% fall in emissions in the "Activity" source.

We used information from Silva et al. (2016) to calculate the investment cost required for intensification. We used the cost differential between pasture types D (lower productivity) and B (higher productivity) as the cost of intensification in our model.[9] In this case, we were able to calculate a cost/productivity elasticity, which relates those two model variables, with value 5.76. This means that in our model each 1% increase in livestock productivity is obtained through a 5.76% increase in investment in the activity.[10]

7.5 Simulation Strategy

We simulate a 50% reduction in the livestock productivity gap over a 15-year period. The initial model database (2005) was updated to 2015 through a historical simulation, imposing on the model the observed trajectory of macroeconomic aggregates. All production data, exports, etc., as well as population variation by state, are updated in order to satisfy the observed macroeconomic (such as the GDP variation) and demographic aggregates.

[6]The calculations by Silva et al. (2016) are for the Cerrado biome only. We generalize those values for all biomes, due to the lack of information at this point. Future ongoing research must improve this information.

[7]Silva et al. (2016) compute emissions in all sources, including input use and deforestation. The TERM-BR model properly accounts for the other sources, so we have only used information on emissions variations for the herd and pasture.

[8]We have used the emissions/productivity differential between systems type D (lower productivity) and type B (higher productivity). The intensification costs are also for those two types of pastures.

[9]The highest productivity type in Silva et al. (2016) is type A. Type B is the second highest productivity, which we have chosen as reference.

[10]At this point we do not distinguish between increases in production due to pasture increases or in herd quality, a point which deserves better future elaboration.

The evolution of deforestation and land use followed the procedure proposed by Ferreira Filho et al. (2018). Deforestation figures for the three most important biomes (Amazonia, Cerrado, and Mata Atlantica) were updated up to 2015 (the historical period) as well as the evolution of the total area of crops and forestry. Thus, the projections run from 2016 until 2030. The main features of the baseline are:

- Projections of population growth by state (IBGE): Aggregate growth of 20.1% over 2016–2030, but with faster growth in the states/regions of RestNe (Rest of Northeast) and GoiasDF (Goias plus Federal District), and least growth in the states of São Paulo and Minas Gerais.
- Projected real GDP growth of 2.5% per year.
- Deforestation projections per biome and region, based on the last 5 years average for Amazonia and Mata Atlantica, and 3 years average for Cerrado. Total deforestation in the baseline of 12.8 million hectares (Mha) by 2030, of which 7.5 Mha is in the Amazonia biome, 5 Mha in the Cerrado biome, and 0.17 Mha in the Mata Atlantica biome.
- Aggregate crop area growth projections, by state and biome, according to the observed 5-year (2015–2011) average, with an annual increase of approximately 2.5 Mha, a total expansion of 37.5 Mha in crop area in the period 2016–2030 (Amazonia, Cerrado and Atlantic Forest biomes only).
- Projected growth of commercial forests area (*Eucalyptus* and *Pinus* plantations, or forestry) of 0.49 Mha per year, implying a total expansion of 7.1 Mha over the period.

The use of the Transition Matrix ensures consistency between total land use: The sum of the changes in crop, pasture, and forestry areas must be equal to the change in the deforested area. With areas of crops, forestry, and deforestation projected exogenously in the baseline, the pasture area is the variable that adjusts. The baseline projections described above are consistent with a reduction of 30.4 Mha in pasture area, from 2016 to 2030. We chose pasture area as the adjustment variable because agricultural activities generally have higher rates of return than livestock. With faster growth of crops and forestry relative to grassland in the base year, projected deforestation is consistent with that decline.

As mentioned before, the extra shock for our policy simulation is a 50% reduction in Brazil's livestock productivity gap. To compute shocks we transform information from the fourth column of Table 7.3 into annual variations in land productivity by state, defined as the (percentage change in the) ratio of livestock production/pasture area. This increase is obtained with additional investment expenses in the livestock sector (Table 7.4).

The investment increase in livestock production to reach the targeted productivity increase is sizeable. We specified no explicit mechanism to fund this productivity rise. Rather, we fixed aggregate national investment at baseline levels. This means that some investment redistribution mechanism is operating, such as a public credit

Table 7.4 Annual productivity increases, and investment costs to close 50% of the yield gap in livestock production in Brazil. Percentage changes

Regions	Productivity	Investment
1 AcreRond	0.82	4.72
2 AmazRor	2.71	15.6
3 ParaAmap	3.52	20.27
4 Tocantins	0.7	4.03
5 Maranhao	0.54	3.11
6 RestNe	1.54	8.87
7 Bahia	1.59	9.16
8 MinasG	1.24	7.14
9 RestSE	2.21	12.73
10 SaoPaulo	2.97	17.1
11 Sul	3.04	17.5
12 MtGrSul	0.85	4.89
13 MtGrosso	0.85	4.89
14 GoiasDF	0.97	5.59

Source: Authors' calculations, based on Silva et al. (2016)

line redirected toward livestock.[11] Even though this represents a severe constraint on economic expansion, it suits the main purpose of the chapter, which is to shed light on the role of carbon storage in pasture intensification.

Finally, for the purposes of this study, the model database was aggregated to 14 regions and 38 commodities and sectors.

7.6 Results

Closing the yield gap in livestock production in Brazil would have important economic effects (Table 7.5). Even though we have used a conservative hypothesis regarding the pasture area involved (namely closing 50% of the yield gap in areas with a very high and high aptitude for livestock production) the productivity shocks still apply to 66 Mha, or 37% of total pasture area in the base year.

Notice that the general economic adjustment would imply a reduction in the production of some commodities, as is the case of soybean (Table 7.6). This happens due to competition for land and other primary factors in the traditional regions, where there is no land expansion (or deforestation) in the baseline, since natural stocks were depleted a long time ago. The yield gap is notably high in the South (Sul) region, an important soybean production region in Brazil. With

[11] Actually, Brazil has currently an important public credit line for livestock production, which includes pasture productivity investments, the Programa ABC (the Low Carbon Agriculture Program).

Table 7.5 Model results. Macroeconomic variables. Percent variation in relation to base, accumulated to 2030

Variable	% variation
Household consumption	−0.05
Investment	0
Government spending	−0.05
Exports (Volume)	1.85
Imports (Volume)	−0.31
Real GDP	0.43
Real wage	0.81
Capital stock	−0.60

Source: Model results

Table 7.6 Model results. Agricultural production variation. Percent variation in relation to base, accumulated to 2030

	Brazil	Frontier region	Traditional region
Rice	5.3	6.7	4.3
Corn	2.3	2.6	1.8
Wheat	−2.7	−0.9	−2.8
Sugarcane	2.4	3.1	2.3
Soybean	−0.8	−0.2	−2.4
Other agric	−1.1	−0.3	−1.7
Cassava	2.7	3.0	2.1
Tobacco	−0.5	2.4	−0.5
Cotton	2.6	2.6	−0.5
Citrus fruits	3.9	4.0	3.9
Coffee	−0.7	−0.4	−1.7
Forestry	−2.1	−1.2	−2.8
Livestock	23.5	18.4	35.5
Raw Milk	6.4	7.0	4.3

Source: Model results

total investment fixed at baseline level in the closure, the increase in investment in livestock must reduce investment, and capital accumulation, in other activities, generating negative impacts in production.

The increase in livestock productivity is not the only effect of increasing GDP. This increase is equivalent to an increase in land availability for the economy, or a displacement of the production possibility frontier: the transition matrix approach allocates land spared in livestock production to flow to other agricultural activities, or even to reduce deforestation. Closing the yield gap would allow a 23.5% increase in livestock (beef cattle) production, while reducing 2030 pasture area by 4.24 Mha relative to the base (Table 7.7). This represents a 1.5% per year increase in livestock production above the baseline trend. Beef pasture area would be relocated to agriculture (1.41 Mha, including forestry), milk livestock (1.96 Mha), and to sparing forests from clearing (0.88 Mha), with both economic and environmental benefits. In Table 7.7, “Frontier” refers to the agricultural frontier region, where deforestation occurs, while “Traditional” refers to the older agricultural regions where natural forest stocks have run out.

Table 7.7 Land-use change (Million ha). Frontier and traditional agriculture regions. Accumulated to 2030

Activities	Aggregated region		Total
	Frontier	Traditional	
Rice	0.18	0.06	0.24
Corn	0.40	0.10	0.50
Wheat	0.00	−0.02	−0.02
Sugarcane	0.11	0.08	0.19
Soybean	0.55	−0.19	0.36
Other agric	0.03	−0.05	−0.02
Cassava	0.06	0.01	0.07
Tobacco	0.00	0.00	0.00
Cotton	0.06	0.00	0.06
Citrus fruits	0.01	0.03	0.04
Coffee	0.00	−0.01	−0.01
Forestry	0.00	0.00	0.00
Livestock	−3.85	−0.39	−4.24
Milk	1.57	0.39	1.96
UNUSED (Natural forests).	0.88	0.00	0.88

Source: Model results

Regional land-use effects vary, depending on the regional production composition (Table 7.7). Soybean, for example, increases land use (and reduces production) in the agricultural frontier region by 0.69%, but reduces in the traditional region (South and Southeast Brazil), where there is no room for land expansion in aggregate, and where competition for land is more intense. This suggests that land relocation in the frontier (where land availability increased) induces an endogenous fall in soybean productivity. Tobacco, on the other hand, does not change land use in all aggregated regions, but production decreases in the main (South) producing region, due to competition for labor and capital.

The change in land-use composition triggered by closing 50% of the yield gap in livestock production has different regional economic impacts (Table 7.8). The highest GDP impact is in the ParaAmap region (the northern states of Para and Amapa). Those states, apart from showing a high yield gap (see Table 7.3) have a high share of livestock in regional GDP.

The regional composition of economic activities, of course, affects the regional benefits of closing the yield gap in livestock. While the largest gap was in the Sul (South) region, this has a diversified economy, and so gets a smaller GDP increase than MtGrSul (in the Center-west), which has a much smaller yield gap, but where livestock has a higher share in regional GDP.

We mentioned before that LUC emissions are an important target in Brazil's iNDC, and livestock is an important component within LUC emissions. Traditionally, livestock is associated with GHG emissions in two main ways: through a process of clearing forests for pasture expansion, and through increases in emissions by the herd. The last source of emissions is mainly CH4, with a high Global Warming Potential (GWP).

Table 7.8 Regional results, macroeconomic variables. Percentage change, accumulated to 2030

	Real GDP	Household	Real wage	Yield gap
AcreRond (N)	2.58	−1.33	−0.01	0.51
AmazRor (N)	0.09	0.14	1.20	1.36
ParaAmap (N)	6.95	2.68	3.27	2.00
Tocantins (N)	2.59	−1.04	0.41	0.24
Maranhao (NE)	0.44	−0.94	0.50	0.16
RestNe (NE)	0.67	0.46	1.24	0.46
Bahia (NE)	0.49	−0.40	0.57	0.32
MinasG (SE)	−0.05	−0.63	0.33	0.33
RestSE (SE)	−0.58	−1.00	−0.02	0.91
SaoPaulo (SE)	−0.13	−0.12	0.72	1.18
Sul (S)	0.83	0.74	1.40	1.28
MtGrSul (CW)	4.16	0.35	1.07	0.29
MtGrosso (CW)	3.49	0.45	1.18	0.33
GoiasDF (CW)	0.98	−0.02	0.80	0.45

Source: Model results. N: North; NE: Northeast; SE: Southeast; S: South; CW: Center-west (Midwest)

To those two effects, we add in this chapter a third one: more carbon storage in pasture, as pasture productivity increases. In increasing livestock productivity, then, we consider three effects for emissions: a land-sparing effect, a herd increasing effect, and a pasture intensification effect. For the sake of comparison, we perform the accounting of emissions in the "Activity" source in livestock production in two different ways: the traditional one, in which emissions are proportional to production, and an alternative one, in each per output emissions in the "Activity" source reduce with productivity increases.

Those three effects were discussed before; here we present the net emissions effects (Table 7.9). This table displays the percent variation in emissions by source, computed by the two alternative methods. As it can be seen, the only difference between the two methods is in the "Activity" source, which is much smaller in the second (Alternative) method.

The first two, Traditional, columns of Table 7.9 shows that the 9.7% fall in emissions associated with the land-sparing effect (8176.5 Gg CO2 eq) is not enough to compensate for the increase in emissions from other sources, notably emissions linked to Activity. But the last two columns show that when we allow for increased soil carbon storage (alternative method), our yield gap closing scenario would reduce net emissions. Note that emissions in the "Activity" source would grow by 13.67% in the traditional accounting method and only by 1.58% in the alternative one. Emissions in the other sources remain the same in both methods.

This effect can be further analyzed through the carbon intensity (emissions intensity) in production, defined as the carbon content of each unit of production. Emissions intensity include all emissions in fuel use and in the "Activity" source,

Table 7.9 Model results. Variation in emissions, by emitting source. Accumulated to 2030

	Traditional (%)	GgCO2eq	Alternative (%)	GgCO2eq
Mining	−1.21	−3087.0	−1.21	−3087.0
Gasoline	−1.49	−1283.5	−1.49	−1283.5
Gasoline C (gasoline + ethanol)[a]	−0.55	−118.1	−0.55	−118.1
Combustible oil	0.03	13.4	0.03	13.4
Diesel oil	−0.32	−621.6	−0.32	−621.6
Other Petro	−0.73	−202.5	−0.73	−202.5
Activity	13.67	99, 008.7	1.58	9571.6
LUC	−9.71	−8176.5	−9.71	−8176.5
Brazil	5.91	85, 533.1	−0.29	−3904.1

Source: Model results
[a]Gasoline C is the regular gasoline used in Brazil, a mix of pure gasoline and ethanol (27%)

Table 7.10 Model results. Emissions intensity, deviation from the baseline, two emissions accounting methods. Percent variation, accumulated to 2030

	Emissions accounting method	
Activities	Traditional	Alternative
Rice	0.21	0.21
Corn	0.08	0.08
Wheat	0.01	0.01
Sugar cane	0.03	0.03
Soybean	0.04	0.04
Other agric	−0.02	−0.02
Cassava	0.14	0.14
Tobacco	0.01	0.01
Cotton	−0.01	−0.01
Citrus fruits	−0.01	−0.01
Coffee	−0.02	−0.02
Forestry	−0.05	−0.05
Livestock	0.90	−18.29
Milk	0.57	0.57

Source: Model results

but does not include emissions from LUC. Table 7.10 displays the results for both accounting methods.

We see from the table that the emissions intensity in livestock production would increase by 0.90% in the traditional accounting method, but decrease by 18.29% when carbon storage in the pasture is accounted for.[12] The alternative method, then, maybe more appropriate for pasture productivity increases. It shows that it is possible to increase livestock production in tropical conditions without seriously compromising emissions reduction targets. Intensification in livestock production is

[12]For the sake of illustration, Silva et al. (2016) found an approximate 31% reduction in emissions intensity in pasture intensification, for the Cerrados biome.

desirable not only because it spares forests, but also because it increases soil carbon storage, further offsetting herd emissions.

This is very important for agricultural policy in Brazil—a major beef exporter, and one of the few countries that still has the potential for significant increases in beef production. Environmental constraints will reduce forest clearing, reducing land supply for crops and livestock. Output expansion via intensification is not just possible, but desirable, in both economic and environmental terms.

The cost of this intensification, however, remains a challenge. According to our calculations, investment in livestock production necessary to guarantee the productivity improvement simulate in this chapter would be sizeable, reaching by 2030 6 times the investment value in the baseline. This amounts to an extra R$0.9 billion per year on average for 15 years, or about R$13.7 billion in 15 years. With that, investment in livestock would change from 0.5% of total investment in Brazil in the baseline in 2030 to 2.7% of total investment in 2030. To put those numbers in perspective, total rural credit in Brazil in 2018 amounted to R$151 billion, of which R$40 billion was for investment. The ABC Program, the credit line most closely linked to pasture intensification, received just R$2 billion in 2018.

7.7 Final Remarks

In this chapter, we shed light on the potential of pasture intensification for emissions reductions in Brazil. Increasing livestock productivity is seen in the literature as important for both saving forests and reducing GHG emissions. Our results support this view, but only when carbon storage in pasture is included in the calculations. Livestock productivity increases can be important for sparing forests from clearing, but the increase in herd emissions would offset that effect if the carbon storage improvement associated with pasture productivity increase is ignored.

Closing the yield gap under the hypothesis used in this chapter would release 4.69 Mha of pastures for other uses, which would be directed partially to crops (1.7 Mha), and avoided deforestation (1.13 Mha), while increasing GDP. For a beef exporter like Brazil, the profitability increases brought by increasing productivity can generate strong increases in herd size. Livestock emissions are mostly due to CH4, a GHG with a high GWP. Thus, the productivity increase may raise emissions, in spite of land sparing, if we use the traditional emissions accounting method. But we reach the opposite conclusion when we recognize that pasture intensification increases soil carbon storage, so that net emissions decrease.

The cost of pasture intensification is important. As we have shown, it would require a massive investment in livestock productivity, which should include both the herd and pasture, to achieve the simulated productivity gains. Under present fiscal constraints in Brazil, this funding is unlikely to come from public sources. The ABC Program, for example, the most important credit program targeting emissions in agriculture and livestock production, was allocated just R$2 billion in 2018/1019. The importance of pasture intensification for emissions reductions, as shown in this chapter, suggests that this would be an efficient instrument for climate policy, for both Brazil and the world. Mechanisms like the Fundo Amazonia, which mobilizes resources for actions in the Amazon region, could be considered.

Finally, we recognize the limitations of our analysis. We use parameters adapted from the literature (Silva et al. 2016), a study conducted for the cerrado biome, and applied these to the other biomes in Brazil. Ongoing field studies may yield better estimates for future simulations. The same applies to the cost of pasture intensification, adapted from the same study. Emissions from livestock activity, either in pastures or in livestock digestion is an active research field in animal sciences, and the incorporation of these developments into economic models should be in the forefront of land use and emissions modeling efforts.

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Chapter 8
The Economic Impacts of UK Fiscal Policies and Their Spillover Effects on the Energy System

Andrew G. Ross, Grant Allan, Gioele Figus, Peter G. McGregor, Graeme Roy, J. Kim Swales, and Karen Turner

Abstract The energy system and the economy are inextricably intertwined. Whilst this interdependence is, of course, widely recognized, it has not featured prominently in assessing the likely impact of economic policies. In principle, fiscal policies are likely to have an influence on key elements of the energy system, the neglect of which may lead to inefficiencies in the design of appropriate energy and economic policies. The importance of this in practice depends on the strength of the spillover effects from fiscal policy instruments to energy policy goals. This is the focus of this chapter. We employ a multi-sectoral computable general equilibrium approach for the United Kingdom that allows us to track the impact of key fiscal policy interventions on goals of economic and energy policies. We explore whether it is possible to stimulate the economy through fiscal policy without generating an adverse impact on the energy system. Overall, our results suggest that it is unlikely that an increase in current public spending or a fall in the income tax rate will generate a simultaneous increase in GDP and fall in emissions in the United Kingdom context. Nonetheless, there are undoubted differential spillover effects on key components of the energy system from tax and public spending interventions that may prove capable of being exploited through the coordination of fiscal and energy policies. Even if it seems doubtful that fiscal policies would be formulated with a view to improved coordination with energy policies, policymakers can benefit from knowledge of the likely direction and scale of fiscal spillover effects to key elements of the energy system, since this reveals, for example, the extent of

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any energy policy adjustment that would be required to maintain a given level of emissions.

Keywords CGE · Energy policy · Fiscal policy · Income tax · CO_2 emissions

JEL: C68, D58, Q43, Q48

8.1 Introduction

The interdependence of the energy and the economic systems hardly features in the ex ante appraisal, or ex post evaluation, of policies that primarily have economic objectives (Cox et al. 2016; Royston et al. 2018). There are many Computable General Equilibrium (CGE) analyses of fiscal issues (e.g., Holmøy and Strøm 2013). Also, energy–economy–environment CGE modelling has recognized the impact of the economy on energy use (Bergman 2005; McKibbin and Wilcoxen 2013; Ross et al. 2018a). However, there are few examples that combine these to provide an analysis of the impact of fiscal policy on environmental objectives.

Potentially fiscal interventions have a significant influence on the energy system, the neglect of which might lead to inefficiencies in the design of appropriate energy and economic policies. The practical importance of this depends on the strength of the spillover effects from fiscal policy instruments to energy policy goals. This is the focus of the present chapter. We track through simulation the impacts of UK fiscal policies on key elements of the energy system and on energy policy goals such as reducing energy use and CO_2 emissions. Isolating these impacts allows identification of the adjustments to energy policy that would be required to compensate for any adverse emissions impact of expansionary fiscal policies.

We begin by considering the effect of an unfunded increase in current government spending and follow this by exploring the impact of an increase in the average income tax rate. We then consider the implications of a balanced-budget rise in the income tax rate, where additional tax revenues are matched by a corresponding rise in government spending. Since it transpires that the direct linkages between fiscal policy instruments and the energy system depend to a significant degree on the behaviour of the labour market, we investigate the effect of imposing a range of alternative assumptions about wage determination. We employ a multi-sectoral CGE approach that captures key economic and energy systems interdependencies.

This chapter is organized as follows. Section 8.2 provides an ex ante macroeconomic labour market analysis of separate government expenditure and taxation increases and of a balanced-budget public expenditure expansion. Section 8.3 discusses the structure and parametrization of our UK energy–economy–environment model. Section 8.4 reports results and Sect. 8.5 summarizes the main conclusions.

8.2 Ex ante Labour Market Analysis of the Impacts of Government Spending and Taxation

This section provides analytical insight into the factors underlying the impact of the various fiscal policies that we model, focusing on the labour market to highlight the implications of alternative perspectives on wage determination. This proves important for both the economic and energy system outcomes. Whilst our underlying assumptions are UK specific, the labour market analysis has wider applicability (see, for example Ross et al. (2019) for a regional analysis). For simplicity, we assume that the change in fiscal policy is insufficient to generate a reaction from the Bank of England's Monetary Policy Committee, so that no financial "crowding out" occurs.[1] Throughout, again for simplicity, we take government expenditure to be current spending that has no immediate impact on the supply side of the economy.[2]

8.2.1 Increase in Government Expenditure

Consider first the case of a bond-financed increase in government spending. Figure 8.1 represents the long-run interactions of the general equilibrium labour demand and supply/wage setting curves in the UK labour market. The analysis is comparatively static and illustrates the long-run system-wide impact on the real wage and employment of a permanent step increase in government spending.

In Fig. 8.1, the labour demand curve D_0 represents the initial long-run general equilibrium relationship between the take-home real wage and employment. This incorporates the entire system-wide impact on labour demand for a change in the real wage. There is a strong presumption that these curves have a negative slope in real wage–employment space due to the adverse competitiveness effects of an increase in the real wage and this is the case with the default parameter values of our CGE model (described in Sect. 8.3).[3]

The initial equilibrium is represented by the intersection of this labour demand curve, D_0, and the alternative wage setting/labour supply curves, at point A, generating the initial equilibrium employment and real wage levels rw_0, and E_0. In this long-run equilibrium not only do all markets clear but the capital stock is optimally adjusted. This means that investment simply covers depreciation and is

[1] In effect, this is "as if" the United Kingdom is operating in a "liquidity trap".

[2] Clearly, some expenditure classified as current would be expected to have supply side effects, e.g. spending on education provision via its impact on human capital. We return to this in due course.

[3] Labour demand could rise with an increase in real wages because an increase in the real wage could increase household income and consumption demand. However, in comparatively "small" (as a proportion of total world trade), open economy like the United Kingdom we expect competitiveness effects to dominate income effects.

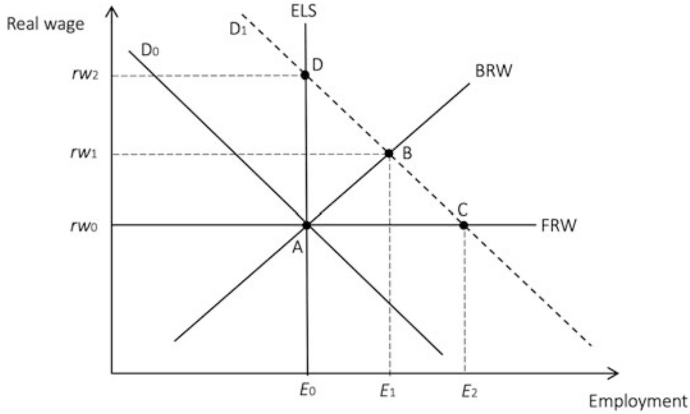

Fig. 8.1 The long-run system-wide labour market impact of an increase in government spending

therefore determined by sectoral activity levels and capital intensities. The increase in government spending shifts the long-run general equilibrium labour demand curve to the right, from D_0 to D_1, indicating that more labour is demanded at each real wage.[4] Alternative versions of the wage setting mechanism determine the effect of this demand stimulus on wages and employment and therefore the wider economy. Figure 8.1 illustrates a number of alternative approaches.

Our default CGE model specification is the bargained real wage curve (BRW), which embodies an inverse relationship between the rate of unemployment and the real wage, with the working population assumed to be exogenously fixed (Blanchflower and Oswald 2005). Substantial international evidence supports such a model specification [as detailed in Ross et al. (2018b)] with the workers' bargaining power increasing as the unemployment rate falls.[5] This labour market model also implies the presence of involuntary unemployment, with the BRW function lying above the competitive supply curve for labour.

In the employment-real wage space of Fig. 8.1, the bargained real wage function, BRW, the real take-home wage is shown as positively related to the employment rate[6]; as employment increases, workers are able to bargain for higher wages. At the initial equilibrium real wage, the shift in labour demand curve increases the workers' bargaining power, which exerts upward pressure on the real wage, leading to a degree of crowding out through the induced loss in competitiveness. The new

[4]In the short run, the rightward shift is more limited, because of capacity constraints. However, capital rental rates will increase, spurring sectors to invest leading to increased capacity and a higher demand for labour in the long run.

[5]An efficiency wage explanation is also available. Additionally, we separately explore the consequences of adopting a wage curve that relates the *pre-tax* wage to the unemployment rate. (See the subsequent discussion of the social wage case.)

[6]The employment rate is one minus the unemployment rate.

long-run equilibrium is established at point B, where both employment and the real wage increase to E_1 and rw_1, respectively. Since economic activity is stimulated, so too, in general, is the demand for energy used in both production (intermediates) and final demand.[7]

Whilst evidence supports our default wage curve specification, we consider a number of other labour market closures, in part to reflect alternative views of how the UK labour market operates, but also to provide useful alternative limiting benchmark cases that reflect different sensitivities of the wage bargaining process to changes in employment/unemployment. So there exists genuine uncertainty about the current operation of the UK aggregate labour market (Bell and Blanchflower 2018) and we also wish to identify the sensitivity of spillovers from economic policies to the energy system to variations in UK labour market behaviour. This gives some measure of how robust our conclusions are with respect to the choice of labour market behaviour.

In one alternative approach, the labour market is characterized by workers seeking to maintain a given real consumption wage over a range, so that any adjustments in labour demand can be met by a corresponding change in the level of employment at a fixed real wage (FRW). Historically, this case was motivated as "real wage resistance", with workers seeking to maintain the real value of their take-home pay in the face of macroeconomic demand disturbances. However, the experience of the United Kingdom over the past decade—with very little movement in the real take-home wage—fits that account reasonably well empirically. It seems unlikely that these circumstances will continue to prevail and, at least in the long run, the real wage would be expected to respond to market forces.[8]

In the FRW case, the wage-setting curve is horizontal through point A and employment adjusts in response to labour demand solely through changes in the unemployment and participation rates. Accordingly, only quantities change within the economy in response to a demand shock, since prices are invariant across long-run equilibria; a result reminiscent of a traditional "Keynesian" perspective.[9] The new labour market equilibrium is at point C in Fig. 8.1 with the real wage unchanged at rw_0 and employment increasing to E_2.

A further labour market closure often adopted in national CGE models imposes full employment with an exogenous labour supply (ELS).[10] In this closure, employment is effectively fixed and is represented by the vertical ELS curve through

[7]In the context of a multi-sectoral model, the link is not inevitable given the importance of changes in the composition of economic activity as well as its level.

[8]In general, net in-migration could generate such a response without incurring any capacity constraint. However, given language barriers and movement costs this seems unlikely to be of sufficient scale in practice to motivate the FRW case for the United Kingdom, even in the long run.

[9]In a multi-sectoral context demand disturbances generate results that are effectively those of an augmented input–output system in the long run (McGregor et al. 1996). However, the same is not true of supply disturbances, as we shall see.

[10]Partridge and Rickman (2010) give a brief discussion.

point A in Fig. 8.1.[11] In this limiting case, labour supply is effectively completely inelastic with respect to the real wage; this is the opposite "extreme" to the FRW case. Following the demand stimulus, a new long-run equilibrium is established at point D, where the real wage rises to rw_2 so that the stimulus to labour demand is entirely suppressed. In this case, the economy is largely tied down by the supply side; changes in demand basically impact the composition of economic activity and changes in capital intensity. There is complete crowding out in terms of employment, which remains fixed at E_0. In a multi-sectoral context, there may be some change in GDP as resources are reallocated across sectors in response to the demand stimulus and significant upward pressure on real wages, but the direction will depend on sectoral export, labour and intermediate intensities and key elasticities. However, if GDP increases, it is certain to be a much more modest change than is associated with either the BRW or the FRW labour market closures (since they reflect only changes in the sectoral composition of economic activity). Similarly, we would expect any stimulus to energy use in production and final demands to be less than in the other cases.

The BRW closure is taken as our default model given the overwhelming weight of empirical evidence in favour of wage curves of this form. Consideration of the other cases effectively provides an analysis of the impact of varying the sensitivity of wage bargaining to employment/unemployment.

In general, total energy use—in both production and final demand—is expected to increase broadly in line with economic activity, so that the energy, GDP and employment impacts should have similar rankings. However, there is an important compositional effect in this example: in general UK public spending is significantly less energy and emissions intensive than private expenditures, such as consumption and investment. Under the FRW, the absence of crowding out implies emissions must rise because government spending has increased and no element of private spending has fallen and indeed household expenditure and investment have increased. At the other extreme, in the presence of complete crowding out, with the ELS closure, the increase in government expenditure is likely to lead to a fall in emissions. However, there will also be price effects, which will impact energy intensities in individual sectors. Again, the BRW closure lies somewhere between these two extremes. In practice, whether total emissions rise or fall in response to an increase in government spending depends on its impact on private expenditures and exports. Certainly, it is perfectly feasible for an expenditure-generated fiscal expansion to result in a decline in emissions and a simultaneous rise in economic activity; a kind of "double dividend" for policy in that a single policy intervention simultaneously improves two policy goals.

[11]Labour supply can adjust through natural population change, but we abstract from long-term demographic change throughout for simplicity. However, ELS effectively precludes net-inmigration in response to an increase in the real wage, a restriction that seems inappropriate for the United Kingdom as long as it remains a member of the EU and therefore is subject to freedom of movement.

8.2.2 Increase in the Income Tax Rate

Figure 8.2 is constructed on the same principles as Fig. 8.1. It illustrates the impact of an increase in the income tax rate with no change in public expenditure, which would correspond to the actions of a government wishing to reduce the fiscal debt through increased revenues. The original equilibrium is again represented by point A where employment and real wage levels are E_0 and rw_0. The increase in the income tax rate shifts the general equilibrium demand curve for labour downwards. At any given level of labour demand, the post-tax (take-home) real wage received by the worker is reduced as a result of the increased income tax. However, this is only a partial equilibrium account. Because at any employment level household consumption is now lower, the real wage must fall further for exports to replace lower household consumption. The long-run general equilibrium labour demand curve, therefore, shifts from D_o to D_1. As previously, alternative visions of the responsiveness of effective labour supply to the real wage play a key role in determining the overall impacts.

The FRW is the most straightforward case. In this closure, the nominal wage to the firm must rise to take into account the additional tax and the increase in the consumer price index (CPI) that the rise in domestic labour costs implies. The fall in household expenditure and UK competitiveness reduces labour demand and the new equilibrium is at point C, with employment and the real wage given by E_1 and rw_0, respectively.

At the other extreme, where the labour market is characterized as having an exogenous labour supply, the new equilibrium is at point B in Fig. 8.2 (ELS). The real wage has to contract to rw_1 in order to maintain employment at E_0. The reduction in the real take-home wage increases UK competitiveness, and therefore

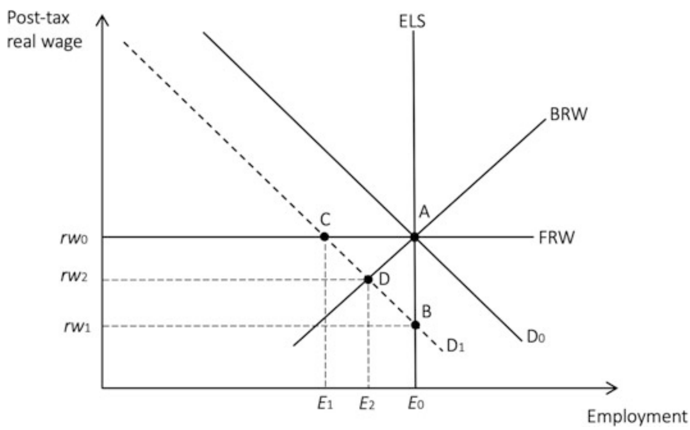

Fig. 8.2 The (long run) system-wide labour market impact of an increase in the income tax rate

exports, by just enough to offset the reduction in household demand following the increased tax take.

Under the BRW case, the impact is between the FRW and ELS extremes. The equilibrium is at point D, with the real wage and employment rw_2 and E_2. Here workers' bargaining behaviour results in falls in both the employment and the real take-home wage rates in response to the tax increase.

As previously, we would expect total energy use—in both production and final demand—to fall with the level of economic activity, and so the energy impacts are ranked similarly to the likely employment (and GDP) effects. Notice that here we expect quite a close linkage between the change in economic activity generated by a tax rise and energy use and emissions. This is because adjustments occur within economic activity directed towards household consumption and exports. This contrasts markedly with the case of UK government spending given its comparatively low energy and emissions intensity.

Whilst we have conducted the analysis for the case of an increase in the average income tax rate, it is easily extended to the (opposite) case of a tax fall. Here an induced expansion in the economy would operate through its stimulus to (energy and emissions intensive) private sector economic activity.

8.2.3 Balanced-Budget Fiscal Expansion

In the balanced-budget fiscal expansion, in contrast to the previous case outlined in Sect. 8.2.2, the increased income tax revenues are recycled to finance current government expenditure. As outlined in Sect. 8.2.1 and 8.2.2, increases in government spending and taxation produce contrary movements in the general equilibrium labour demand curve. Therefore, a key issue is: what is the net impact?

This is an empirical issue. UK public expenditure is less import intensive than consumption, so that in so far as a balanced-budget fiscal expansion implies the substitution of public for private expenditure, this will tend to increase labour demand. However, the increased income tax generates an adverse impact from reduced competitiveness at any real take-home wage. We do not know a priori which of these effects will dominate but in a small open economy, we might expect the negative competitiveness effect to be greater and Fig. 8.3 is drawn on the assumption.

In Fig. 8.3, the initial equilibrium is again at point A. In this case, we expect the labour demand curve to shift inwards to D_1, though this inward shift is less marked than in the pure tax reduction in Sect. 8.2.2. Essentially, if workers increase the pre-tax wage to offset the rise in tax, the negative competitiveness effects more than offset the demand stimulus from higher public expenditure. The analysis with the alternative wage-setting functions is qualitatively the same as in Fig. 8.2. Under our default BRW model, there is a fall in the post-tax real wage and in employment, to point D ($E_{2,}$ rw_1); this is the most likely outcome. Under FRW and ELS equilibria would be established at points C and B, where the changes

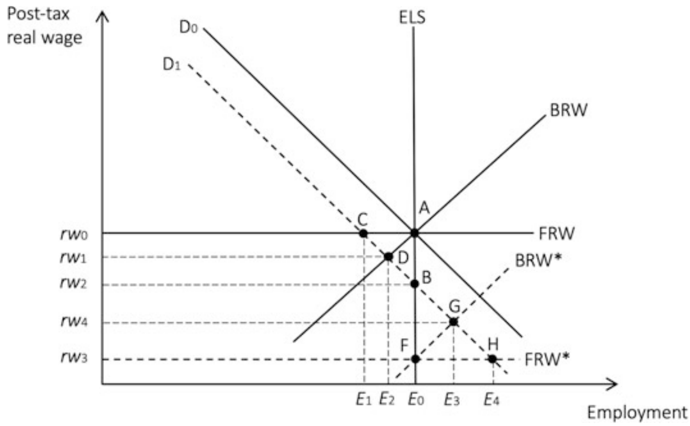

Fig. 8.3 The (long run) system-wide labour market impact of a balanced budget increase in the income tax rate

in employment and the take-home real wage are non-positive; these outcomes are E_1, rw_0,; and rw_2, E_0, respectively. Note that although there is an expansion in public expenditure, employment does not rise in any of these cases, reflecting the (presumed) predominant adverse supply impact.

One possibility with the balanced-budget expansion is that the workers bargain not in terms of their real take-home wage, but rather for a "social wage". In constructing the alternative BRW^* and FRW^* curves in Fig. 8.3 we assume that the worker receives the same benefit from the amenity value of additional public expenditure as they would have from the reduction in private household consumption from payment of the tax. We also assume that wage-setting reflects this social wage, which is the sum of private and public consumption (Lecca et al. 2014b). This would require at least a tacit agreement between trade unions and government. This means that at any level of employment, workers are happy for their real take-home wage to be reduced by the proportion of any additional rise in the income tax rate.

In Fig. 8.3, the social wage bargaining curves all pass through point F, where employment is at the initial level, E_o, and the real take-home wage is rw_3. It is an empirical matter as to whether employment at point F is above or below that at B. The construction here is consistent with simulations reported in Sect. 8.5. Where the labour market is characterized by an exogenous labour supply, the fact that workers value the public expenditure has no impact on the labour market outcome. Though it does mean here that workers are better off after the fiscal expansion; workers would have been prepared to accept a real take-home wage of rw_3 though they will actually receive a higher amount, rw_2. With a bargained real social wage (BRW^*), employment will rise to E_3, with a real take-home wage of rw_4, at point G, whilst with the fixed real social wage, employment increases further to E_4, at the real take-home wage rw_3, at point H.

As previously, we would expect total energy use—in both production and final demand—to fall with the level of economic activity, and so the energy impacts are ranked similarly to the likely employment (and GDP) effects.

8.3 Model and Calibration

We simulate the impacts of illustrative fiscal policies using a computable general equilibrium (CGE) model of the United Kingdom, UK-ENVI. This model was purpose built to capture the interdependence of the energy and non-energy subsystems. Versions of this model have been employed to analyse the impacts of increased efficiency in the industrial use of energy (Allan et al. 2007), to quantify the impacts of energy efficiency programmes on households (Figus et al. 2017), and to identify total energy rebound effects of improvements in household energy efficiency (Lecca et al. 2014a). Ross et al. (2018a) detail the main elements of the model, with a particular emphasis on the linkages between the economic and energy sub-sectors, and a full mathematical account is given by Ross et al. (2018b). We outline here how we treat public expenditure and how the model is parameterized.

The model is calibrated using information from the UK Social Accounting Matrix (SAM) for 2010, the latest data available at the time of writing. It has 30 separate production sectors, including the main energy supply industries; coal, refined oil, gas and electricity.[12] Also identified are the transactions of UK households (by income quintile), the UK Government, imports, exports and transfers to and from the rest of the World (ROW). Base year industrial territorial CO_2 emissions are linked to sectoral primary fuel use, as outlined in Allan et al. (2018). This essentially converts data on sectoral physical use of energy to CO_2 emissions using UK technology assumptions; a proportioned emission factor for each of the three primary fuels (coal, oil and gas). CGE simulations generate sector-specific changes in the use of each of the primary fuels, thereby generating a new set of emissions.

8.4 Simulation Results

In the following subsections, we outline the results for a number of simulations including individual permanent step increases in government spending and the income tax rate and similar balanced-budget fiscal expansions. The economy is taken to be initially in long-run equilibrium prior to the fiscal shock, so that if the model were run forward in the absence of any disturbance it would simply replicate

[12]Ross et al. (2018b) give a list of the 30 sectors. Emonts-Holley et al. (2014) give a detailed description of the methods employed to construct the SAM which is available for download at: https://doi.org/10.15129/bf6809d0-4849-4fd7-a283-916b5e765950

the base year SAM in each period. The results reported here represent the values of endogenous variables in the new long-run equilibrium. This is where all markets clear and capital stocks in all sectors are fully adjusted to the new output levels and the ruling input and output prices. The results are presented as percentage changes relative to initial equilibrium values and all of the effects are directly attributable to the exogenous shocks.

8.4.1 Government Spending

Table 8.1 reports the results of a 5% stimulus to government expenditure. Figures are given for fixed real take-home wage (FRW), bargained real take-home wage (BRW) and exogenous labour supply (ELS) labour market closures. The impact on aggregate economic and energy use variables are affected by the labour market assumptions, in line with the discussion of Fig. 8.1 in Sect. 8.2. Employment, GDP, total energy use and CO_2 emissions effects are all ranked FRW > BRW > ELS, with the ranking reversed for real wage changes.[13]

Under the fixed-wage closure, there is no crowding out from the supply side in the long run: there are no changes in (real or nominal) wages or prices so that with this labour market closure and a simple demand shock UK-ENVI behaves like an extended Input–Output model (McGregor et al. 1996). This means that accompanying the direct expansion in production from the increase in government expenditure, there is indirect and induced activity generated by additional intermediate, investment and consumption demand. Note, however, that exports are unchanged, reflecting unchanged competitiveness. GDP and employment increase by 1.76% and 2.01% with energy use in production and final demand rising by 1.32% and 0.79%, respectively. Energy and emissions intensities therefore both fall as UK government expenditure itself has a relatively low energy intensive (Ross et al. 2018b). However, as we have already noted, the notion that a national economy could be entirely free of any supply constraint in the long-term seems unrealistic (although continuing membership of the EU would render it less so). Yet this is the only case in which territorial emissions actually rise in response to increased government spending because of the much greater stimulus to GDP associated with this case.

With the BRW the 0.80% employment increase bids up the real wage, which results in an accompanying 0.80% rise in the CPI, a loss of competitiveness and

[13] Many conventional models treat the labour supply decision as a labour/leisure trade-off, in which context GDP would be an inappropriate indicator of welfare. Here the real-wage decision reflects bargaining behaviour and implies the presence of involuntary unemployment even in long-run equilibrium. The UK Government tends to focus, rightly or wrongly, on GDP and employment as the main macroeconomic indicators. (Unemployment always figures large, and negatively, in studies of well-being.)

Table 8.1 Long-run effects of a 5% increase in government spending

	FRW	BRW	ELS
GDP	1.76	0.59	−0.18
CPI	0.00	0.80	1.34
Unemployment rate (pp difference)	−1.89	−0.75	0.00
Total employment	2.01	0.80	0.00
Nominal gross wage	0.00	1.73	2.90
Real gross wage	0.00	0.92	1.54
Household consumption	1.32	1.02	0.82
Government budget	10.26	15.28	18.63
Government consumption	5.00	5.00	5.00
Investment	1.36	0.26	−0.47
Total energy use (intermediate+final demand)	1.14	0.32	−0.22
– Electricity	1.40	0.60	0.08
– Gas	1.34	0.70	0.28
Energy use in production (total intermediate)	1.32	0.34	−0.30
Energy consumption (total final demand)	0.79	0.32	0.02
– Households	1.30	1.17	1.10
– Investment	1.30	0.26	−0.43
– Government	5.00	5.00	5.00
– Exports	0.00	−0.91	−1.51
Energy output prices	0.00	0.54	0.89
Energy intensity (Total energy use/GDP)	−0.61	−0.27	−0.04
Territorial CO_2 emissions	1.04	−0.07	−0.79
Emission intensity (territorial CO_2/GDP)	−0.71	−0.65	−0.62
Total imports	1.49	2.21	2.70
Total exports	0.00	−1.40	−2.31

% changes from base year; all values in real terms except where otherwise stated; Government budget deficit (+), surplus (−)

a corresponding 1.40% fall in exports.[14] Consumption rises by only 1.02% and investment by 0.26% (which is equal to the percentage change in the capital stock in long-run equilibrium).[15] This crowding out effect ensures a smaller expansion than under FRW, but this is a more realistic outcome. The crowding out of some private sector expenditures and exports is reflected in a rise in total energy use of only 0.32% and total CO_2 emissions actually fall slightly by 0.07%, in response to a change in sectoral mix and type of fuel use. Whilst total energy use and individual fuel use rise, there is a shift in the fuel-mix consumed by individual sectors. This

[14]In all the model closures here, a government expenditure shock is always accompanied by a non-positive change in exports net of imports so that some emissions are shifted abroad and therefore no longer count in the UK's territorial emissions.

[15]Investment is driven by the gap between rental rates and the user cost of capital. The depreciation rate is fixed as is the world interest rate.

shift entails a fall in emissions from oil (and coal), whilst those from gas increase in response to relative price changes. The fall in oil emissions is sufficient here to counter the rise in gas emissions for total industrial territorial CO_2 emissions to fall.

Under the ELS closure, employment is unchanged so that the 1.54% real wage rise re-equilibrates labour demand to the fixed supply. GDP and investment fall by 0.18% and 0.47%, respectively.[16] Here, GDP is very largely determined by the supply side.[17] Other things being equal we would expect a substitution in favour of capital in this case, but the sectoral composition shifts against capital intensive industries and the capital stock falls by more than GDP. Exports are crowded out through real exchange rate changes, falling by 2.31%, and these are on average are more capital intensive than the public sector expenditures which replace them. Under ELS, total energy use is reduced: again relatively low energy intensity government expenditure displaces private expenditure. Whilst household consumption and energy use increases, total final demand use increases only very slightly (due to the fall in investment), and this is more than offset by the reduction in energy use in production.

Overall, UK Government expenditure is intrinsically low energy intensive, so the impact on total energy use becomes critically dependent on the scale of any stimulus to, or contraction in, private sector activity induced by the increase in public spending. Accordingly, where there is complete labour-market crowding out (under ELS), energy use falls; where there is no crowding out (FRW) energy use rises. In intermediate cases, it depends on the strength of the supply side constraint: here with BRW, whilst there is an increase in energy use, emissions actually fall due to the changes in the composition of energy use.

Of course, in practice, energy policies directed at decarbonization are in place, and given that emissions in the electricity production sector have fallen by nearly 50% in the United Kingdom over the last 7 years, it is not unreasonable to suggest that the increases in emissions observed here could be offset by modest further decarbonization of the electricity sector.

8.4.2 Taxation

Table 8.2 summarizes the long-run impact of a 5% rise in the average income tax rate used solely to reduce the Government's debt. The qualitative results vary significantly across different labour market closures and confirm the discussion of Fig. 8.2 given in Sect. 8.2. In this case, both demand and (where applicable) supply-side pressures are contractionary, generating non-positive changes in employment and economic activity. In particular, the absolute values of employment changes are ranked: FRW (5.21%) > BRW (2.43%) > ELS (0.00%).

[16] In the long run, the percentage change in the capital stock equals that of investment.

[17] See, e.g. Adams (2005), Adams and Parmenter (1994) and Dixon and Rimmer (2005).

Table 8.2 Long-run effects of a 5% increase in the income tax rate

	FRWpre	FRW	ELS	BRW
GDP	−1.39	−5.17	−0.13	−2.48
CPI	0.00	2.69	−0.86	0.76
Unemployment rate (pp difference)	1.23	4.90	0.00	2.28
Total employment	−1.30	−5.21	0.00	−2.43
Nominal wage	0.00	5.94	−1.82	1.64
Nominal wage after tax	−3.07	2.69	−4.83	−1.48
Real wage	0.00	3.17	−0.96	0.88
Real wage after tax	−3.07	0.00	−4.00	−2.22
Household consumption	−2.67	−3.62	−2.33	−2.95
Government budget	−10.56	5.64	−15.83	−6.04
Government consumption	0.00	0.00	0.00	0.00
Investment	−1.53	−5.09	−0.34	−2.56
Total energy use (intermediate+final)	−1.51	−4.15	−0.61	−2.27
– Electricity	−1.74	−4.29	−0.88	−2.48
– Gas	−1.82	−3.88	−1.11	−2.41
Energy use in production (total intermediate)	−1.51	−4.66	−0.45	−2.42
Energy consumption (total final demand)	−1.44	−2.94	−0.92	−1.88
– Households	−2.50	−2.88	−2.35	−2.62
– Investment	−1.61	−4.97	−0.47	−2.58
– Government	0.00	0.00	0.00	0.00
– Exports	0.00	−2.98	1.01	−0.86
Energy output prices	0.00	1.78	−0.58	0.50
Energy intensity (Total energy use/GDP)	−0.11	1.07	−0.48	0.21
Territorial CO_2 emissions	−1.45	−5.02	−0.24	−2.49
Emission intensity (territorial CO_2/GDP)	−0.06	0.15	−0.11	−0.01
Total imports	−1.67	0.67	−2.40	−1.02
Total exports	0.00	−4.55	1.54	−1.32

% changes from base year; all values in real terms except where otherwise stated; Government budget deficit (+), surplus (−)

We consider first a benchmark outcome where there is no change in the pre-tax real wage after the imposition of the tax. This is shown in the first column of Table 8.2. Here, there is simply a contractionary demand effect because, whilst the pre-tax wage paid by the firm is unaffected, after-tax real take-home wage falls significantly. This reduces households' labour income and wealth, inducing a fall in consumption demand. There is no adverse supply impact in this case, as all prices remain unchanged in the long run, so that competitiveness (and therefore exports) is not adversely impacted. The fall in household consumption is accompanied by a fall in intermediate demand and a 1.53% decrease in investment, though neither government nor export final demand is impacted.[18] GDP and employment fall by 1.39% and 1.30%, and this decline in economic activity reduces energy use in both production and final demands, with an accompanying fall in emissions and the energy and emissions intensities. The issue is how will the labour market react to the reduction in employment, together with the 3.07% fall in the real take-home wage after the tax increase?

The most extreme case is where workers are able to restore their real take-home wage, generating the results reported in the second column of Table 8.2. Given that the general equilibrium labour demand curve is in practice downward sloping, restoring the real take-home wage will further reduce employment and GDP, which fall by 5.21% and 5.17%, respectively. The nominal wage, that is the wage relative to the price of foreign goods rises by 5.94%, so that there are sizeable trade effects, exports falling by 4.55%. There are relative price effects operating here too with energy output prices increasing by less than the CPI and general domestic output. Energy use and CO_2 emissions fall, by 4.15% and 5.02%, respectively, but this is by less than GDP so that energy and emissions intensities both rise.

On the other hand, under the ELS closure, the take-home real wage falls further—by 4.00% rather than the 3.07% with the benchmark fixed pre-tax wage case—so that employment is retained at the initial level. With ELS, in response to the lower real take-home wage, domestic prices fall with an induced 0.86% reduction in the CPI. Again, the supply side largely ties down GDP. The change in GDP is a weighted average of the change in employment and the capital stock, and here the latter falls by 0.34%, reflecting the lower capital intensity of exports. The fall in consumption is counterbalanced by the improvement in net exports (a 1.54% increase in exports and a 2.40% fall in imports). There is a gain in competitiveness, which limits the reduction in GDP to 0.13%. In this case, energy prices decline by less than the price of domestic output, and both energy use and CO_2 emissions decline by less than GDP so that energy and emissions intensities rise.

In the FRW simulation results, employment falls where workers maintain their initial real take-home wage. In the BRW labour market closure, workers cannot maintain their take-home real wage because their bargaining power has been reduced. However, the 2.22% fall in the real take-home wage is not as much as with ELS and is not enough to reduce domestic prices so that the CPI increases by 0.76%. Competitiveness and household consumption both fall so that GDP, employment, exports and investment are reduced by 2.48%, 2.43%, 1.02% and 2.56%, respectively. In this case, total energy use falls by 2.27% and CO_2 emissions by 2.49% so there is an increase in energy intensity but a very slight fall in emissions intensity.

In the fixed real pre-tax wage simulation, only the adverse demand effects generated by reducing household income are present. Where the labour market adjusts to the reduced real wage and employment, supply-side price effects are

[18]The model here operates as an extended IO with endogenous household consumption and investment, where the household consumption coefficients have been reduced.

generated which can reduce or accentuate the pure demand-side effect. However, in this case, this is never enough to overcome the negative impact on GDP and there are corresponding reductions in energy use and CO_2 emissions. When tax reductions are used to stimulate the economy, the impact on the environment is adverse—which contrasts with the impact when government spending is used under the BRW or ELS labour market closures. We next explore this differential energy impact of public spending and taxation when viewed as alternative policy instruments for achieving the same economic goal.

8.4.3 The Comparative Impact of Tax and Public Spending

Table 8.3 reports the impact on other economic and energy/environment variables of achieving a 0.6% rise in GDP through alternative fiscal policies with the bargained take-home real wage closure.[19] The simulated GDP increase requires either a 5.08% rise in government expenditure (similar in scale to the stimulus used to generate the results reported in Table 8.1) or a much smaller 1.34% reduction in income tax. We focus here on energy and environmental impacts.

Note that the adverse impact on the public sector deficit is much more marked for the expenditure increase than the income tax fall. However, the tax and expenditure impacts on the deficit in the cases where prices do not change in Tables 8.1 and 8.2 are in fact very similar. It is the price reduction and increased activity on the supply side which gives rise to the differential impacts reported in Table 8.3.

In both cases, total energy use is increased but by much less, 0.32%, with higher public spending than the 0.57% increase for lower taxation. Reduced taxation provides a relatively greater stimulus to private, as compared to UK public, spending and the former is more energy and emissions intensive. The link between economic activity and total energy use and emissions is therefore much stronger in response to tax reductions than to public expenditure increases. Indeed emissions actually fall slightly in the public-spending-induced expansion. Moreover, for any given fiscal stimulus, adverse energy and emissions impacts would be limited by stimulating government spending rather than reducing taxation.[20]

[19]The qualitative results are broadly similar across other closures.

[20]As noted previously, energy policies directed at decarbonization are in place. For example, a 1.75% fall in emissions in the electricity generation sector would offset the emissions arising here from the reduction in income tax.

Table 8.3 Long-run effects of a 5.08% increase in government spending, and a 1.34% reduction in the income tax rate, BRW closure

	Increase in government expenditure	Reduction in income tax
GDP (calibrated)	0.60	0.60
CPI	0.81	−0.15
Unemployment rate (pp difference)	−0.76	−0.55
Total employment	0.81	0.58
Nominal wage	1.75	−0.32
Nominal wage after tax	1.75	0.50
Real wage	0.93	−0.17
Real wage after tax	0.93	0.65
Household consumption	1.04	0.79
Government budget	15.54	1.97
Government consumption	5.08	0.00
Income tax rate	0.00	−1.34
Investment	0.26	0.63
Total energy use (intermediate+final)	0.32	0.57
– Electricity	0.61	0.63
– Gas	0.71	0.62
Energy use in production (total intermediate)	0.34	0.60
Energy consumption (total final demand)	0.33	0.48
– Households	1.19	0.71
– Investment	0.26	0.64
– Government	5.08	0.00
– Exports	−0.93	0.17
Energy output prices	0.54	−0.10
Energy intensity (Total energy use/GDP)	−0.27	−0.03
Territorial CO_2 emissions	−0.07	0.61
Emission intensity (territorial CO_2/GDP)	−0.67	0.01
Total imports	2.25	0.33
Total exports	−1.42	0.26

% changes from base year; all values in real terms except where otherwise stated; Government budget deficit (+), surplus (−)

8.4.4 Government Taxation: Balanced Budget

Here we consider the impact of a balanced-budget fiscal expansion—a rise in taxation matched by a rise in government spending. Again, we employ a benchmark case where the real pre-tax wage remains constant, so that there are no long-run price effects following the fiscal intervention. The outcome is shown in the first column of results in Table 8.4. This reveals a stimulus to aggregate economic activity as GDP, employment and government expenditure rise, by 0.43%, 0.78% and 5.25%

Table 8.4 Long-run effects of a 5% increase in the income tax rate under a balanced budget

	FRWpre	ELS	FRW	BRW	SOCW
GDP	0.43	−0.29	−6.09	−2.20	−0.09
CPI	0.00	0.29	2.69	1.06	0.21
Unemployment rate (pp difference)	−0.73	0.00	5.88	1.93	−0.21
Total employment	0.78	0.00	−6.26	−2.06	0.22
Nominal wage	0.00	0.62	5.94	2.29	0.45
Nominal wage after tax	−3.07	−2.47	2.69	−0.85	−2.64
Real wage	0.00	0.33	3.17	1.22	0.24
Real wage after tax	−3.07	−2.75	0.00	−1.89	−2.84
Household consumption	−1.34	−1.67	−4.31	−2.54	−1.57
Government budget	0.00	0.00	0.00	0.00	0.00
Government consumption	5.25	4.38	−2.70	2.05	4.62
Investment	−0.14	−0.76	−5.80	−2.42	−0.59
Total energy use (intermediate+final)	−0.34	−0.83	−4.75	−2.12	−0.69
– Electricity	−0.32	−0.84	−5.02	−2.21	−0.69
– Gas	−0.44	−0.90	−4.58	−2.11	−0.77
Energy use in production (total intermediate)	−0.16	−0.74	−5.35	−2.25	−0.58
Energy consumption (total final demand)	−0.64	−0.94	−3.35	−1.73	−0.85
– Households	−1.19	−1.45	−3.56	−2.15	−1.38
– Investment	−0.27	−0.87	−5.65	−2.44	−0.70
– Government	5.25	4.38	−2.70	2.05	4.62
– Exports	0.00	−0.33	−2.98	−1.20	−0.24
Energy output prices	0.00	0.19	1.78	0.70	0.14
Energy intensity (Total energy use/GDP)	−0.76	−0.53	1.42	0.08	−0.60
Territorial CO_2 emissions	−0.39	−0.96	−5.56	−2.48	−0.80
Emission intensity (territorial CO_2/GDP)	−0.82	−0.67	0.55	−0.29	−0.71
Total imports	−0.14	−0.14	−0.16	−0.15	−0.14
Total exports	0.00	−0.51	−4.55	−1.83	−0.36

% changes from base year; all values in real terms except where otherwise stated; Government budget deficit (+), surplus (−)

respectively, but the real take-home wage, household consumption and investment falls by 3.07%, 1.34% and 0.14%.[21]

It is clear that the pure demand effects are driven by the differences in the composition of household and public expenditure as import-intensive private consumption is replaced by labour-intensive government spending. These compositional effects are also reflected in the energy-system and environmental impacts. Although output is increasing, total energy use falls by 0.34%, as do emissions by 0.39%. Again, this reflects the low energy (and emissions) intensity of government spending relative

[21]Notice that the FRW result in Table 8.1 and the FRWe result in Table 8.2 imply similar impacts of the expenditure and tax changes on the public sector budget. However, the expenditure effect on employment is greater, hence the positive results reported for GDP in the first column of Table 8.4.

to that of private spending. These results suggest that there is a potential "*double dividend*" available with a balanced-budget expansion as key government economic and energy policy goals are simultaneously improved, but the benchmark is a rather special case.[22]

More generally, the question arises as to how the labour market will react. With fixed pre-tax real wages, employment is increasing but the take-home real wage has fallen. ELS is the most straightforward case. We know that the general equilibrium labour demand curve is downward sloping. In order to maintain the initial employment level the take-home real wage must therefore rise above that under the fixed pre-tax wage closure. The results are given in column 2 in Table 8.4. Whilst the real take-home wage is still 2.75% below its original level, the nominal pre-tax wage has increased by 0.62%, so that there are relative price and adverse competitiveness effects. Reduced export demand now offsets the demand-side stimulus and although employment is fixed, GDP falls by 0.29%. Compositional effects are still apparent in total energy use and emissions, which both fall by more than GDP so that energy and CO_2 emissions intensities also fall.

Being able to identify ELS allows us to anchor the general equilibrium labour demand curve. Both the FRW and the BRW closures will involve reductions in employment and under BRW the bargained real take-home wage will be below its initial value. With FRW, workers succeed in defending their take-home real wage in the face of the fiscal changes but only at the cost of much lower employment. The FRW results are reported in column 3 of Table 8.4. Here there is a large contraction in the economy as GDP, employment, investment, exports and public expenditure fall by 6.09%, 6.26%, 5.80%, 4.55% and 2.70% in response to the 5.94% increase in the nominal pre-tax wage required to maintain the real take-home wage.[23] Not surprisingly, there are large falls in energy use and CO_2 emissions. However, energy and CO_2 intensity increase.

One way of thinking about these results for the BRW case is that they are approximately a weighted average of the corresponding results in Table 8.3. The BRW labour market closure produces an outcome intermediate between ELS and FRW. There is still a 1.89% fall in the take-home real wage, but this is less than for ELS. GDP and employment fall by 2.20% and 2.06%, respectively. Again, the 2.29% increase in the pre-tax nominal wage has negative competitiveness effects, with exports 1.83% below their initial level. There is a big, 2.12%, reduction in energy use and a 2.48% reduction in CO_2 emissions, producing a small (0.08%) increase in energy intensity and 0.29% reduction in CO_2 emissions intensity. Under these circumstances, the balanced-budget fiscal expansion has a contractionary impact on the economy, which moderates energy use and emissions. Under none

[22]Note that this result reflects compositional changes (rather than incentives).

[23]Note that the reduction in economic activity is even greater than in the comparable simulation in Table 8.2. This is because the tax take actually falls here, so that reduced public expenditure adds to the contractionary effects.

of the conventional labour market closures is there a prospect of a double dividend, and indeed even the primary objective of the fiscal expansion is not achieved.

What if workers value increased public spending at the margin as much as their loss of after tax income and that this was fully reflected in their bargaining behaviour? Under this “Social Wage” (SOCW) case, workers would accept a fall in their post-tax wage because they value the increase in government expenditure and feel no worse off after the change (Lecca et al. 2014b). Accordingly, bargaining would effectively focus on the pre-tax real wage. The impact of the balanced-budget fiscal expansion, in this case, is summarized in the final column of Table 8.4.

In the benchmark simulation, with a fixed pre-tax real wage, employment increases. Where workers bargain over the pre-tax wage, the outcome, therefore, lies between that benchmark and the ELS closure. Employment increases by 0.22% but there is also an increase in domestic prices, so that the CPI rises by 0.21% and GDP experiences a slight fall of 0.09%. Total energy use and emissions, and their intensities, fall. So in the Social Wage case there is a double dividend in terms of employment and emissions, both of which simultaneously move favourably; however, the dividend does not here extend to GDP. This suggests that limited double dividends from a fiscal expansion are possible where workers are willing to accept cuts in their post-tax wage to finance valued public goods. However, in the conventional labour market models, ELS, BRW and FRW, economic activity falls along with total energy use and emissions if tax increases are used to finance increased government expenditure.

8.5 Summary and Conclusions

Though recognized as important, the interdependence between the energy and the economic systems has not featured prominently in assessing the full impact of economic policies. Our primary focus in this chapter, therefore, has been to use an economy/energy/environment multi-sectoral computable general equilibrium (CGE) model to simulate the impacts of fiscal policies on energy policy goals. We consider a number of different labour market models and find that the wage determination process plays a major role in governing the impact of fiscal policy changes on the economy, energy use and emissions. Given the widespread international evidence in favour of the “wage curve” (bargained real wage) we have generally adopted this as the default specification in our models.

In the context of a balanced-budget fiscal expansion, there are typically countervailing demand- and supply-side influences. Under a Social Wage arrangement, workers would effectively bargain for a pre-tax wage in return for appropriate augmentation of public services. In these circumstances, the adverse supply effect of an increase in taxes is mitigated, and our results suggest that a double dividend—a simultaneous stimulus to the economy and a reduction in emissions—induced by an increase in current public spending or a fall in the income tax rate, are possible in certain circumstances. However, currently the UK labour market seems insufficiently centralized, and trade union influence too limited, to be conducive to the establishment of a Social Wage.

Nevertheless, differential spillover effects on key elements of the energy system from tax and public spending policies might be capable of exploitation through the coordination of fiscal and energy policies. Also, even if it seems unlikely that fiscal policies would be adjusted so as to improved coordination with energy policies, policymakers should at least be aware of likely direction and scale of fiscal spillover effects to the energy system.

In future research, we aim to extend the analysis in a number of ways. We wish to relax the assumption that current government consumption has no supply side impact effects (e.g. through human capital investment) and also explore the possibility of the social wage case being linked to the composition of government spending. We also plan to analyse the spillover effects arising from a larger menu of taxes and to investigate the impact of imposing a wider range of macroeconomic constraints.

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Chapter 9
Modelling the Economic Impacts of Epidemics in Developing Countries Under Alternative Intervention Strategies

Nicholas Geard, James A. Giesecke, John R. Madden, Emma S. McBryde, Robert Moss, and Nhi H. Tran

Abstract Modern levels of global travel have intensified the risk of new infectious diseases becoming pandemics. Particularly at risk are developing countries whose health systems may be less well equipped to detect quickly and respond effectively to the importation of new infectious diseases. This chapter examines what might have been the economic consequences if the 2014 West African Ebola epidemic had been imported to a small Asia-Pacific country. Hypothetical outbreaks in two countries were modelled. The post-importation estimations were carried out with two linked models: a stochastic disease transmission (SEIR) model and a quarterly version of the multi-country GTAP model, GTAP-Q. The SEIR model provided daily estimates of the number of persons in various disease states. For each intervention strategy the stochastic disease model was run 500 times to obtain the probability distribution of disease outcomes. Typical daily country outcomes for both controlled and uncontrolled outbreaks under five alternative intervention strategies were converted to quarterly disease-state results, which in turn were used in the estimation of GTAP-Q shocks to country-specific health costs and labour productivity during the outbreak, and permanent reductions in each country's population and labour force due to mortality. Estimated behavioural consequences

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(severe reductions in international tourism and crowd avoidance) formed further shocks. The GTAP-Q simulations revealed very large economic costs for each country if they experienced an uncontrolled Ebola outbreak, and considerable economic costs for controlled outbreaks in Fiji due to the importance of the tourism sector to its economy. A major finding was that purely reactive strategies had virtually no effect on preventing uncontrolled outbreaks, but pre-emptive strategies substantially reduced the proportion of uncontrolled outbreaks, and in turn the economic and social costs.

Keywords CGE · Disease modelling · Ebola · Developing countries · Asia-Pacific

JEL Classification: C68, D58, I15, H51

9.1 Introduction

The Ebola outbreak which began in West Africa at the end of 2013 became by far the most severe Ebola epidemic to date. At the time we began the research reported in this chapter in late 2014, fears were held of exponential growth in infections in West Africa and the spread of the virus to other countries around the world. Fortunately, over the succeeding months the situation stabilised and by late 2015 the epidemic, which had cost over 11,300 lives, appeared over. As the Ebola emergency faded, there was an increasing focus on learning lessons from the outbreak in order to improve preparedness for any subsequent outbreak of Ebola, and of other emerging infectious diseases (EIDs) in general.

The research reported here was part of a 2014–15 study of the risks and consequences of Ebola spreading to certain developing countries in the Asia-Pacific region (McBryde et al. 2015). In this chapter, our concern is with the part of the study that examined the economic consequences that might have occurred if the disease had spread to two of these Asia-Pacific countries. Our estimations were carried out with two linked models: a stochastic disease transmission model and a multiregional dynamic computable general equilibrium (CGE) model of the world economy (a 9 industry, 15 region, quarterly version of the GTAP model, GTAP-Q). In this chapter, we report on simulations for two small countries, Fiji and Timor-Leste (East Timor).

Modelling the economic consequences of epidemics and pandemics forms an important component of preparing contingency plans for possible new outbreaks. In recent years there have been a number of such CGE studies, both with global CGE models (e.g. Lee and McKibbin 2004; Verikios et al. 2016) and national CGE models (e.g. Dixon et al. 2010; Verikios et al. 2012). Some of these CGE studies use historical disease data in developing the economic shocks in modelling actual outbreaks. In order to model on-going or hypothetical outbreaks, disease models are a good method for estimating the possible course of an outbreak. Verikios and his co-authors use versions of the long-established SIR epidemiological model to estimate infection numbers for a hypothetical H1N1 epidemic in Australia (Verikios et al. 2012) and possible global influenza pandemics (Verikios et al. 2016).[1]

To date, CGE modelling of pandemics has primarily been of strains of influenza and viral respiratory diseases, such as SARS. Compared to these diseases, Ebola is characterised by a considerably longer delay between infection and symptom onset, an increasing degree of infectiousness as the disease progresses in the individual, a much longer period for an outbreak to reach epidemic proportions, and a much higher fatality rate (around 70% if untreated).

The difference in the time course of Ebola from those EIDs modelled to date raises a very different set of issues on response and intervention. Pandemic influenza outbreaks are much more likely to be self-limiting than a large Ebola outbreak, which in the absence of an effective response has the potential to cause larger scale, more damaging outbreaks.[2] Another difference relates to prophylactic behaviour. Crowd avoidance can decrease influenza transmission, but has a more limited effect in the case of Ebola for which there is no airborne transmission.[3] On the other hand, Ebola is transmitted by contact with blood or bodily fluids of an infected person, even after death (at which time the viral load is at its height). An effective Ebola transmission reduction response, therefore, includes a public education program informing of the dangers of cultural practices that involve long delays in burial and intimate contact with dead bodies.

In this chapter, we outline the approach taken to capture these distinctive features of an Ebola outbreak. This is reflected in the disease model developed for the study and the link with the CGE simulation. For a detailed discussion of the disease model, see Annex B of McBryde et al. (2015).

In Sect. 9.2.1, we describe the disease model; a stochastic SEIR-type model with additional compartments designed to capture essential features of Ebola transmission and proposed interventions. The model contains the key features of Ebola transmission described above, plus an explicit representation of the healthcare workforce capturing their varying exposure risks compared to the general population and their importance to impact control, the effects of local responses (e.g. hospital- and home-based isolation, tracing and monitoring of contacts and health capacity constraints), potential for interventions to assist early detection and case assessments, and behavioural modifications (e.g. safer burial practices).

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[1]The Susceptible-Infected-Removed (SIR) epidemiological model was first developed by Kermack and McKendrick (1927) and there have been many versions, usually involving more disease compartments over the past nine decades. SEIR models contain an extra compartment, E (Exposed).

[2]Influenza outbreaks (even pandemics) tend to be contained (at least in terms of greatest impact) to a single season, while the West African Ebola outbreak showed little indication of seasonality, and hence could have been anticipated to persist for a longer duration. Prior to its 2013–2015 West African outbreak, Ebola outbreaks had also been self-limiting, mostly due to their occurrence in very isolated rural regions of Africa.

[3]The portrayal in the media of Ebola as an unfamiliar and "horrific" disease may well mean that it has had greater impact on the public's perception than influenza. It might thus be anticipated that there is a stronger behavioural response in respect to international tourism and trade.

An important feature of our disease modelling is that it is stochastic, rather than the deterministic modelling used in previous CGE exercises. This choice is driven by our stronger focus on the very early stages of a potential outbreak, and whether it is likely to occur or not, and what can be done to contain it at this stage, rather than assuming (as is more typical with influenza) that the outbreak will occur and then explore the effect of longer-term control strategies in containing the size of the outbreak.

These features of the disease model have implications for the CGE component of the modelling. The stochastic nature of the disease modelling allows probabilities to be put on the different CGE scenarios modelled. Also, the treatment of the relationship between behavioural responses and transmission probabilities allows aspects of the CGE modelling to be tied to disease modelling. For instance, costly crowd avoidance behaviour forms an important CGE shock, but due to its general ineffectiveness in transmission prevention, typical crowd avoidance behaviour does not impact on the disease model.

The structure and parameters of the SEIR model are based on published literature, including data stemming from the 2013–2015 West Africa outbreak and past outbreaks in Central Africa (e.g. Chowell and Nishiura 2014; The WHO Ebola Response Team 2014). Important aspects of the social and healthcare systems of the target countries were then incorporated using a combination of expert consensus, literature review and analysis of global datasets.

9.2 The Models

9.2.1 The Disease Model

9.2.1.1 The Compartments

We start by describing our compartmental model of infection used to simulate the dynamics of an Ebola outbreak. We build this up in three stages, commencing with Stage 1, the basic model of compartments prior to detection of the disease, as depicted in Fig. 9.1. Here, since at the start of the 2013–2015 outbreak there was no available vaccine and limited potential for prior immunity, all individuals are initially classed as susceptible to infection (S). After infection, a person enters a latent incubation stage (E), from which they subsequently transition to an infectious, but not yet symptomatic, state (I^0). At the time they develop symptoms (I), the person's infectiousness increases. Post-infection, individuals either recover with probability (1 minus the case fatality rate, CFR), and cease to be infectious (R), or die and remain infectious (D) until buried (B).

The outbreak is seeded with a single exposed individual, who we assume to be an active Ebola case who has travelled, undetected, from a region where Ebola is currently circulating. Susceptible individuals can then be infected by either

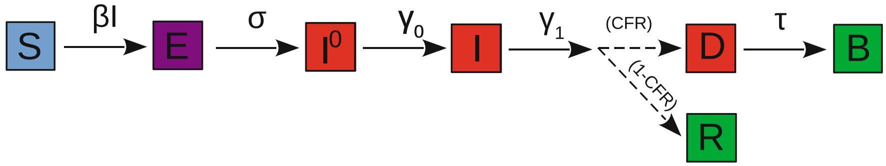

Fig. 9.1 Basic Ebola disease model

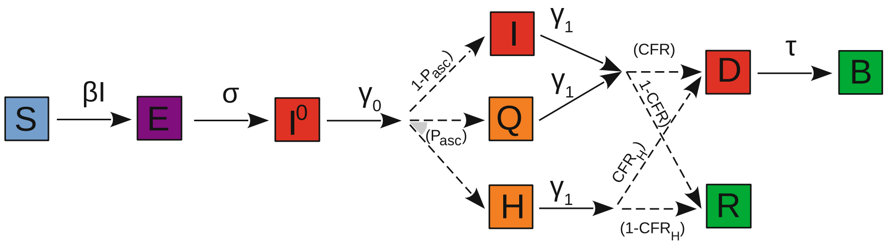

Fig. 9.2 Ebola disease model with isolation in a home (Q) and hospital (H) setting

infectious and pre-symptomatic cases (at rate β_{I0}), infectious and symptomatic cases (at rate β_I) or dead but not yet buried individuals (at rate β_D).[4]

In Fig. 9.2, we add two more compartments to represent the isolation of infectious cases in a hospital or home setting. Once Ebola is detected, future symptomatic cases are ascertained with probability P_{asc}, and subsequently isolated in hospital (H). The hospital-based isolation removes the risk of onward transmission to the general population, lowers the risk to healthcare workers and visitors, and increases the probability of survival $(1 - CFR_H)$.[5] Hospital beds/isolation wards are limited; and any cases ascertained while hospital-based isolation is at capacity are instead isolated in home quarantine (Q), which is assumed to reduce (but not remove) the risk of onward transmission, but not to affect the probability of recovery. Home quarantine is also limited, by a finite stockpile of personal protective equipment (PPE) and training capacity. Once this stockpile is exhausted, all future detected cases remain fully infectious and untreated in the community (I).

The full disease model is depicted in Fig. 9.3 where extra compartments are added to account for contact tracing and monitoring. In Fig. 9.3 monitored individuals are indicated by subscript T. Monitored individuals undergo a similar disease

[4]The parameters σ, γ_0, γ_1 and τ are the rates at which the exposed person becomes infectious, the rate at which the infectious person becomes symptomatic, and the rate at which symptomatic persons recover or die, and the rate at which a dead person is buried, respectively.

[5]In order to capture differences in exposure, the population is stratified into the general community and healthcare workers. Prior to detection the latter are at greater risk, but post-detection they are at a lower risk due to the adoption of stringent infection control measures. These risk differences are incorporated in separate βI parameters for the two groups. It is also assumed that if healthcare workers become depleted beyond a certain proportion all case ascertainment would cease and isolation of cases would no longer be possible.

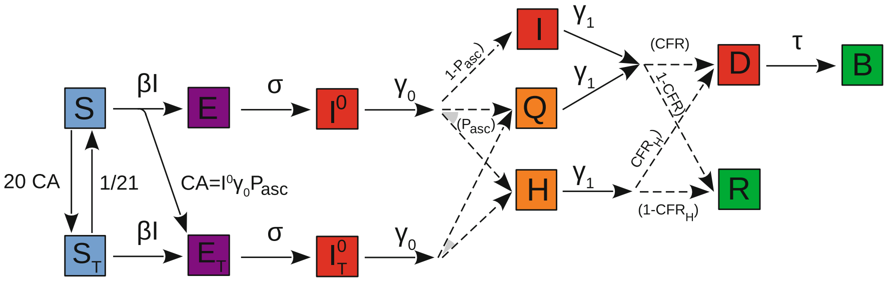

Fig. 9.3 Ebola disease model tracing and monitoring of contacts of ascertained cases

progression to the general community, but are always isolated if they become symptomatic, provided the healthcare capacity persists. For each ascertained case, 20 contacts are monitored for 3 weeks, subject to capacity constraints.

9.2.1.2 Interventions

We compare several types of intervention:

(a) Improved surveillance, which may reduce the time to first Ebola detection, and/or increase the probability of ascertaining subsequent cases.
(b) Increased isolation capacity (hospital-based and/or home quarantine/PPE), increasing the number of cases that can be isolated and/or traced and monitored.
(c) Increased healthcare workforce, reducing the probability of depletion and collapse of the healthcare system.
(d) Improved hospital facilities (disease treatment), reducing the case fatality ratio of hospitalised cases.
(e) The introduction of safer burial practices, decreasing the delay between death and burial (τ) and/or reducing the rate of transmission per day from deceased cases.

We conduct alternative simulations based on the timing of these interventions: either deployed *pre-emptively*, prior to detection of the first Ebola case or *reactively*, at some point after first Ebola detection.

9.2.1.3 Patches

We model Ebola transmission and control in one or more *patches*, each corresponding to a single region within a country. We divide Timor-Leste and Fiji into two patches each—one urban, representing Dili and Suva respectively, and one rural, representing the remaining areas of each country. The numerical values of parameters differ between patches to capture regional differences in population density (crowded living conditions in urban slums can increase transmission rates), quality of healthcare (size of healthcare workforce and number of hospital beds) and cultural differences (e.g. with burial practices). The patches are linked together by estimated daily people movement flows.

9.2.1.4 Simulation Outputs

The disease model is run stochastically to capture the distribution of possible outcomes arising from a small *initial* number of cases in a fashion that allows for the possibility that an outbreak would fail to occur, even in the absence of any response, simply due to initial cases recovering or dying without onward transmission. The model tracks the number of people in each disease compartment and is updated in discrete time steps of 1 day. At each time step, the number of people leaving each compartment is sampled from a Poisson distribution with a mean equal to the deterministic outflow rate for that compartment. Where there were multiple outflows from a compartment (e.g. from infectious (I) to dead (D) or recovered (R)), the number of people leaving was divided between the two destination compartments by sampling from a binomial distribution. Due to the stochastic nature of the model, each scenario was run 500 times to provide a probability distribution over possible outbreak sizes. We classify these outcomes into three broad categories:

- Stochastic fade out: Due to chance, insufficient people are infected for transmission to become established and the outbreak ends with fewer than 10–15 cases.
- Controlled outbreak: Transmission becomes established, but the local response and/or external intervention are able to limit the spread of infection and the outbreak ends with 100–500 cases (<0.1% of total population infected over 2.5 years).
- Uncontrolled outbreak: Transmission becomes established and grows to the point where the local response and an initial external intervention of the scale explored in this project are unable to prevent the continuing spread of infection, resulting in a substantial fraction of the population becoming infected during the outbreak.

As noted above, multiple realisations of the model were simulated for each scenario. For the purposes of CGE modelling, representative single realisations were selected from each of the Controlled and Uncontrolled Outbreak categories. These selections were made by choosing the realisation for which the final outbreak size was closest to the median final outbreak size for that category. Table 9.1 shows the proportions of simulations for each country by each intervention scenario that resulted in controlled outbreaks (first and third results column) and in uncontrolled outbreaks (second and fourth columns).

The results here are generated by multi-patch simulations. External interventions are of a pre-specified size, are triggered by detection of the outbreak, and are deployed in the capital; there is no adaptive response to outbreak conditions, and no "follow-up" interventions should control of the outbreak not be achieved. Beyond

Table 9.1 Percentage of simulation runs resulting in controlled/uncontrolled outbreaks

	Fiji		Timor-Leste	
	Controlled	Uncontrolled	Controlled	Uncontrolled
Baseline	0	100	0	100
Reactive Small	0	100	0	100
Reactive Large	0	100	0	100
Pre-emptive Small	27.4	72.6	90.5	9.5
Pre-emptive Large	29.7	70.3	90.8	9.2

the change in burial practices, there is no adaptive change in population behaviour in response to outbreak conditions.

Table 9.1 excludes those simulations that resulted in stochastic fade-outs, which occurred in around 30% of cases. It can be seen that if the disease does not fade out that both reactive interventions, just as in the no-response baseline, result in uncontrolled outbreaks in 100% of cases. Only if interventions are pre-emptive are a proportion of outbreaks controlled.

9.2.2 The Economic Model

9.2.2.1 GTAP-Q

Given the quick rate at which global pandemics can spread, it is important that their economic effects are modelled dynamically with each period being considerably shorter than the annual basis upon which most dynamic CGE models are conducted. Consequently, Verikios et al. (2016) developed a quarterly version of the GTAP model (Hertel and Tsigas 1997; Ianchovichina and McDougall 2012), which we refer to here as GTAP-Q.[6] We use the theoretical structure of the GTAP-Q model for the present study of the economic impacts of Ebola.

The development of GTAP-Q required the introduction to the standard version of GTAP of two dynamic mechanisms. These relate to capital accumulation and labour market adjustment. The first of these ensures that a regional industry's capital stock at the start of a period is equal to its capital stock at the beginning of the previous period plus gross investment less depreciation during the previous period. Regional investment in a period is an increasing function of the region's expected rate of

[6]Quarterly models are particularly important when pandemics involve short and sharp peaks in their effects (see Verikios et al. 2016, p. 2). Thus, even an outbreak that is quickly contained might have a particularly disruptive effect for at least one quarter as a result of aversion behaviour. The consequent adjustment problem is likely to be missed if the impact on, say, tourism is averaged out over a year. Similarly, a rapid medical response to Ebola in a single quarter is likely to place considerably greater stress on the health system than a similar size response spread over the course of a year (a similar point was made by Dixon et al. (2010), with reference to an H1N1 outbreak).

return relative to the global rate of return. The second dynamic mechanism relates to the incorporation of a lagged wage adjustment process. In simulating the impact of an event, or policy change, a gap may open up between the demand and supply of labour in a region. The wage adjustment mechanism imposes sluggish movement in a region's wage rate such that it only slowly returns the regional labour market to equilibrium. Thus, short-run labour market responses to a shock (like Ebola) tend to be mainly expressed as changes in the unemployment rate (with little change in average wage rates from baseline), whereas long-run responses tend largely to be expressed as changes in average wage rates (with little change in unemployment rates from baseline). GTAP-Q is parameterised so that the deviation from baseline in excess labour demand or supply is eliminated in approximately 20 quarters.

Running simulations with a dynamic CGE model, like GTAP-Q, requires two simulations. The first simulation involves a baseline forecast driven by quarterly business-as-usual forecasts for certain variables with which the model is shocked.[7] The baseline simulation then computes the changes in all other variables consistent (in terms of the model's theory and database) with these outside forecasts. In the second simulation, normally referred to as the policy simulation, the model is run again with an *additional* set of shocks to reflect the particular policy, or event being analysed. The cumulative deviations between the results from the policy simulation and the baseline simulation thus represent the effects of the policy or event.[8] It is such deviations from baseline, which are reported below as the impact of the events (i.e. regional Ebola outbreak scenarios) modelled.

9.2.2.2 Adapting GTAP-Q for Modelling Asia-Pacific Developing Countries

The GTAP database allows flexibility with the countries and industries that are separately identified in the model. The GTAP-Version-9 database contains the required multi-regional input–output data for 140 regions and 57 sectors. The 140 regions comprise 121 individual counties, plus 19 regions, which each cover a group of countries. Neither of the two countries for which we model hypothetical Ebola outbreaks is included as a separate country in the 140-region GTAP database. Fiji is amongst the 23 countries that form the region "Rest of Oceania", while Timor-Leste is included in "Rest of Southeast Asia" (along with Myanmar).

A major task, therefore, was to separate out these two countries (plus PNG, which was also modelled in the full study) from their respective regions. Only a limited amount of data is available for these countries, with the World Bank, UNSTATS

[7]Where possible these are driven by macroeconomic and demographic forecasts from outside experts and trends in tastes and technology. For this study, the baseline forecast is driven by estimates for future quarterly movements in GDP and population for each of the model's regions.

[8]For the technical details on dynamic CGE policy analysis (such as the necessary changes to model closure between baseline and policy simulations), see Dixon and Rimmer (2002).

and the US Central Intelligence Agency being the major sources. Using this data, we employed estimation procedures developed by CoPS for splitting out countries from composite regions (i.e. from regions of more than one country) that generate the required multi-country input–output database (including international trade flows). For details of the procedures, see Horridge (2011).[9]

The outside data required to perform the regional disaggregation include:

- Value added, by industry, for Fiji, PNG and the remaining 21 countries in Rest of Oceania.
- Value added, by industry, for Timor-Leste and Myanmar in Rest of Southeast Asia.
- Value of international exports and imports by commodity for the countries within the two original composite regions.

As many of the 23 countries in the Rest of Oceania are very small, data for them are often not included in a single data source. Therefore, we have combined data from the following sources:

- UNSTATS: statistical databases from the United Nations Statistics Division. These include Commodity Trade Statistics Database (COMTRADE), and national accounts statistics on GDP and value added for industries at the one-digit level for both countries in Rest of Southeast Asia, and for 14 out of 23 countries in Rest of Oceania[10].
- The CIA World Factbook and World Development Indicators, which contain GDP and three broad sectors (agriculture, industry and services) for almost all countries in the world.

These data are used by the SplitReg program to calculate the shares of all countries within each of the original composite regions (Horridge 2011). For each relevant composite region, the program then uses these shares to split the region's original GTAP input–output data into a region of focus and a residual region. This generates the required multi-regional input–output data for the composite region's new sub-regional structure.

The outcome was a GTAP-Q model comprising 15 regions, each containing 9 industries. The 15 regions consist of 6 separate countries (Australia, New Zealand, Fiji, Papua New Guinea, Timor-Leste and Indonesia) plus 9 multi-country regions (China and Hong Kong, Rest of Asia and Oceania, the United States and Canada, Rest of America, Europe, Middle East, West Africa, Rest of Africa and Rest of the World). The 9 industries are agriculture, fishing and forestry;

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[9]The procedures are carried out using the SplitReg program available from the Centre of Policy Studies archive at www.copsmodels.com/archivep.htm#tpmh0105

[10]The countries not covered by UNSTATS are American Samoa, Northern Mariana Islands, Pitcairn, Tokelau, United States Minor Outlying Islands and Wallis and Futuna.

mining; manufacturing; utilities; construction; trade; transport; other services; and government, education and health).[11]

9.2.3 Linking the Models

We conduct GTAP-Q simulations for the Ebola outbreak scenarios examined in the disease modelling for each of the four focus countries. From the disease modelling there are potentially 20 types of outbreaks, 10 for each country. These can be seen in Table 9.1 that shows for each country, and for each of 5 intervention scenarios, the proportions of outbreaks that result in small (controlled) outbreaks, and in large (uncontrolled) outbreaks. As noted in Sect. 9.2.1.3, for both Fiji and East Timor, baseline and reactive interventions result in 100% of outbreaks falling entirely into the uncontrolled outbreak category. This reduces the number of CGE simulations to be undertaken to 14.

For each outbreak scenario, we use as input to the economic modelling daily figures for disease prevalence by treatment and mortality for a representative outbreak event. This information from the disease modelling includes daily figures for prevalence, distributed among those persons hospitalised, those isolated in home quarantine and those fully infectious persons remaining in the community untreated.[12] It also included figures for the number of deaths and the number recovered on each day.

These figures were used to compute for each quarter, the number of hospital days and the number of days of home isolation. The daily figures were further disaggregated by persons of working age and non-working age. Applying participation and employment rates allowed the computation of working days lost each quarter due to illness—under the assumption that once a person becomes sick (infectious) they are (in non-fatal cases) either absent from work, or at work but largely unproductive, until 30 days after recovery.

9.3 The GTAP-Q Simulations

The disease model results discussed in Sect. 9.2.3 formed the basis on which to estimate the direct costs of each Ebola outbreak modelled: medical costs; reduced productivity through sickness, carer activities and quarantine; and a permanent reduction in a country's workforce through Ebola fatalities. We also use the information, particularly that of outbreak size, to estimate economic shocks

[11] The model is kept to 15 regions in order to facilitate the analysis of the economic effects within the focus regions themselves, and the degree of spillover of economic effects to regions not experiencing the hypothetical outbreaks.

[12] That is, distributed into the categories H, Q and I as defined in Sect. 9.2.1.1.

resulting from behavioural effects that an outbreak is likely to induce.[13] Such shocks include aversion effects impacting on inbound and outbound (international) tourism, disruption to freight and passenger transport and a reduction in consumption associated with avoiding public places.

9.3.1 Increased Demand for Medical Services

The estimation of the quarterly medical costs of Ebola required the computation for each country of the daily costs of hospital-based isolation and treatment, of home-quarantine treatment, of case-tracing, Ebola testing, cleaning and burial costs.[14]

In order to estimate hospital costs in each focus country, we commence with daily hospital costs in each of the four countries, plus some comparison countries. These are shown in the first three columns of Table 9.2 for three categories of hospital. The daily hospital cost for treating Ebola cases in the United States is reported in the media to be between $8000 and $24,000. We assume a typical US hospital cost for Ebola of $16,000 per day. We then estimated the daily hospital cost to treat Ebola in a focus country as equal to the daily US hospital cost for Ebola multiplied by the ratio of normal hospital costs in the country to normal hospital costs in the United States (shown in the last three columns of Table 9.2).

This method yielded the following hospital costs (in $US):

	Per day	Per case
Fiji	$919	$5512
East Timor	$82	$494

Other medical costs were estimated as (1) Ebola tests—$US 244 per test; (2) contact tracing—$225 per infectious case and (3) burial and sanitation—$404 per death. For home isolation cases, it is assumed the household is provided with a personal protection kit, and some elementary training in its use. The cost of the kit and training is assumed to be $48 per case.

[13]The World Bank (2014) state that fear of contagion can cause both private persons and governments to undertake behaviours that disrupt trade, travel and commerce. They note that it is believed that such behavioral effects are believed to have been responsible for up to 80% or 90% of the economic effects of recent pandemics (SARS and H1N1), citing Lee and McKibbin (2004).

[14]At this stage, we do not include ambulance services as an extra cost, but rather assume that this is incorporated within hospital costs for Ebola cases.

Table 9.2 Daily hospital costs

	Unit hospital cost estimates ($), may include drug or lab costs			Ratio to the United States		
	Primary-level hospital	Secondary-level hospital	Teaching hospital	Primary-level hospital	Secondary -level hospital	Teaching hospital
Australia	1483.61	1547.76	2001.33	1.01	1.01	1.01
Fiji	84.64	88.30	114.18	0.06	0.06	0.06
PNG	21.12	22.03	28.48	0.01	0.01	0.01
Timor-Leste	7.59	7.92	10.24	0.01	0.01	0.01
Indonesia	43.67	45.56	58.91	0.03	0.03	0.03
United States	1474.12	1537.87	1988.53	1.00	1.00	1.00

Source: World Health Organisation

9.3.2 Reductions in Productivity and Workforce

It was assumed that one working day was lost for each day an employed person was symptomatic, and if they recovered for an additional 30-day period after that—representing the estimated time before they are fit to return to work. Following Verikios et al. (2011), these lost days are treated as reductions in labour productivity. That is, we assume that employers continue to make payments to Ebola-stricken persons by way of sick leave or incur other equivalent costs, and thus suffer an increase in their real unit (of output) labour costs during the lost days.[15]

We also assume that workdays are lost due to workers having to stay at home to care for Ebola patients, and to family members of Ebola patients having to undergo a period of home quarantine.

Little information on which to estimate lost-carers days was available. We made estimates using a Fijian example of patient employment status and household composition as a rough guide. Fiji is estimated by 2015 to have an average household size of 4.5, of whom on average 1.6 persons are employed (including in subsistence activities), 0.7 persons are engaged solely in home duties. 1.3 persons are under 15, a third of a person is over 14 and engaged in full-time study, and the remainder is unemployed, retired, etc. We consider separately Ebola patients who are employed and those not employed, and by whether they are hospitalised, quarantined at home, or are untreated and then estimate whether they require care, and/or quarantine, by household members who are employed. Clearly, there are many other factors that might affect the amount of carer leave taken, and our estimates should be considered very broad indeed. We estimated on this basis that on average a lost workday by an employed Ebola sufferer involved the loss of a further 0.4 workdays for a carer/quarantined person in treatment, or an additional 0.2 days for an untreated person.[16] For an Ebola patient (in treatment/quarantine) who was not in employment in the quarter, we estimate that for every sick day, an additional 0.7 days are lost. For non-employed untreated patients the additional lost days are half that. The reason for the greater number of lost days when the patient was not in work prior to becoming ill is that there are fewer available non-working family members to care for them (and a greater number of employed family members quarantined). When a patient died from Ebola, it was assumed that an additional 3 person-days were lost by grievers.

In the case of the death of persons of working age, we impose negative shocks to both the nation's population and its workforce size. In the case of Ebola-related fatalities of persons of non-working age a permanent reduction to population only is imposed.

[15]This assumption is unlikely to be of any significance for the results reported in Sect. 9.4. It simply means that the cost of sick (and carer) leave is born entirely by owners of capital.

[16]The smaller workdays lost for an untreated patient is based on the assumption that this does not result in the quarantining of any other family members.

9.3.3 Behavioural Effects 1: A Reduction in International Tourism

A well-known effect of pandemics is its impact on international tourism (e.g. McKercher and Chon 2004). Verikios et al. (2011), citing Pine and McKercher (2004) and Wilder-Smith (2006), consider that regions undergoing a widespread influenza epidemic could incur reductions in inbound tourism in the range of 20%–70% during the peak infection period. Given the reports in the media regarding the reaction of international tourists (including government and airline travel restrictions) for the current West Africa Ebola outbreak, we assume that reductions in inbound tourism are likely to be at the high end of estimates reported in the literature. We assume, for both Fiji and Timor-Leste, a reduction of 50% in inbound tourism for a controlled outbreak, and an 80% reduction for an uncontrolled outbreak. These reductions are assumed to commence in the quarter that the outbreak is announced, moving to the full size of the assumed reduction by the next quarter. It is assumed for all countries that outbound tourism from the affected country falls in line with reductions in income. International tourism is assumed to begin to recover only after no new infections are observed in the affected country.

9.3.4 Behavioural Effects 2: Crowd Avoidance

Just as international tourists are likely not to visit countries with Ebola outbreaks, persons living in affected countries are likely to experience a significant fear of contagion. While, unlike international tourists, most residents must remain in the affected country, they are likely to avoid crowds where this is possible.[17] This necessarily means a reduction in expenditures that involve mixing in large crowds (e.g. large sporting and cultural events, markets and crowded retail precincts, public transport). Dixon et al. (2010) assume a 10% reduction in leisure purchases for a hypothetical H1N1 outbreak in the United States. Congressional Budget Office (2006) assumes a similar size reduction, but more concentrated; a 20% reduction in such purchases for one quarter.

Ebola outbreaks are likely to be longer lasting, and possibly generate more fear, than recent pandemics. In light of this, the above estimates may be considered a lower bound for the case of an Ebola outbreak. It is difficult, however, to ascertain the degree to which crowd avoidance for a United States pandemic might translate for developing countries analysed here. We modelled crowd avoidance for

[17] Much of this type of behaviour can be considered sensible measures to avoid contagion. However, McKercher and Chon (2004) claim that in the case of SARS there was evidence that behavioural changes greatly exceeded this. Schulze and Wansink (2012) find that in that responses to perceived risk are more proportional where deliberation is possible, but disproportional for emotional or stressful situations.

uncontrolled outbreaks as though there were a 10% impost on purchasing outputs from service sector—that is, from Trade, Transport and Other Services. We include transport on the basis of the findings of Becker and Rubinstein (2011) that the “Al-Aqsa” Intifada terror attacks reduced bus tickets purchased by up to 9% in the subsequent week.[18]

9.3.5 Behavioural Effects 3: Increased Trade Costs

Insufficient information was available to ascertain whether freight and port costs on merchandise trade to and from an infected country would be materially affected, or by how much. No effects of this type were modelled.

9.4 GTAP-Q Simulation Results

In this section, we report simulation results for the effects of the 7 Ebola outbreak scenarios described in Table 9.1. We describe the economic effects of outbreaks in each country in turn, showing the time paths for the effects on GDP of the different outbreak scenarios in one figure and the time paths for the employment effects in a second figure. For each figure, the time paths are shown in terms of the percentage deviation from the baseline forecast for the variable (GDP or Employment) which results from the outbreak scenario.

9.4.1 A Fijian Outbreak

Looking at Fig. 9.4 we see the time paths of the effects on GDP from the seven outbreak scenarios for Fiji. The time paths break into two identifiable groups: those for the two controlled outbreaks and those for the five uncontrolled outbreaks. Both controlled outbreaks involve pre-emptive action. The effects of both these scenarios follow an extremely similar time-path. The disease modelling showed a similar cumulative incidence over the four quarters of the outbreak for these scenarios, although there is some difference in their time path, with the prevalence more spread out (with more hospitalisation) under the slower/larger reactive intervention. However, the direct effects on GDP of the disease (increased medical costs, reduced productivity and reduced labour supply) are very small. It is the behavioural effects

[18] A number of other behavioural reactions are not modelled. Examples include absenteeism from work as a crowd avoidance response, and lost days by parents needing to undertake child care as a result of school closures (as occurred in West Africa).

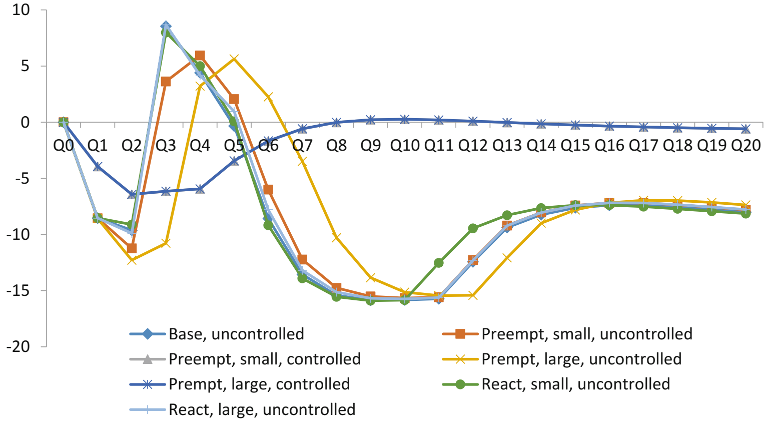

Fig. 9.4 Effects of different scenarios on Fiji's real GDP (percentage deviation from baseline)

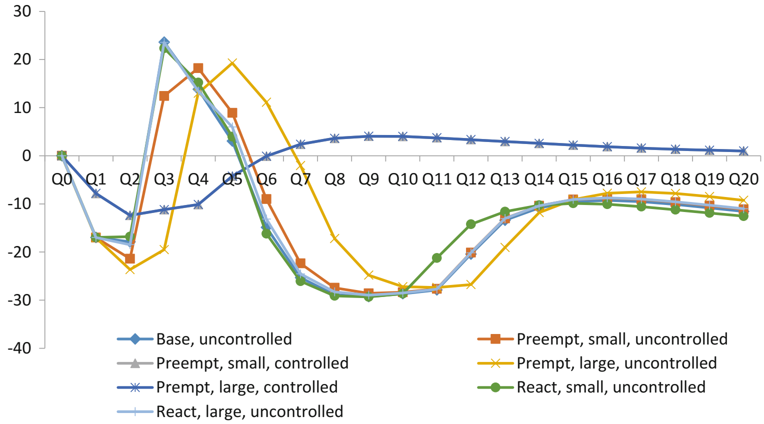

Fig. 9.5 Effects of different scenarios on Fiji's employment (percentage deviation from baseline)

caused by the Ebola outbreak, which are responsible for nearly all of the GDP and employment impacts for these controlled outbreak scenarios. On the news of an Ebola outbreak in Fiji, it is assumed that international inbound tourism demand falls below baseline by almost 30% in the first quarter (Q1) of the outbreak; and by the second quarter (Q2) it is assumed that tourism demand falls further—to 50% below baseline demand (see Sect. 9.3.4). This results in GDP falling (relative to the baseline) by over 6% by Q2 for the two controlled outbreaks.

In Fig. 9.5, it can be seen that employment moves above baseline for 3 quarters from Q3 (or Q4 for the pre-emptive large outbreak) in the uncontrolled scenarios, and then from Q6 (or Q7 for the pre-emptive large outbreak) slowly move back towards baseline, and ultimately reaches a new equilibrium below baseline, over the remaining quarters of the simulation. The initial over-shooting of employment for the 3 quarters is the result of interaction between the path for the wage rate and the path for the imposition and then attenuation of the direct economic consequences of the outbreak. Over the first two quarters in particular, as the direct effects of the outbreak are imposed on the Fijian economy, the real wage partly accommodates this by falling below baseline. Hence, when the direct effects of the outbreak attenuate over subsequent quarters, the real wage is temporarily below the level consistent with the return of the unemployment rate to baseline, leading to transitory employment overshooting.

Looking further at the uncontrolled outbreak cases, it can be seen that GDP and employment are negatively affected during the first two quarters of the outbreak due to adverse behavioural effects. For uncontrolled outbreaks, international tourism by Q2 is 80% below its baseline value, and the tourism sector represents around a quarter of the Fijian economy. By the third or fourth quarter, however, infections and their associated medical costs have risen enough to raise aggregate demand to a level sufficient to move GDP above baseline. The real wage (which moved below baseline with reduced tourism in the first two quarters) begins to adjust, however, to move resources towards the expanded medical sector. As medical expenditure peaks, increases in the real wage and negative movements in labour productivity put downward pressure on GDP and employment. By around Q10 GDP is about 16% below baseline for most uncontrolled outbreak scenarios, and employment around 29% below.

From Q11 to Q13, however, the end of the uncontrolled outbreaks sees international tourism demand commence its return towards baseline. This causes a smaller negative deviation in GDP over the remaining quarters of the simulation. By Q20, we see that employment is permanently below baseline, reflecting the reduction in the labour supply accompanying Ebola mortality.

9.4.2 A Timor-Leste Outbreak

The effects of seven Ebola outbreak scenarios on Timor-Leste's GDP and employment are depicted in Figs. 9.6 and 9.7.

Unlike Fiji, controlled scenarios have only a small effect on the Timor-Leste economy. The direct impacts are small and Timor-Leste also has a relatively small tourism sector. Since crowd avoidance is not modelled for controlled scenarios, there is little by way of behavioural effects from the controlled outbreaks.

For the case of uncontrolled outbreaks, crowd avoidance causes a small reduction in aggregate demand in the first two to three quarters, before rising health costs results in a demand-induced increase in GDP in the next few quarters. After that, the labour market effects and the peaking of health expenditure results in increasing negative percentage deviations in GDP and employment from around Q6 to Q8 (depending on the time path of the direct effects of the uncontrolled outbreak). By Q20, GDP is about 3% below its baseline forecast value. This reflects the long-run

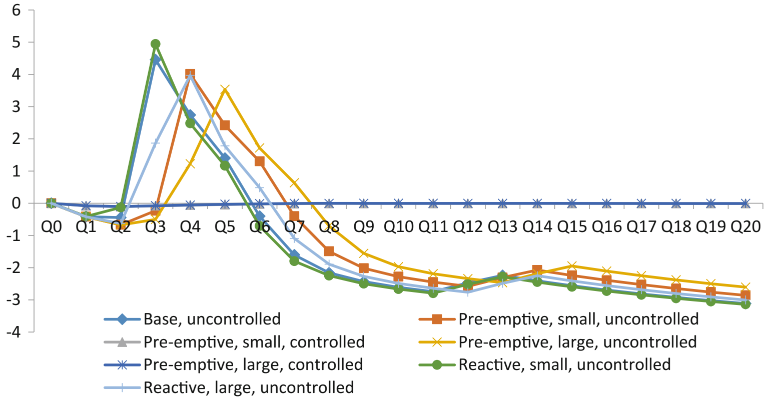

Fig. 9.6 Effects of different scenarios on Timor-Leste's real GDP (percentage deviation from baseline)

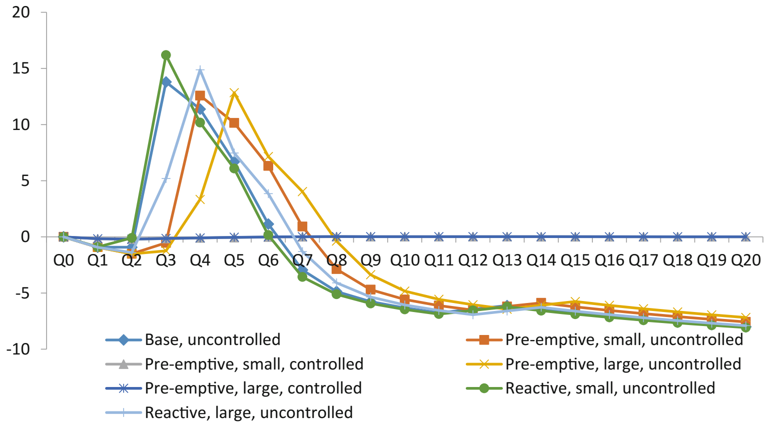

Fig. 9.7 Effects of different scenarios on East Timor's employment (percentage deviation from baseline)

fall in employment (about 6% relative to baseline) due to Ebola mortality reducing labour supply.

9.5 Concluding Remarks

In this chapter, we report the economic effects of hypothetical Ebola outbreak scenarios for two illustrative examples of developing countries in the Asia-Pacific region, Fiji and Timor-Leste. The simulations revealed very large economic costs associated with uncontrolled Ebola outbreaks, and in the case of Fiji, considerable economic costs even for small outbreaks, due to that country's substantial reliance on international tourism.

The simulations were conducted over 20 quarters, with outbreaks commencing in the first quarter. While controlled outbreaks generally lasted only 3–5 quarters, and large outbreaks generally finished within 11–13 quarters, the economic effects were projected to last for a longer period. While the economy returned to close to its baseline forecast within the period modelled for those controlled outbreaks lasting only a few quarters, for uncontrolled outbreaks the economic effects extend beyond the 20 quarters of the simulations. For the large outbreaks, Ebola deaths reduced labour supply below baseline by as much as 18% by the end of the outbreak, but by Q20 there was insufficient time for labour–market adjustment to reduce employment by the same degree. Nevertheless, even for the period modelled, the economic impacts of large outbreaks on GDP and employment are large. For Fiji, the present value of the reduction in GDP over the 20 quarters is of the order of $1.7 billion for the five large outbreak scenarios.[19] Furthermore, simulations were conducted under the assumption that affected countries borrowed to cover increased medical costs during the outbreak.[20] The present value of the increase in Fiji's external debt over the period is around $1.1 billion to $1.2 billion for the large outbreak scenarios.

The international tourism sector comprises about a quarter of Fiji's economy. A substantial portion of the cost for that country's economy is due to the contraction in this sector during the outbreak. Timor-Leste experiences large outbreaks infecting about the same proportion of its population as Fiji and has a population about one third larger than Fiji. However, with a much smaller tourism sector, Timor-Leste is projected to experience falls in GDP relative to baseline of the order of around $0.7 billion to almost $1.0 billion.

The direct effects of controlled outbreaks are small, and such outbreaks have only a negligible effect on the Timor-Leste economy, where the behavioural effects have limited impact. However, while the tourism reduction is smaller in Fiji for a controlled outbreak (50% rather than 80%), it still is sufficient to result in a negative impact on the nation's GDP for seven quarters; starting at almost 4% below baseline in Q1 before falling to almost 6% below baseline for the next three quarters, and then gradually returning to the baseline over the next three quarters. Since there are few deaths for controlled outbreaks, they cause little in the way of permanent effects on the Fijian economy. However, the temporary tourism reduction does have a negative impact on the country's trade balance for the period it lasts. The present value of Fiji's increased debt is just over $0.3 billion.

The shocks for each CGE scenario were formed on the basis of simulation outputs of a stochastic disease model. This allows us to place probabilities on whether an outbreak is controlled or uncontrolled for each intervention scenario. Thus, assuming there is no stochastic fade out, all reactive interventions result in uncontrolled outbreaks. In the case of Fiji between 27% and 30% of small and

[19]Dollar values are in USD.

[20]The reduction in Fiji's tourism exports also acts to increase the country's external debt.

large pre-emptive interventions, respectively, are estimated to result in controlled outbreaks, while for Timor-Leste pre-emptive interventions result in just over 90% of outbreaks being controlled. Thus, our linked disease-CGE model points to the importance of pre-emptive measures in improving the chances of reducing the substantial economic costs, as well as the human costs, of an uncontrolled Ebola outbreak if an infected person were to enter either of the illustrative countries examined.

It should be borne in mind, however, that while the economic and human costs for uncontrolled outbreaks are shown to be extremely high, these results should be viewed from the perspective that we assume no further response—either innate behaviour change by the population or additional external intervention—to escalating outbreak conditions. While such responses are likely, the range and complexity of potential effects require model development and parameterisation that are beyond the scope of this chapter.

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Part II
Issues in Environment, Energy, Risk Management, and Economic Development: Japan's Perspectives

Chapter 10
Critical Factors Affecting the Socio-economy of Japan: An Introductory Essay to Part II

Yoshiro Higano

Abstract This is an introductory essay to Part II, Issues in Environment, Energy, Risk Management, and Economic Development: Japan's Perspectives. What had caused and directed the current situation which Japan now faces is briefly explained focusing on factors which are taken in the chapters as critical ones considering the future of the Japanese economy and society. Strong points of the analysis are highlighted in terms of theoretical as well as experimental contributions to the body of knowledge in the fields of regional science.

Keywords Socio-economy of Japan · Declining birth rate · Population aging · Climate change · Risk of natural disasters

10.1 Japan's View on the Socioeconomic Structure and Critical Factors in the Past, Present, and Future

Since the collapse of the asset-inflated bubble economy in the late 1980s through the early 1990s, the recession of the Japanese economy with deflation had continued so long time. We had experienced several alternate phases between the recovery and recession and almost zero or even negative economic growth rate with the crisis of deflation and higher unemployment ratio. Although a huge amount of non-performing loans of *banks* accumulated during the bubble economy was disposed of by 1997, the Japanese economy had not yet recovered from the impacts by the collapse of the bubble economy till the early 2000s. We had experienced economic booming during 2002–2008, one of the longest periods after the Second World War. Some argue it was a result of the structural reform by the Koizumi cabinet though the risk of deflation was rather increased. In the late 2000s, the recovery was pausing

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and just when it was about to turn to the booming a little in the very early 2010s though it was fragile, the Japan was hit by the Great East Japan Earthquake on March 2011.

When the second Abe Cabinet has started on December 26, 2012, it was highly expected that the Japanese economy would be able to attain economic recovery and overcoming the deflation thanks to so-called Abenomics that was the name given to the principle of monetary and fiscal policy adopted by the cabinet though it was also predicted that the damage by the Earthquake on the Japanese economy would be huge and continue so long time. Though the average economic growth rate was 1.2% that is lowest and therefore lower increase rate of wages compared to the growth rates attained in other booming periods, a longest booming period has been continued since 2012 by keeping the unemployment rate stably lower. Someone argues Abenomics was successful and others not as usual.

To change the view, several factors other than up and down or twists and turns policies and politics must be taken into account when we consider the Japanese economy in the long run. Most influential and critical for Japan are (1) continual declining birthrate that has started in 1970s and recently the total fertility rate is changing around 1.41 stably, which is a little bit higher than the critical value, 1.30; (2) population aging that has started, and been accelerated since 1970s, too, and the rate of aging (the percentage of people older than 65) now become greater than Western countries such as Germany, France, Sweden, the United Kingdom, and the United States; (3) impacts of climate change due to increasing GHG emission; and (4) risk of the great earthquakes, other natural disasters, infections, etc. in near future.

The continual falling birthrate and aging cause declining of regions because the phenomena are most typical and critical in localities. The falling birth rate causes a shortage of labor supply and crisis of the pension system in future that is worsened by aging. The countermeasures to the falling birthrate and aging taken by the Japanese Government are basically to create a work environment that is friendly to anybody.

Though an effective protocol has not yet concluded among the Parties in COP, it is the top must for people on the earth considering recent meteorological phenomena that ought to be taken as the climate change due to the GHG emission. The commitments of promise to reduce GHG emission must be strict and decisive for all the countries for any decision making and stricter for Japan because the nonfossil-oriented energy ratio is now lowest among developed countries. The basic act on the energy policy of Japan was basically dependent on nuclear energy since the 1960s and now the operations of most of the nuclear power stations in Japan have been stopped after the Earthquake in 2011. In this sense, the Great East Japan Earthquake had damaged the Japanese economy by destructing the economy physically as well as will damage it through the coming stricter commitment to the reduction in GHG emission.

Japan is likely to experience many disasters such as typhoon, earthquake, tsunami, etc. It is forecasted that at least three big earthquakes, Great Kanto, Tokai, and To-Nankai Earthquakes, that are almost the same scale as the Great East Japan

Earthquake will hit Japan in near future with a probability of 40% to 70% according to the observed cycles in the past. Though forecasted damages due to climate change themselves are huge, climate change and earthquakes will make bad impacts on each other. For example, damage by tsunami becomes worse due to rise in sea level, huge landslide due to heavy rain is triggered by an earthquake, etc.

Part II contains chapters contributed by colleagues and former students of Professor Yuzuru Miyata. In each chapter, an insightful analysis is developed focusing on one of or some of the above-mentioned factors and research topics are rich in variety as Professor Yuzuru Miyata's research topics were in the major fields of regional science such as regional environment, environmental policy, national account of economy and environment, computable general equilibrium analysis, and risk assessment.

10.2 Is Population Agglomeration Compatible with Economic Development and GHG Emission Reduction?

In Chap. 11, A. Otsuka (2020) has conducted a novel analysis of the question. It is one possible way for the Japanese economy to grow stably that we rely on the city development thanks to agglomeration economies, though some regions have to increase risk of declining. However, in case the answer to the question is yes, it is one possible way for making economic development and GHG emission reduction compatible in the sense that it can at least postpone the critical timing predicted by IPCC.

Based on a regression model of panel data with 47 Japanese prefectures from 1990 to 2010, changes in energy efficiency in industrial (energy consumption per value added) and residential sectors (per floor space) are explained with independent variables of socioeconomic factors such as residential floor area, capital–labor ratio, population density, real income per capita, and energy price. The generalized method of moments is adopted and it enables identification of short- and long-run effects of significant factors. The results show that the most sensitive factor to improve energy efficiency is population density in both residential and industrial sectors, which derives an answer of yes to the above question, and the effects are strongest in larger metropolitan areas including the Greater Tokyo Area. Next sensitivity in the industrial sector is increase in capital–labor ratio caused by mechanization of the production process and the effects are observed in all prefectures.

10.3 Does Technological Progress Resulted in by Research and Development (R&D) Investments Make the Japanese Economy Stably Grow?

Since 1970s when Japan had experienced the first and second oil shocks and heavy environmental pollution and whenever Japan had to face economic crises due to internal and external factors, it has been argued that uninterrupted technological progress in the production process and the society can enable stable economic growth of Japan by keeping competitiveness of industrial sectors in the international markets.

In Chap. 12, Y. Kunimitsu (2020) has constructed a spatial dynamic computable general equilibrium model (SD-CGE model) and developed a novel analysis of the question focusing on the coming era of declining population. The technological progress is simulated in terms of increase in the total factor productivity. It is endogenously dependent on (1) the private and public knowledge capital, which is defined as the accumulation of R&D investments for the pre-specified period in the past; and (2) the public capital stocks of social infrastructure including agricultural base facilities like irrigation and drainage canals. Parameters of the model are calibrated based on the social accounting matrix (SAM) that was estimated using the inter-regional input–output table with 9 regions (Districts) of Japan in 2005. The simulation is conducted with (1) two reference cases of with population declining (rate is 0.4% per year) and constant; and (2) cases of endogenous growth with R&D investments; for the period of 37 years from 2014 to 2050.

The results suggested that impacts of technological progress that may be enhanced by R&D investments make the trajectory of Japanese GDP upward and in 2050 GDP is raised by 11% compared to case of no technical progress. However, the effect is not so strong compare to impacts of population decline which make the trajectory downward and decrease GDP by 23% compared to the case of constant population. This implies that an answer to the question is no contrary to expectation. Even, the technological progress itself may be delayed due to population decline. Another interesting result is that technological progress may enhance disparities in terms of per capita GDP between individuals as well as regions though per capita GDP may increase even with case of population decline.

10.4 Future of Agriculture in Japan

Drastic changes in the agricultural policies in Japan were historically triggered by several socioeconomic internal and external factors. A typical and most decisive one which basically shaped the current agriculture industries in Japan was the farmland reform, a kind of emancipation of farming land, enforced by the occupation army, GHQ, during 1946–1948, just after the end of the last Second World War. Other examples were elimination of agricultural subsidiary policies, which moderately met the requests by manufacturing industries responding to every request by the United States to increase import of agricultural products in the 1960s (agenda items of the trade friction between Japan and the United States were color TV, iron, and steel), 1970s (automobile), and 1970s–1980s (semiconductor).

Another typical one was rice riot. The rice production in Japan was critically dependent on the weather condition before the last Second World War. The rice riots in 1890 and 1897 were triggered by increase in rice prices mainly due to the bad crop of rice in previous years. On the other hand, the rice riot in 1918 was triggered by a sudden increase in rice prices due to the rice corner by rice merchants as well as withholding of rice by farmland owners. Cause of the last one was slightly different from the former two though they were all called as "riot," the basic factor for the three rice riots was that the productivity of rice had been kept low even after the Japanese economy had taken off compare to the smooth economic development of other sectors. Implicit factors behind the low productivity were: (1) negative and inactive attitude of farmland owners, who should have had taken initiative actively against investments in improvement of agricultural infrastructures such as irrigation system, R&D investment in rice production and (2) agricultural protection policies taken by cabinets for the benefits of farmland owners, etc. The rice riot in 1918 was most influential and biggest in the sense that Terauchi cabinet had resigned and Hara cabinet had started to expand political freedom a little bit. After that, the Government had actively committed to and taken initiatives in improvements in agricultural infrastructure and R&D investments in rice production technologies.

Mt. Pinatubo had erupted in June, 1991, and it is generally thought that the average temperature in summer in 1993 was decreased by 2–3°C compare to a normal year caused by the eruption. The bad crop of rice in 1993 due to the record-breaking cold summer, was the worst one after the last Second World War. It had caused social disorder such as (1) corner and withholding of rice, and (2) different type of business like a major electronics retail chain had entered in the rice market that has been systematically regulated and ordered by the Government based on Staple Food Control Act and had started to sell black-rice market rice at a reduced price. This social disorder is called Heisei rice riot, because drastic changes in agricultural policies had happened afterward just the same as the above-mentioned three rice riots before the last Second World War, though nothing violent meant by "riot" had happened. A typical change was acceptance of request for import liberalization of rice during the Uruguay Round in 1994, which meant abandonment of the sanctuary. Another one was elimination of the Staple Food Control Act by putting the New Act on Food Control into effect in 1995. After the new Act was enforced, two rice distribution channels coexist which are regulated and not regulated by the Government. The latter distribution of rice is influential since anybody (individuals or companies) can produce rice and sell it in the markets through the rice distribution channel that is not regulated by the Government. This has caused decreasing trend of the rice price in the market jointly with the liberalization of import rice. To foster large-scale rice farmers was the direction of the agricultural policy taken against the liberalization of import rice and the pressure by the trade negotiation since 1990s, it seemed that the policy had failed again due to unexpected rapid decrease in the rice price.

Chapter 13 is a short chapter written by H. Isomae (2020) focusing on the future of the agricultural industries in Japan. It can be said that agricultural policies taken by the Government since the Second World War pursued to increase productivity of rice per land in order to sustain livelihood of many small farmers that were generated through the farmland reform. Rice had been the main crop for farmers so long time because (1) the government had put emphasis on the production of rice since rice is the food staple in Japan and shortage of the supply immediately causes social disorder; and (2) rice is, therefore, an advantageous crop for farmers irrespective of the productivity of land which must be dependent on local weather and water supply conditions since the government provided huge subsidies directly and indirectly for the production of rice and the price of rice, with which the government bought out all the rice supplied by farmers, was fixed and renewed every year through negotiation between the farmers and the government considering the economic situation as well as rice harvest prospects. The selective breeding of rice robust against cool weather damage and usage of pesticides and herbicides was successful in a sense. Mechanization of the rice production with land improvement projects in which the Government invested a huge amount of money every year was successful, too, in that such policy contributed to labor productivity but not successful in that it less contributed to land productivity than expected. It was a natural result in a sense as it can be said the land productivity of rice with the conventional way had been almost saturated. The next policy was the development of large-scale farmers of any crops including rice. This reflected declining birthrate and aging population, which are especially critical in localities as abandoned fields due to no successors become social issues. Although the acquisition of agricultural land by judicial persons had been strictly regulated by the agricultural committee established in each municipality under Agricultural Act after the agricultural land reform, the purchase and acquisition of paddy fields by the judicial person, which is named as—agricultural judicial person, was admitted and even promoted by the agricultural committee after elimination of Food Staple Act. The increase in the abandoned fields due to no successor in localities enhances the acquisition by the agricultural judicial person. However, it is still unclear whether sustainability of agriculture will be secured in the future in Japan. Impacts of (1) further liberalization of imports of crops on the domestic crop markets and (2) typhoon and flood, abnormal weather like cold summer and warm winter, and plant disease on crop loss due to climate change; are unknown.

Supposing possibility of the next "rice riot" which may again change the agricultural policy in Japan, H. Isomae, having an insightful view, argues effectiveness of the application of artificial intelligence (AI) technology to the large-scaled agricultural production in terms of land area that is currently in progress in a rapid pace reflecting issues of abandoned agricultural fields. In his view, the expansion of the scale of agricultural land must meet a saturating point (around 10 ha) in terms of increase in land productivity and/or profitability, especially due to difficulty in the fertility management. However, such a saturation point can be extended to a practically useful point thanks to the application of AI technologies. Actually, unattended operation of agricultural machines like tractors, medicine sprayers, harvesting, and processing machines combined with GIS are currently about to be utilized in practice. Replacement of the conventional internal combustion engine by the motor of renewable energy may further contribute to labor-saving as well as decrease in GHG emission.

10.5 Recovery Process of the Supply Chain Cut Off by the Earthquake

Having experienced the Great East Japan Earthquake, we had acknowledged vulnerability of the production system that was dependent on the global supply chain and the international logistics in the globalization of economy because the production had to be stopped just parts were unable to be provided to the assembly line due to the cutoff of supply chain caused by the earthquake. Such vulnerability was reacknowledged with the assembly line of automotive and electronics industries in Thailand as well as other countries in Asia including Japan were stopped due to the flood in Thailand in October, 2011.

In Chap. 14, H. Shibusawa and R. Hanaoka (2020) simulate the recovery processes of economy in 57 municipalities of Aichi Prefecture after the Great Tokai Earthquake strikes. Mainly focusing on possible disconnection of supply chains within Aichi Prefecture due to decrease in production (including shutdown), they have developed a novelty model in order to simulate the bad impacts by the cutting-off of supply chain on the recovery process of production in the municipalities. Due to the data availability, they constructed inter-*municipality* input–output table of the noncompetitive import type using the 2011 Aichi Prefecture Input-Output Table. Damage due to the (partial or total) disconnection of the supply chain within Aichi Prefecture, where the automobile cluster is organized center on the factories of Toyota company, is direct one if shortage of the supply is not substituted by imports from outside of Aichi Prefecture. Of course, such substitution cannot be made in the short run. Such bottleneck of the production is gradually cancelled by assuming that the shortage of the supply of intermediate goods compares to those required for meeting the production level at the normal time (case of without the earthquake) in this year is supplied by imports from other regions than Aichi Prefecture in the next year. Though production level at the normal time is fixed (or cannot grow and is kept) with the level at the time when the earthquake strikes, the gradual bottle-neck cancellation increases the production level and again shortage of the supply occurs, which is cancelled in the next year, and so on.

Though the dynamic recovery process from the damage of social and private capital stocks is not explicitly treated in the model, it is rather a novelty of the article in that it enables the analysis only focus on the production. No need for endogenous treatment of the allocation of value added (gross products), i.e., the composition of final demand in the model and shortage in the final demand (especially consumption if critical) is implicitly assumed to be fixed via other ways, e.g., transfers. The production level to be recovered is the level when the earthquake strikes. Of course, nobody knows when it happens. However, the model is of linearity and when it happens and, therefore, which level of the production to be recovered does not matter as far as the model is concerned. This enables analysis of the recovery process without being bothered by knowing or predicting when it strikes.

In the coastal area of Aichi Prefecture, factories of the automobile cluster as well as Nagoya Port and Mikawa Port that is the main port of automobiles in Japan, are located. The damage caused by the tsunamis, which damage the production facilities in the coastal area, is specified in terms of rate of decrease in the production compared to the production that is attained at the virtual normal period when the earthquake strikes. The damage rates (the maximum is 100%) are estimated based on the hazard map of the Aichi Prefecture. Scenario analysis, which also substitutes the explicit treatment of the recovery process from the damage, is conducted with three cases: (1) Basic Scenario: the damage rate recovers by 10% every period; (2) Optimistic Scenario: the damage rate recovers by 20% every period; and (3) Pessimistic Scenario: the damage rate does not change (does not recover) ($\alpha = 0$). It is logically natural result that the recovery process is faster in case of Optimistic Scenario (the production will recover to the level of the normal time within 7–8 years) than Basic Case (11 years) and the production will not recover forever with case of Pessimistic Scenario. However, the results show that during the recovery process with any scenario, the production of manufacturing sectors in municipalities of the coastal area becomes zero quickly after the earthquake and the recovery is made at a slower pace. Damages due to the bottleneck of the supply chain on the whole economy in Aichi Prefecture is critical and huge than expected.

The simulation model is generally applicable to any region as far as inter-regional (or municipalities) input-output table of the non-competitive import type is available with minute regions. It provides useful information for disaster management like tsunami before it attacks, which nobody knows when, as well as after that.

10.6 Impacts of Climate Change on the Rice Production and Effectiveness of the Adaptation via Breed Improvement and Organization the Food Processing Cluster of Rice

It is reality that even countries/regions in COP have started to consider adoption of adaptive measures against climate change though the adaptation is not a substantial solution framework against global warming but still effective in a sense in the short run. In Chap. 15, S. Tokunaga, M. Okiyama, and M. Ikegawa (2020) have developed a novel analysis of the effectiveness of the adaptation measures against the bad impacts on the rice production caused by climate change due to the global warming.

As mentioned above, rice is the staple food and people are stick to pleasant rice produced in Japan. One novelty of the article is that they analyze not only loss and recovery in the rice production due to increase in temperature and thanks to the breed improvement, respectively, but also the loss of value added of low-quality rice that is to be produced with the weather condition of higher temperature in western Japan.

Spatial CGE model is constructed with 9 regions of Japan based on the inter-regional input–output table of the competitive import type of Japan in 2005, which is the latest one available. Based on the prediction made by the Japan Meteorological Agency, it is assumed that increase in temperature due to the global warming by 2076–2095 in Japan is 4 degree Celsius on average and it is slightly larger than the average in northern Japan and slightly lower in the western. The rice yield production function, which is dependent on the capital–land ratio of the current period, the land productivity of rice in the previous period, and increase in the mean temperature from April to October, is estimated.

It is shown that the welfare loss due to the climate change which is measured in terms of equivalent variation per (representative) person per year compare to the normal case (without climate change) assuming utility function of Cobb-Douglas type, is larger than expected though the contribution of rice production to GDP is less than 1%. It is a natural assumption that impacts of climate change on the rice production are negative and larger in western Japan. On the other hand, it is positive in northern Japan and biggest in Hokkaido in that the rice production rather increases thanks to increase in temperature. Such a difference in the impacts of climate change will enhance regional disparities in terms of changes in the equivalent variation. Most badly affected regions are Chugoku and Shikoku. The decrease in the equivalent variation is around 1300 JPY (12.00US$). In Hokkaido and Tohoku, the impacts are positive and they are around 200 JPY or so. This implies that the global warming has bad impacts on the economy in the sense that it not only decreases the GDP but also expand disparities between regions in terms of the welfare attained by households.

Adoption of breeding improvement technology in the production of rice, which shifts upward the production possibility frontier of rice in western Japan, of course, recovers the welfare loss to a certain degree though the recovery is not enough to attain the normal case. This result is based on extremal assumption that rice produced under the weather condition of higher temperatures has no value as a staple food. Shortage in the supply of locally grown rice is met by imports from northern Japan where the production of rice of good quality is increased. However, such rice of poor quality still can have value when it is used as input for food processing industries. Currently, rice used as inputs to food processing industry is very limited and mostly old or imported one from abroad. Assuming that "rice" produced in western Japan can be utilized as inputs to food processing clusters, recovery impacts of both breeding improvement technology and the organization of food processing clusters are simulated. The results show that the welfare level is recovered in all the regions but Okinawa, which is composed of small islands remoted from the big four islands of Japan. Especially, the recovery in the Chugoku and Shikoku regions are resounding. Crops varieties are increased by reallocation of capital, labor, and land.

Those results revalidate effectiveness of a sixth industry, which is made through the combination of the primary, secondary, and tertiary industries and therefore there are quite a few successful examples in Japan so far, when it is taken as a countermeasure against bad impacts of climate change as well as a strategy in order to generate further value added in the agriculture sectors.

10.7 Theoretical Analysis of the Control of Nonpoint Source Pollution and Practical Suggestion for the Regulatory System

Traditionally, it has been said that Japan is "Sanshi-Suimei-No-Chi," which means Japan is a place celebrated for its beauty in natural scenery. Environmental degradation had become serious through 1960′ and 1970′ in Japan as the economy developed rapidly on the top priority basis. Strict laws were by adopting international standards or tougher than that. The basic principle that had been generally applied to the claim for loss was changed to non-fault liability in the case of damage due to environmental pollution. As a result, most noticeable and serious environmental issues due to air pollution, toxic heavy metal pollution, noise pollution, etc. were fixed and currently Japan has no issues due to the diffusion of such materials through environmental media. The environmental laws have been effective to control the emission of pollutants with the cases in which: (1) the polluter(s) and its victim(s) can be identified with one-to-one correspondence in every sense and therefore non-fault liability works as a deterrent against emission of pollutants presuming a court battle; (2) at least polluter(s) can be identified with emission of pollutants that cause health damage to human beings and therefore the regulation of total emission shall be forcibly applied; and (3) practically, the cost necessary for the identification, in either case, is within a tolerable amount to common sense. On the other hand, in reality, there exist environmental issues that are unable to be fixed through such environmental laws. Typical one is the deterioration of the water in lake, river, and sea, etc., in which water pollutants are emitted in a dispersed way being linked with land use of spacious areas such as agricultural fields. In those cases, polluters can be known and even the amount of emitted pollutants can be known for almost all cases but it is very difficult or costly to identify the contribution by a certain polluter (pollution source) to the environmental deterioration in a certain specific point or space (e.g., river) where the deterioration had or has happened at a specific time or period. The difficulty is owing to that: (1) polluters' location and places where the deterioration had or has happened are far remoted from each other through space and time; and (2) the mechanism of pollutant transportation is very complex and it cannot be practically identified. Such source of pollution is called as nonpoint source with comparison to point source of pollution, which can be controllable in the above sense (1) or (2) and (3), typically through end-of-pipe policy of the emission standard.

In Chap. 16, A. Matsumoto et al. (2020) have developed a novelty analysis of the control system of nonpoint source of pollution. They have constructed and applied a Cournot three-stage game to the analysis of the regulation system of nonpoint source of pollution. Cournot game implies that firms adjust the quantity of product(s) being given price(s) and each firm behaves in a duopoly market by taking a given quantity of product(s) produced by other firm(s). The analysis developed is based on a simplified model specification and it is informative and thought provoking for consideration of the regulation system of nonpoint source of pollution and related issues in a practical sense.

Two players (firms) emit pollution and the emission monitoring cost is prohibitively high. The government that controls the total emission of pollution to maximize the social welfare with emission tax (ambient charge) that is levied on the difference between the total emission by two players and a certain constant amount, E, prespecified by the government. In case $E = 0$ it means zero-emission policy adopted as it shall be the case with toxic pollutant. A positive E can be interpreted as a total emission standard that is socially acceptable and tolerable that shall be determined based on other criteria/value judgment such as impacts on human health and/or biodiversity. This formulation of environmental tax presumes that the amount of pollution emission by the individual player cannot be known in any sense and case of (2) in the above does not hold. In case the total emission is larger than E, positive tax (a sort of penalty) is charged on each player. In case the total emission is less than E, a reward is given to each player. It seems that such an environmental tax system raises other unresolved issues such that how to finance if the tax becomes negative and how to spend tax revenue if it is positive, if firms would accept the tax system which is based on a kind of joint responsibility, and so on. The most novelty point of the article is that it has shown the tax system works well as designed and the optimal tax rate, optimal emission by firms (optimal selection of technology), optimal quantity of production (maximized profit), and optimal (tolerable) level of damage due to the optimized total emission of pollution can be determined so as to maximize the social welfare through the Cournot three-stage game by controlling tax rate being independent from the value of E. The constant E can be, therefore, equated with the optimized total emission as it is independent from the value of E, which means net tax payment of firms are zero, which suggests effectiveness of the tax system in a practical sense.

With the first stage, the government determines the environmental tax at the optimal level. The government must have information about the structure of the market or markets, production technology and pollution abatement technology if any necessary to be adopted, etc. Or, at least the government must know how firms respond to the tax and eventually how quantity of production and maximized profit, price in the market, consumers surplus, environmental damage, etc. respond to the tax rate while both players attain their own optimality being given the tax rate, etc. It may be costly or practically impossible to know corporate information in a globally competitive situation. An interpretation of the second stage suggests negotiation between the government and an association of firms, which may make introduction of such tax smooth or difficult in a practical sense. As far as the monitoring of the total emission can be precise and is not so expensive, the proposed model can be developed into a dynamic model of an ad hoc and trial and error process without precise information about technology and market(s). Necessary information can be minimized by looking at if the model, in which an ad hoc and trial and error process are built in, can be applied to a practical issue by only identifying general and probable structures of technologies and markets (e.g., emission of pollution increases as production increases; market price increases as demand increases, environmental damage increases as the total emission increases, etc.) that are to be specified in the model. In this sense, the simple specification in the article seems to be enough to be able to be developed into such a model of ad hoc and trial and error mechanism process.

10.8 Assessment of Impacts by Unknown Natural Disaster on Regional Economy with CGE Modelling of Monte Carlo Simulation Informative for the Damage Management

Japan has to face many natural disasters of variety. One of the most issues is that it is unknown when it happens and with what is the scale of damage even if probability of their occurrence may be able to be estimated. Actually, it has been said more than 50 years that a magnitude 6–7 earthquake or greater than that, of which scale is equivalent to the Great Kanto earthquake in 1923, strikes in the Kanto region in near future and it did not so far. It is also said that such a big scale earthquake will strike in Tokyo within 30 years and still nobody knows when and with what scale.

We have experienced that a big scale earthquake will definitely strike in Japan in due course even if its predicted or estimated probability is almost zero. It is a famous story that in 2009–2010 when a government committee discussed about the safety of the nuclear plants in Fukushima prefecture against earthquakes and an expert in the related field pointed out a magnitude 8 earthquake or greater than that, which had stroked in and around Fukushima prefecture in the past, committee members had laughed it down once they knew that it was an earthquake in *869*. To change the view, we should more focus on the damage once a great earthquake strikes. Expected value of the damage becomes almost zero and maybe negligible but the scale of the damage cannot be neglected once it has happened. In case predicted damages and sufferings by the disaster are fatally huge with scale, scope, and time, a kind of min–max principle (minimization of the maximum damage) should be adopted for the disaster damage management.

In Chap. 17, H. Sakamoto (2020), having such a view, has developed a novelty analysis of damages by natural disasters. He has constructed a CGE model based on the 2001 inter-regional input–output table of two regions—Fukuoka and other prefectures. Fukuoka is located in the northern part of Kyushu Island and natural disasters like typhoons and earthquakes sometimes attacked there. Assuming that a natural disaster expected in the future will damage the production factors of capital and labor and distribution networks in and around Fukuoka prefecture, impacts of such damages on the economy of Fukuoka prefecture and other regions in Japan are analyzed.

The damage to the economy is, of course, dependent on the scale of natural disaster. The scale itself even can be taken as an uncertain variable once a natural disaster has attacked. As for earthquake nobody knows with what scale it strikes as well as when and as for typhoon nobody knows the scale of the typhoon till a tropical low occurs and it develops into typhoon. However, based on the events of natural disasters in the past, we can estimate the probability distribution function in the scale of damage.

In Simulation 1, it is assumed that (1) the event probability of natural disaster whatsoever in Fukuoka Prefecture is 50% and the event follows the binomial distribution; (2) the damage ratios against labor and capital in Fukuoka stochastically distributed with the uniform distribution from 0 to 0.08 and 0.40, respectively; (3) the damage ratio against logistics within Fukuoka prefecture has the uniform distribution from 0 to 0.80; and (4) the logistic damage ratio between Fukuoka and other prefecture does from 0 to 0.40. In Simulation 2, 3, and 4, the uniform distribution, half-normal distribution, and triangular distribution (peak and mode = 0) are, respectively assumed with damages on the labor and capital in Fukuoka and the logistics. In Simulation 2, 3, and 4, the average of the distribution is set equal to the average of the distribution utilized in Simulation 1 by adjusting parameters. In order to simulate randomness and uncertainty of disaster occurrence and/or the scale of damage (even if their probability distributions are known), Monte Carlo experiment applied with the given probability distribution functions and the max, min, and average of damage ratios is compared. The Monte Carlo experiments are repeated 500 times with all the simulation cases but in Simulation 1 both stochastic occurrences of disaster and scale of damage are simulated with the Monte Carlo experimental method and, on the other hand, in other simulations it is applied to only the stochastic occurrence of the scale of damage by incorporating the occurrence probability of disaster, 0.50, into the adjustment of parameters with the average in Simulation 1.

The uniform distribution in Simulations 1 and 2 presumes uncertainty of the scale of damage in the sense that the probability distribution of damage scale is unknown though the maximum damage can be predicted based on the past events. Damage more than that could occur, especially with damage on capitals, and the disaster damage management by the local authority has almost no meaning as the economy is almost completely collapsed in that case. The other distributions presume that the probability distribution of damage scale is known and events of smaller damage scale have a larger probability.

As expected, the average of predicted damage ratios of capital and labor and, therefore, simulated damage ratios of real income (GDP) using CGE model, are almost the same between all the Simulations. However, the variance of damage ratios is largest in Simulation 1 and the maximum damage ratio is largest in Simulation 1, too, because Monte Carlo experimental method is applied to not only the prediction of damage scale but also the prediction of earthquake occurrence in Simulation 1. This becomes clearer with comparison between the results of Simulation 1 and Simulation 2 as probability distribution functions of damage scale are same in both Simulations. The most novelty of the article is that the CGE analysis combined with the Monte Carlo experiment provides meaningful and useful information for the disaster damage management in case the min-max principle is adopted and it implies the expected value approach does not work well as designed in disaster management.

10.9 Contributions from Bangladesh

Chapters 18 and 19 are contributions by scholars in Bangladesh. Dr. M. Fakrul Islam and his spouse, Dr. Wardatul Akmam, were my former Ph.D. students at the University of Tsukuba. He had first contacted Prof. Yuzuru Miyata at the Toyohashi University of Technology as a Monbusho Scholarship student and Prof. Miyata had suggested him go to Tsukuba for writing Ph.D. Thesis. Dr. Islam and Dr. Akmam were successful students in Tsukuba and they became youngest Professors in their Departments at Rajshahi University. Prof. Miyata had celebrated their success as if their own children. Dr. Islam is specialized in the social program for the development of Bangladesh and Dr. Akmam is in the improvement of social conditions for children and women. Both chapters are written with different perspectives as social conditions in Bangladesh are fairly different from Japan and their analyses are still insightful for the consideration of the Japanese economy and society in the long run.

It is often said Bangladesh is a riverine country as rivers flow everywhere. The geographical and natural situation of the riverine country is typically characterized as follows: rivers have too much water to overflow when they do not need anymore and less water when they do more. In Chap. 18, M. F. Islam and M. M. Hossain (2020) have conducted a social survey in two villages of Naria Upazila named “Charjujira” and “Condipur” in near River Padma at the Shariatpur district, focusing on the scale and frequency of bank erosion recently occurred, damages by riverbank erosion on the local economy, livelihood of displaced people, government attitude and recovery taken against riverbank erosion, etc. It is found that (1) the frequency of riverbank erosion and the scale of damage is increasing due to climate change; (2) recovery of displaced people is little assisted by governments, (3) it looks riverbank erosion is a minor issue for governments and effective protection is not implemented though local people exposed to the risk anticipates it; (4) displaced people had taken varieties of recovery strategy against damage of riverbank erosion and community of relatives, friends, and NGOs are helpful with the recovery but they are not enough capable; (5) governments should realize socioeconomic conditions of regions exposed to the risk of riverbank erosion and livelihood of displaced people; etc. It is officially reported that the number of deaths, of which cause of mortality can be directly and/or indirectly associated with the Great East Japan Earthquake, has become 3739 as of the end of 2019. Their survey results, as well as the case in Japan, well suggest the necessity of further research in the disaster damage management.

In Chap. 19, W. Akmam, S. L. Hasin, and M. F. Islam (2020) have developed a comprehensive analysis of the vulnerability of people living in places exposure to the risk of river erosion in Bangladesh. Social surveys are conducted in two unions, Kornibari and Kutubpur, within Sariakandi Upazila of Bogra, where the erosion of Jamuna River sometimes hit in the past. Following the definition by IPCC and others, the vulnerability is calculated as the product of sensitivity indicator and the difference between risk exposure and adaptive capacity indicators, in which indicators are each normalized between 0 and 1. Social factors, which are significantly associated with the vulnerability among age, gender, education, income, family composition, etc., are identified using Chi square test.

Results have shown that significant association between the level of vulnerability and (1) age (older people are less vulnerable as expected. Actually, around 90% of the Great East Japan Earthquake-related deaths had reached to 66 years old or more when they passed away); (2) to be solvent (having enough allowance for necessities of daily life), (3) family income, having access to financial institutions, getting help of neighbors, (4) having completed at least five years of schooling (making vulnerability less), (5) having sources of income other than agriculture, and (6) having experienced erosion more than once (This was observed in case of the Great East Japan Earthquake as saying "First priority shall be put on the rescue of him/herself when preparing for tsunami just after the earthquake"). However, contrary to a generally approved hypothesis, especially in a developing country, e.g., in case of the Indian Ocean Tsunami triggered by the large-scale earthquake off the coast of Sumatra, gender was not significantly associated with vulnerability as the percentage of women who have completed at least 5 years schooling is greater than male. These results show the effectiveness of measures conducted as disaster damage management such as disaster education in schools, preservation of disaster site as a kind of visible forethought (may have a different negative effects), etc., which have been reacknowledged and enriched after the Great East Japan Earthquake.

10.10 Conclusion

Research topics in Part II of the book are diversified in terms of fields and methodologies, each chapter provides insightful results that are helpful in consideration of the Japanese economy and society in Japan. Focuses are made on impacts of the critical factors, exogenous or endogenous to Japan, (1) continual declining birthrate; (2) population aging; (3) impacts of climate change; and (4) risk of the great earthquakes and other natural disasters in near future. Professor Yuzuru Miyata had energetically conducted researches on those topics and published many papers and books of meaningful and useful original contributions to the body of knowledge.

Editors sincerely present the book to Professor Yuzuru Miyata as a token of the authors' gratitude to his contribution in the fields of regional science.

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Chapter 11
Energy Intensity and Population Density in Japan

Akihiro Otsuka

Abstract In the Japanese economy, complying with environmental regulations while achieving a balance between greenhouse gas emissions and regional economic growth is an important policy issue. From the perspective of national land policy, spatial agglomeration of populations is a potential solution to this issue. This study clarifies whether population agglomeration, which is a source of economic growth, contributes to the improvement of energy intensity in the residential and industrial sectors by using a dynamic panel model. The use of this model enables a simultaneous understanding of the short- and long-term effects of population agglomeration on energy intensity. The results of the analysis reveal that population agglomeration influences improvements in energy intensity. Specifically, over the observation period, population agglomeration improved energy intensity in large metropolitan areas, including the Greater Tokyo area and the Chubu and Kansai regions. In contrast, for less urbanized areas, population dispersion exacerbated energy intensity. These results suggest that forming population agglomerations will lead to improvement in energy efficiency. That is, they suggest that a compact city policy that agglomerates populations in city centers may be effective in improving energy efficiency across Japan.

Keywords Energy intensity · Residential energy · Industrial energy · Population agglomeration · National land policy

This chapter is based heavily on Otsuka (2018a, b). This chapter rebuilds the empirical model and expands it by adding an analysis of sectoral demand.

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11.1 Introduction

Energy consumption in Japan has been affected by changing lifestyles as well as changes in its social structure; with rising individual incomes, the pursuit of convenience and comfort in daily life has led to an active increase in energy consumption. These energy consumption levels are significantly affected by energy intensity (*EI*) (Otsuka 2017a). *EI* has improved in both the residential and industrial sectors due to more efficient home appliances and the upgrading of factory facilities. However, as a result of increases in the size and diversity of energy-consuming equipment, as well as their rising popularity, overall energy consumption in Japan has grown. Measures for solving the problem of increasing energy demand have focused on promoting energy conservation and improving energy efficiency. In particular, a key issue for Japan's environmentally constrained economy is reducing greenhouse gas emissions by simultaneously achieving higher economic growth and energy efficiency. To this end, the Japanese government has implemented a variety of policies to promote green innovation and renewable energy. However, the immensity of the problem of climate change far exceeds what can be handled with existing technologies. Thus, the Japanese government must promote national land planning by introducing new system designs and modifications and enacting new energy and environmental policies to create a low-carbon society.

From the perspective of national land policy, spatial agglomeration of populations is a potential solution to these problems. In areas where the population is spatially concentrated, the use of multi-dwelling houses allows for more advanced energy efficiency than areas where the population is dispersed. Multi-dwelling houses, such as apartments, are generally concrete structures with narrow rooms and few windows. Thus, their thermal insulation level is higher than detached housing, causing them to waste less energy than detached housing. Additionally, cities with high-density populations have more opportunities to share electric lighting and pool cars. This type of sharing can lead to significant energy savings. Energy markets in cities with high population densities also have fierce competition between power and gas, so there is a greater incentive to supply energy efficiently. The fact that urban agglomerations with high population densities improve energy efficiency has been confirmed by a great number of prior studies (Newman and Kenworthy 1989; Bento and Cropper 2005; Brownstone and Golob 2009; Karathodorou et al. 2010; Morikawa 2012; Otsuka et al. 2014; Otsuka and Goto 2015, 2017; Otsuka 2018a, b).

Furthermore, even in the industrial sector, population agglomeration affects energy efficiency.[1] It has been confirmed that economies with agglomeration have

[1]Traditionally, the economic effects of population agglomeration are explained in the context of production activities (Marshall 1890). Agglomeration economies refer to the improved cost savings and productivity achieved when populations are spatially agglomerated. Many prior studies have found that population agglomeration serves as an external economy for firms (Combes and Gobillon 2015; Otsuka 2017b).

improved energy efficiency and heightened productivity (Otsuka et al. 2014; Otsuka 2019a). Firms held to strict environmental regulations, such as CO_2 reduction obligations, are expected to invest in research and development and improved productivity to maintain their international competitiveness. If firms are spatially agglomerated, the technological knowledge generated by these firms easily spills over to other firms through face-to-face communication and the movement of knowledge workers among the firms. In other words, agglomeration economies serve to create technological knowledge and improve productivity through spillover (Fujita and Thisse 2002). Innovations of this kind emerging under environmental constraints result in the construction of energy-efficient production systems. Porter and van der Linde (1995) indicate that attempts to improve production processes under proper environmental regulations lead to a relative decrease in energy use, which results in improved energy efficiency. Boyd and Pang (2000) have empirically proven that improvement in productivity itself fosters higher energy efficiency. Thus, they stress that energy efficiency acts as a guidepost to productivity improvement.

This study investigates the effect of population agglomeration on *EI* from the perspective of sectoral (end-use) energy demands. This topic has already been studied by Otsuka and Goto (2017) and Otsuka (2018a, b). Otsuka and Goto (2017) focus on the effect of population agglomeration on the overall *EI* of all sectors. Otsuka (2018a) analyzes this effect using a demand function approach, while Otsuka (2018b) employs a stochastic frontier analysis approach. This study uses a demand function approach and clarifies the differing impacts of population agglomeration on *EI* by sectoral demand. In addition, geographical differences in the effects of population agglomeration are quantitatively clarified. The analytical framework of this study adopts a dynamic panel model to ascertain the intertemporal effects of population agglomeration on *EI*.[2] The use of a dynamic panel model enables simultaneous understanding of the short-term (short-run elasticity) and long-term (long-run elasticity) effects of population agglomeration on *EI*. Understanding long-term effects make it possible to assess the impact of population agglomeration on changes in *EI* over time with greater accuracy. This is a distinguishing feature of this study.

This chapter is organized as follows: Sect. 11.2 explains the method and data used in the analysis. Section 11.3, then, presents and discusses the results of the analysis. Finally, Sect. 11.4 describes the conclusions and future research agendas.

[2]Panel data is normally more advantageous than cross-sectional data as it includes a time dimension. Specifically, it has the benefit of increasing observed values and allowing for changes in both cross-sections and time. However, it is incapable of fully grasping the dynamic, long-term effects of the factor variables used in a traditional panel data model.

11.2 Methodology

11.2.1 Determinants of EI

This study focuses on energy demand in the residential and industrial sectors. Below, we analyze the determinants of *EI* in each sector. *EI* in the residential sector is defined as energy consumption per unit of residential floor space, while *EI* in the industrial sector is defined as energy consumption per unit of added value.

The focus of this study is to assess the efficacy of population agglomeration in each sector, which is one of the determinants of *EI*. Prior studies indicate a correlation between population density and energy efficiency, suggesting the possibility that population density raises energy efficiency (Otsuka and Goto 2015, 2017). Based on previous studies, this study adopts inhabitable land population density (*D*) as an index of population agglomeration. Inhabitable land population density is calculated by dividing the population by inhabitable land area.

This study adopts several economic variables to explain *EI*. We use energy prices (*EP*), income (*IC*), and variables for cooling (cooling degree days: *CDD*) and heating (heating degree days: *HDD*) as variables common to both the residential and the industrial sectors.

EP: According to economic theory, energy consumption reduces as *EP* rises. If the energy market is functioning properly, then high energy prices are expected to improve *EI* through more efficient energy use.

IC: According to economic theory, higher *IC* raises energy consumption. If people choose a more energy-efficient residential lifestyle as a result of higher incomes, then a rise in income should improve *EI*. However, if people increase their use of energy-consuming appliances when income rises, then higher incomes will worsen *EI*.

CDD and *HDD*: We adopt cooling degree days (*CDD*) and heating degree days (*HDD*) as the variables for the heating and cooling of air temperature. The more severe the temperature in a region, the greater the energy consumption for heating and cooling. Prior studies indicate that these cooling and heating indexes are related to energy consumption (Metcalf and Hassett 1999; Reiss and White 2008).

Next, appropriate socioeconomic variables are adopted for each sector.

Household members (*HM*): We consider how differences in household members in each region influence *EI* in the residential sector. A larger number of household members may increase the possibility of shared home appliances, and, thus, may reduce *EI*. On the other hand, there is also a high likelihood that a larger number of household members leads to higher energy consumption.

Residential floor space (*FS*): We consider how differences in residential floor space influence *EI* in the residential sector. It is believed that the wider the residential floor space, the larger the waste in energy consumption. In the case of large houses, there is an increase in lighting and home appliances, so the energy consumption per house will increase. Thus, *EI* worsens as residential floor space increases.

Capital–labor ratio (*KL*): We discuss how differences in capital intensity influence *EI* in the industrial sector. Thompson and Taylor (1995) indicate that capital and energy are in a substitution relationship over the short and long term.

Capital stock vintage (*IK*): We discuss how differences in the vintage of capital stock influence *EI* in the industrial sector. Low investment in the replacement of capital stock suggests the possibility of high *EI* in the industrial sector. On the other hand, investment in rapid capital stock replacement may indicate an industry with greater energy efficiency, and, therefore, a lower *EI* is expected. This study uses the percentage of investment to annual capital stock to measure this vintage effect.

11.2.2 Model

This study analyzes the determinants of sectoral *EI* based on the above variables. The basic analytical method involves using *EI* as the dependent variable and socioeconomic factors as the independent variables in the regression analysis.

$$EI_{jt} = b_1 EP_t + b_2 IC_{jt} + b_3 D_{jt} + \boldsymbol{b}_4 \boldsymbol{X}_{jt} + b_5 CDD_{jt} + b_6 HDD_{jt} + a_j + u_{jt}, \tag{11.1}$$

All of the variables in Eq. (11.1) are logarithm values. *J* denotes a region ($j = 1, \ldots,$ J), and *t* denotes time ($t = 1, \ldots,$ T). *EI* is energy intensity. In the residential sector, *EI* represents energy consumption per residential floor space. In the industrial sector, *EI* represents energy consumption per added value. This study assumes six independent variables. *EP* is the energy price in a sector, and *IC* is real household income in the residential sector and real income per capita in the industrial sector. *D* represents population density. ***X*** is a vector representing socioeconomic variables other than price, income, and population density; it represents a matrix containing two other independent variables in each sector. In the residential sector, these are *HM* and *FS*, and in the industrial sector, *KL* and *IK* are chosen. *CDD* represents cooling degree days and *HDD* represents heating degree days. *u* represents an error term.

The difficulty with the regression equation shown in Eq. (11.1) stems from the assumption that *EI* responds immediately to changes in socioeconomic variables. The more plausible assumption is that *EI* is affected by changes in socioeconomic variables, such as energy prices, with a time lag. For example, long-term responses to rising energy prices may include buying replacement home appliances and upgrading production facilities. The effects, in this case, are actualized with a lag in time. Hence, in this study, a partial adjustment model is used to control these effects. However, the partial adjustment model uses lagged dependent variables for the explanatory variables. Thus, there is a correlation between the independent variables and error terms, and a new problem arises in the form of a lack of consistency in the regular ordinary least squares estimates (Cameron and Trivedi 2009). Arellano and Bond (1991) propose the generalized method of moments (GMM) estimation (hereinafter, dynamic panel estimation), which is consistent under such conditions, and is, therefore, used as the estimation method in this study. This estimation method is designed for multiple individual effects and short-term panel data, and it is, thus, applied to the data structure used here.

The following is an estimation model for arriving at a dynamic panel estimate for Eq. (11.1):

$$\begin{aligned}\boldsymbol{\Delta} EI_{jt} = \alpha \boldsymbol{\Delta} EP_t + \beta \boldsymbol{\Delta} IC_{jt} + \gamma \boldsymbol{\Delta} D_{jt} + \delta' \boldsymbol{\Delta} \boldsymbol{X}_{jt} + \phi \boldsymbol{\Delta} CDD_{jt} \\ + \eta \boldsymbol{\Delta} HDD_{jt} + \lambda \boldsymbol{\Delta} EI_{jt-1} + \boldsymbol{\Delta} \varepsilon_{jt},\end{aligned} \tag{11.2}$$

where Δ represents differences. The Greek characters used for regression coefficients in Eq. (11.2) are estimation parameters. Elevated *EP* improve energy efficiency, and, thus, the sign on α is expected to be negative. In addition, elevated *IC* also improves energy efficiency; thus, the sign on β is also expected to be negative. If population density (*D*) improves energy efficiency, then the sign on γ will be negative. The estimation parameter λ represents the impact of past *EI* on current *EI*. In other words, if this parameter is significantly positive, then energy-saving behavior is habitual. This expresses adaptive expectations in energy demand.

Short- and long-run elasticity are obtained from Eq. (11.2). We expect short-term energy demand to respond less to prices than long-term demand. This is because home appliance replacement and behavioral habits regarding energy demand do not change immediately. Some habits, such as turning off electric lights or the stove when leaving the room, can kick in quickly in response to a rise in electricity and gas charges. On the other hand, other actions, such as the replacement of household appliances or renewal of factory production equipment, may take more time. Therefore, we cannot expect rapid upgrading in home appliances or production facilities in response to changes in energy prices. Short-term energy demand may, thus, be isolated from long-term optimal consumption. The demand, thus, does not immediately adjust to long-term equilibrium, but gradually converges to an optimum level reasonable for both consumers and producers.

The static and partial adjustment models of energy demand draw upon this idea of reasonable habits. A static model excludes consumption lag variables from the estimates since it lacks steps for adjusting to energy demand. That is, since there is no connection between consumption at different points in time, there is no delay in the adjustment process. The static model is unrealistic as it assumes that there is no cost to expectations that will affect current decision making. On the other hand, a partial adjustment model incorporates steps taken to adjust to energy demand; therefore, consumption lag variables are considered in the estimates. That is, sluggish adjustment steps are allowed between optimal consumption levels (long-term) and short-term consumption levels, and, thus, we can obtain short- and long-run elasticity by using a partial adjustment model.

11.2.3 Data

The data used for analysis is panel data from 47 prefectures from 1990 to 2010. Although data up to 2015 are available, there is a possibility that a large structural change in energy utilization occurred after 2011 because of the Great East Japan Earthquake.[3] Thus, to obtain a reliable result, we decided to use only data before the earthquake. Energy consumption data for each prefecture is from the *Energy Consumption Statistics by Prefecture* published by the Ministry of Economy, Trade, and Industry. Energy price data are the real energy price indexes of each sector according to the International Energy Agency. Income data are from the *Annual Report on Prefectural Accounts* by Japan's Cabinet Office and are deflated according to consumption deflators per prefecture. Data on population and number of households are from the *Basic Resident Register* by the Ministry of Internal Affairs and Communications. Inhabitable land area data are from the *Social Demographic System* of the Ministry of Internal Affairs and Communications. Residential floor space data are from the *Residential Land Statistics Survey* by the Ministry of Internal Affairs and Communications. Employment data are estimated from the *Annual Report on Prefectural Accounts* by Japan's Cabinet Office. Data on capital investment and capital stock are estimates published by the Central Research Institute of the Electric Power Industry. Data on CDDs and HDDs are from prefectural capitals and meteorological stations. A CDD is the sum of the differences between average daily temperatures above 24 and 22 degree Celsius, while an HDD is the sum of the differences between average daily temperatures below 14 and 14 degree Celsius.

Table 11.1 shows the descriptive statistics of the variables used for analysis. The *EI* in the residential sector averaged 0.42 (GJ/m^2) for all samples, and the industrial sector averaged 21.72 (GJ/million yen). Looking at the time-series variation, *EI* worsened marginally in the residential sector from 1990s to 2000s. The rate of change from 1990 to 2010 was 2.4%. On the other hand, the industrial sector improved greatly in *EI* throughout the observation period. The rate of decrease (rate of improvement) during the observation period was −14.7%.

Energy prices in the residential sector fell sharply from 1990 to 2000, followed by a subsequent rise. The industrial sector also saw a significant rise in 2010 compared to the same time in 1990 and 2000. Residential sector income dropped throughout the observation period, whereas industrial sector income rose steadily. It is highly likely that rising income in the industrial sector contributed to higher *EI*.

Population density rose during the observation period, averaging 1355 (persons/km^2). This indicates intensifying population agglomeration throughout the observation period, and it suggests a high probability that improvement in *EI* in the industrial sector was because of advancing population agglomeration.

[3]See Otsuka (2019b) for structural changes in energy demand associated with the Great East Japan Earthquake.

Table 11.1 Descriptive statistics

		Energy intensity		Energy price		Income		Number of household members	Residential floor area	Capital–labor ratio	Capital vintage	Population density	Cooling degree day	Heating degree day
		Residential (GJ/m^2)	Industry (GJ/ million yen)	Residential (2010 = 100)	Industry (2010 = 100)	Residential (million yen)	Industry (million yen)	(person)	(m2)	(million yen/ person)		(person/ km^2)	(degree day)	(degree day)
	Year	EI	EI	EP	EP	IC	IC	HM	FS	KL	IK	D	CDD	HDD
Mean	1990	0.40	23.57	106.5	80.7	8.60	2.74	3.2	98.3	10.7	0.099	1336	412.8	1047.6
Std. dev.	1990	0.10	19.81	0.0	0.0	1.50	0.52	0.3	19.9	1.8	0.009	1574	162.8	410.8
Maximum	1990	0.72	99.32	106.5	80.7	11.73	4.86	3.7	148.7	14.7	0.118	8456	863.8	2239.0
Minimum	1990	0.28	5.67	106.5	80.7	5.80	1.91	2.4	56.8	7.3	0.071	259	45.4	4.6
Mean	2000	0.44	22.26	88.7	80.4	7.89	2.82	2.8	102.0	16.0	0.057	1350	412.4	1140.2
Std. dev.	2000	0.10	17.61	0.0	0.0	1.21	0.46	0.3	20.0	2.4	0.006	1585	140.1	532.7
Maximum	2000	0.77	81.37	88.7	80.4	11.07	5.10	3.3	152.3	20.9	0.078	8413	839.6	2769.2
Minimum	2000	0.33	5.84	88.7	80.4	5.69	2.03	2.2	59.6	11.1	0.044	260	65.6	3.0
Mean	2010	0.41	20.10	100.0	100.0	7.34	2.93	2.5	100.1	19.5	0.045	1360	492.3	1267.0
Std. dev.	2010	0.08	15.85	0.0	0.0	1.12	0.44	0.2	18.7	3.0	0.004	1679	137.0	466.6
Maximum	2010	0.63	77.80	100.0	100.0	10.00	4.97	3.0	143.0	26.2	0.055	9066	909.0	2591.2
Minimum	2010	0.32	5.24	100.0	100.0	5.27	2.22	2.0	61.0	13.0	0.035	249	124.0	122.2
Mean	1990–2010	0.42	21.72	96.3	86.5	7.86	2.80	2.8	101.1	15.5	0.061	1355	367.0	1106.3
Std. dev.	1990–2010	0.09	16.96	6.7	8.9	1.36	0.47	0.3	19.6	3.5	0.016	1592	175.6	470.9
Maximum	1990–2010	0.80	99.32	110.4	111.5	11.73	5.45	3.7	152.9	26.2	0.118	9066	1186.1	2769.2
Minimum	1990–2010	0.28	5.24	87.5	77.7	4.97	1.91	2.0	56.8	7.3	0.035	249	0.0	0.2

Note: Energy intensity (residential): Energy consumption per residential floor area. Energy intensity (industry): Energy consumption per real gross product. Energy price (residential): Real price index of households. Energy price (industry): Real price index of industry. Income (residential): Real income per household. Income (industry): Real income per capita

Looking at household members, a yearly fall is observed. On average, the number of household members was 3.2 persons in 1990, but this had decreased to 2.5 persons in 2010. The size of the average residential floor space increased between 1990 and 2000, and then decreased somewhat in 2010, but the value remained larger than it was in 1990. It is highly likely that the lower number of household members and increase in residential floor space contributed to the worsening *EI* in the residential sector.

Looking at the capital–labor ratio, the capital intensity increased from 1990 to 2010. This is presumably due to greater mechanization in production processes. Turning our attention to capital vintage (investment–capital ratio), the average during the observation period was low at 0.06; this decreased further in the 1990s and 2000s. It appears that there was not much being done to upgrade production facilities. Based on this, it seems that production plant mechanization contributed to improvement in *EI* in the industrial sector.

Table 11.2 presents the regional characteristics of Japan, as of 2010. *EI* appears to differ considerably across regions. The *EI* in the residential sector is high in regions in eastern Japan—Hokkaido, Tohoku, and Greater Tokyo. These areas generally have cold climates with longer heating days. In western Japan regions, including Chugoku, Shikoku, and Kyushu, the *EI* in the industrial sector is high. These western regions have a temperate climate and a longer cooling day. The real income of the residential sector is high in regions such as Greater Tokyo and Hokuriku; conversely, in large metropolitan areas, such as Greater Tokyo, Chubu, and Kansai, the real income of the industrial sector is high. The house floor area is the smallest in the Greater Tokyo area and largest in Hokuriku. The average residential area in Hokuriku is about twice that of the Greater Tokyo area. The *KL*, which represents the degree of mechanization, is high in areas, such as Chubu, Hokuriku, Kansai, and Chugoku, where factories are located. Population density is high in the Greater Tokyo, Chubu, and Kansai regions.

Figure 11.1 (a, b) plots the relationship of the respective changes in *EI* and population density in the residential and industrial sectors during the observation period 1990 to 2010. We find that in both sectors, changes in *EI* and population density had a negative correlation. This suggests that rising population density might have contributed to higher energy efficiency (lower *EI*).

In the residential sector, population density increased in the large metropolitan areas of Tokyo, Saitama, Kanagawa, and Chiba while the *EI* in those regions decreased. In the industrial sector, areas in Aichi, Chiba, Shizuoka, and Shiga with agglomerated manufacturing, saw *EI* decrease as population density increased. These regions show a simultaneous increase in population density and energy efficiency. In the analysis in the next section, we quantitatively identify the degree to which such changes in population density affected *EI*.

To check whether the first-difference GMM estimator of Arellano and Bond (1991) suits the data, this study employs panel unit root tests. Specifically, the unit root is assumed to be the individual unit root process checking for the stationarity of the variables (Im et al. 2003). If the variables integrated are of order 1 [I (1)], the panel co-integration approach is employed, whereas if they are I (0), the first-

Table 11.2 Characteristics of Japanese regions, FY 2010

Variables	EI (residential)	EI (industry)	EP (residential)	EP (industry)	IC (residential)	IC (industry)	HM	FS	KL	IK	D	CDD	HDD
Hokkaido	0.63	16.81	100	100	5.60	2.69	2.1	80.8	15.1	0.035	248.6	124.0	2591.2
Tohoku	0.48	14.07	100	100	7.18	2.66	2.7	116.6	18.7	0.042	473.5	315.4	1907.7
North-Kanto	0.36	17.95	100	100	8.31	3.16	2.6	103.4	19.7	0.046	799.5	450.4	1407.0
Greater Tokyo area	0.52	22.58	100	100	8.07	3.60	2.3	74.2	19.2	0.046	4907.5	492.5	1060.9
Chubu	0.38	16.65	100	100	8.34	3.18	2.6	107.9	21.4	0.046	1261.1	511.0	1270.3
Hokuriku	0.36	13.13	100	100	8.63	3.08	2.8	136.0	20.8	0.043	727.9	476.2	1522.8
Kansai	0.42	16.62	100	100	7.47	3.07	2.4	92.3	20.9	0.047	2406.8	556.5	1116.0
Chugoku	0.36	39.00	100	100	6.93	2.82	2.5	103.1	20.5	0.045	837.2	539.2	1194.3
Shikoku	0.36	20.36	100	100	6.54	2.75	2.4	95.6	19.1	0.046	832.0	572.4	910.6
Kyushu	0.36	22.64	100	100	6.42	2.67	2.4	89.5	18.3	0.047	837.5	545.1	911.8
Okinawa	0.41	9.99	100	100	5.57	2.22	2.5	69.5	13.0	0.052	1204.4	909.0	122.2

Note: The regional classifications are as follows: Hokkaido (Hokkaido), Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, and Niigata), North-Kanto (Ibaraki, Tochigi, Gunma, and Yamanashi), Greater Tokyo area (Saitama, Chiba, Tokyo, and Kanagawa), Chubu (Nagano, Gifu, Shizuoka, Aichi, and Mie), Hokuriku (Toyama, Ishikawa, and Fukui), Kansai (Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama), Chugoku (Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi), Shikoku (Tokushima, Kagawa, Ehime, and Kochi), Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, and Kagoshima), and Okinawa (Okinawa)

Fig. 11.1 Changes in energy intensity and population density. (**a**) Residential sector. (**b**) Industry sector

Table 11.3 Panel unit root test result

Test variables	Without a deterministic trend	With a deterministic trend
ln EI (residential)	−15.66**	−17.69**
ln EI (industry)	−12.15**	−8.68**
ln EP (residential)	−1.18	6.86
ln EP (industry)	−8.24**	−3.73**
ln IC (residential)	−17.33**	−12.52**
ln IC (industry)	−17.69**	−12.87**
ln HM	−5.64**	−3.15**
ln FS	2.37	−1.22
ln KL	−3.79**	−3.15**
ln IK	−11.37**	−8.50**
ln D	−0.11	−2.73**
ln CDD	−25.36**	−20.08**
ln HDD	−27.23**	−22.01**

Note: The panel unit root test statistic (Im et al. 2003; W-stat) follows a normal distribution, N (0, 1). ** and * indicate rejection of the null hypothesis of a unit root at the 1% and 5% significance levels, respectively

difference GMM estimator is used (Baltagi 2013). The results of the panel unit root tests are shown in Table 11.3. The use of the first-difference GMM estimator is justified because the dependent variable does not have a unit root.

11.3 Results and Discussion

Table 11.4 (a, b) shows the estimation results for Eq. (11.2). There should be no serial correlation between error terms when performing dynamic panel estimates, and a consistent estimator is first obtained when this condition is met. Hence, when performing the tests by Arellano and Bond (1991), although a significance level is allowed with the AR (1) test, there is no significant level with the AR (2) test; that is, it must present no serial connection. From the table, the presence of a two-dimensional serial correlation was rejected for all models. That is, the error terms should carry no autocorrelations. Further, the results of the Sargen-Hansen test of exogeneity for the instrumental variables found that the number of instrumental variables was not excessive, so conditions for the dynamic panel estimate were satisfied.

Let us consider the estimated results. The independent and dependent variables are both logarithm values; thus, the estimation parameters express elasticity. Hence, the larger the estimated value of the parameter (elasticity), the larger the effect of an independent variable on a dependent variable. Whatever the sector, the effects of population density tend to be relatively large compared to the effects of other variables. In both sectors, the effects of population density are the largest.

Table 11.4 Sectoral energy intensity regression in Japan

Dependent variable: Δln EI (*t*)	
Regressors	**Model A**
(a) Residential sector	
Δ ln EI ($t-1$)	0.469 (0.022)**
Δ ln EP	−0.082 (0.010)**
Δ ln IC	0.290 (0.028)**
Δ ln D	−1.018 (0.240)**
Δ ln HM	−0.077 (0.056)*
Δ ln FS	−0.123 (0.126)
Δ ln CDD	0.032 (0.007)**
Δ ln HDD	0.176 (0.022)**
Number of observations	893
J-Statistic	43.023
Prob (J-statistic)	0.303
m-Statistic (AR (1))	−31.215**
m-Statistic (AR (2))	0.906
Instruments	EI ($t-2$)
Regressors	**Model B**
(b) Industry sector	
Δ ln EI ($t-1$)	0.433 (0.012)**
Δ ln EP	−0.015 (0.006)**
Δ ln IC	−0.077 (0.009)**
Δ ln D	−0.253 (0.122)*
Δ ln KL	−0.067 (0.006)**
Δ ln IK	−0.017 (0.006)**
Δ ln CDD	0.008 (0.003)*
Δ ln HDD	−0.001 (0.007)
Number of observations	893
J-Statistic	44.386
Prob (J-statistic)	0.255
m-Statistic (AR (1))	−2.193**
m-Statistic (AR (2))	0.507
Instruments	EI ($t-2$)

Note: Regressions are estimated using panel data for all prefectures. Parentheses are used for standard error. The two-step first-difference GMM estimation method is used, and standard errors are given in parentheses under the coefficients. The coefficients' statistical significance is noted at either the 1% level (**) or 5% level (*). The J-statistic results are obtained from the Sargan-Hansen test of over-identifying restrictions for the two-step GMM estimators. The m-statistics refer to tests for first- and second-order serial correlation

Among the socioeconomic variables, the parameters for energy prices take on a negative sign, and thus, the sign conditions are fulfilled. On the other hand, the parameters for income take on a positive sign in the residential sector and a negative sign in the industrial sector, so the effects upon *EI* differ. In the residential sector, rising energy prices result in higher energy efficiency, while an increase in income worsens energy efficiency. This suggests that higher income leads to greater purchases of large-sized home appliances, which possibly increases energy consumption. In the industrial sector, higher energy prices and income lead to lower *EI*, so sign conditions are met.

Statistically significant results are obtained for household members, but the parameter values are low; thus, they have little effect on *EI*. In addition, the levels for residential floor space are not statistically significant. Since parameters for the capital–labor ratio and capital vintage each take on a negative sign, it is suggested that plant mechanization and facility upgrades improved energy efficiency in the industrial sector. Plant mechanization has an especially large effect on *EI*.

Table 11.5 shows the short- and long-run elasticity for the *EI* of each variable calculated, based on the estimation results shown in Table 11.4. The elasticity of population density is −1.018 (residential sector) and −0.253 (industrial sector) in the short term and −1.917 (residential sector) and −0.446 (industrial sector) in the long term, greatly exceeding the elasticity of price and income. For example, in the residential sector, if population density increases 1%, *EI* drops 1.018% in the short term and 1.917% in the long term. Price and income elasticity are quite small in comparison to population density elasticity, so the economic factors of price and income have little effect on *EI*, compared to population agglomeration. Therefore, promoting the formation of urban areas with higher population agglomeration is found to be a cause of higher energy efficiency in both sectors.

Table 11.5 Elasticities

	Short run	Long run
(a) Residential sector		
Price	−0.082	−0.155
Income	0.290	0.547
Population density	−1.018	−1.917
Number of household members	−0.077	−0.146
Residential floor area	−0.123	−0.231
Cooling degree day	0.032	0.060
Heating degree day	0.176	0.331
(b) Industry sector		
Price	−0.015	−0.027
Income	−0.077	−0.136
Population density	−0.253	−0.446
Capital–labor ratio	−0.067	−0.118
Capital vintage	−0.017	−0.029
Cooling degree day	0.008	0.014
Heating degree day	−0.001	−0.002

Let us quantitatively identify the effects of each determinant of *EI* on changes in *EI* based upon the above results. Assuming long-term equilibrium in a partial adjustment model, Eq. (11.2) maybe expanded into the following:

$$\begin{aligned}\Delta EI_{jt} = \tfrac{\alpha}{1-\lambda}\Delta EP_t + \tfrac{\beta}{1-\lambda}\Delta IC_{jt} + \tfrac{\gamma}{1-\lambda}\Delta D_{jt} + \tfrac{\delta'}{1-\lambda}\Delta X_{jt} \\ + \tfrac{\phi}{1-\lambda}\Delta CDD_{jt} + \tfrac{\eta}{1-\lambda}\Delta HDD_{jt} + \Delta\varepsilon_{jt},\end{aligned} \quad (11.3)$$

The first term on the right is a price factor. The second is an income factor. The third term is a population agglomeration factor. The fourth term is a socioeconomic factor. The fifth is a cooling factor. The sixth term is a heating factor, and the seventh term is another factor (error term). The measurement period is 20 years—from 1990 to 2010. Using Eq. (11.3), it is possible to calculate the contribution of each determinant to overall changes in *EI* (annual average, %).

Table 11.6 shows the results of applying the Eq. (11.3) to the residential and industrial sectors. First, we look at the results for the residential sector. The contribution of population density is largest in the Greater Tokyo area (−0.472%), and it explains most of the reduction in *EI*. Next, this effect is found to be actualized in large metropolitan areas in the North-Kanto, Chubu, and Kansai regions, though not in Okinawa. Thus, urbanization and higher energy efficiency are both found in large metropolitan areas as population agglomeration proceeds. On the flip side, in most non-large metropolitan regions, there is no population agglomeration at work, and the population agglomeration factor does not contribute to lower *EI*. Population dispersal deteriorates *EI*, particularly in Hokkaido, Tohoku, Hokuriku, Chugoku, Shikoku, and Kyushu.

The factors causing a deterioration in *EI* in the residential sector were the number of household members and air temperature. Energy consumption increased, as did the number of single-person households. This effect was seen not only in less urbanized areas such as Hokkaido, but also in large metropolitan areas, including the Greater Tokyo area as well as the Chubu and Kansai regions. Additionally, greater use of heating and cooling during the observation period led to wasted energy consumption, which worsened *EI*. This effect was found in all regions of the country. On the other hand, lower household income during the observation period led to families refraining from purchasing energy-consuming appliances, which very likely lowered *EI*. The Greater Tokyo area and Kansai region, in particular, were greatly affected by the loss in income, which resulted in improved *EI* in the residential sector.

Looking at the results from the industrial sector, the contribution of population density resembles trends in the residential sector. The effects of population density could be found in large metropolitan areas in the Greater Tokyo area and the North-Kanto, Chubu, and Kansai regions. However, the extent of the effects was smaller than in the residential sector. The variable responsible for significant effects in the industrial sector is the capital–labor ratio, that is, plant mechanization. Mechanization led to improved *EI* in almost all regions. This conforms to the results of Otsuka et al. (2014), which indicate that *EI* is low in capital-intensive industries.

Table 11.6 Contributions of each factor to changes in energy intensity (1990–2010; annual averages; %)

(a) Residential sector

	Rate of change of energy intensity (Δ Energy Intensity = a + b + c + d + e + f + g + h)								
	Δ Energy intensity	Energy price (a)	Income (b)	Population density (c)	Number of household members (d)	Residential floor area (e)	Cooling degree day (f)	Heating degree day (g)	Other factors (h)
Hokkaido	−0.702	0.026	−0.270	0.215	0.100	−0.021	0.159	0.128	−1.039
Tohoku	0.575	0.026	−0.193	0.302	0.091	−0.003	0.095	0.148	0.109
North-Kanto	−0.094	0.026	−0.232	−0.053	0.093	−0.028	0.057	0.136	−0.094
Greater Tokyo area	−0.455	0.026	−0.352	−0.472	0.085	−0.043	0.049	0.208	0.045
Chubu	0.058	0.026	−0.234	−0.030	0.087	−0.025	0.033	0.153	0.048
Hokuriku	0.075	0.026	−0.241	0.094	0.085	0.008	0.048	0.192	−0.137
Kansai	0.251	0.026	−0.315	−0.028	0.090	−0.010	0.020	0.150	0.318
Chugoku	0.339	0.026	−0.238	0.273	0.085	−0.009	0.018	0.210	−0.027
Shikoku	0.541	0.026	−0.179	0.316	0.088	−0.011	0.021	0.120	0.160
Kyushu	0.125	0.026	−0.102	0.128	0.088	−0.004	−0.007	0.210	−0.214
Okinawa	−0.464	0.026	−0.159	−0.402	0.101	−0.002	0.008	2.873	−2.909

	(b) Industry sector								
	Rate of change of energy intensity (Δ Energy Intensity = a + b + c + d + e + f + g + h)								
	Δ Energy intensity	Energy price (a)	Income (b)	Population density (c)	Capital-labor ratio (d)	Capital vintage (e)	Cooling degree day (f)	Heating degree day (g)	Other factors (h)
Hokkaido	−0.312	−0.016	−0.028	0.053	−0.156	0.058	0.040	−0.001	−0.263
Tohoku	−0.356	−0.016	−0.039	0.075	−0.222	0.071	0.024	−0.001	−0.248
North-Kanto	−0.293	−0.016	−0.031	−0.013	−0.203	0.067	0.015	−0.001	−0.110
Greater Tokyo area	−0.548	−0.016	0.009	−0.117	−0.173	0.071	0.013	−0.001	−0.333
Chubu	−1.368	−0.016	−0.025	−0.007	−0.203	0.069	0.008	−0.001	−1.192
Hokuriku	−0.658	−0.016	−0.021	0.023	−0.167	0.063	0.012	−0.001	−0.551
Kansai	−0.825	−0.016	−0.006	−0.007	−0.191	0.061	0.005	−0.001	−0.671
Chugoku	−0.266	−0.016	−0.021	0.068	−0.217	0.065	0.005	−0.001	−0.148
Shikoku	−0.913	−0.016	−0.040	0.078	−0.223	0.060	0.005	−0.001	−0.777
Kyushu	−0.708	−0.016	−0.060	0.032	−0.195	0.059	−0.002	−0.001	−0.524
Okinawa	−0.312	−0.016	−0.058	−0.100	−0.193	0.061	0.002	−0.015	0.009

Notes: The growth rate of energy intensity is the finite difference approximation of the logarithm of the annual average. The regional classifications are as follows: Hokkaido (Hokkaido), Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, and Niigata), North-Kanto (Ibaraki, Tochigi, Gunma, and Yamanashi), Greater Tokyo area (Saitama, Chiba, Tokyo, and Kanagawa), Hokuriku (Toyama, Ishikawa, and Fukui), Chubu (Nagano, Gifu, Shizuoka, Aichi, and Mie), Kansai (Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama), Chugoku (Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi), Shikoku (Tokushima, Kagawa, Ehime, and Kochi), Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, and Kagoshima), and Okinawa (Okinawa)

Each factor's contribution was calculated based on the estimated results from the dynamic panel analysis, as shown in Table 11.4

Furthermore, in the industrial sector, higher energy prices led to incentives for efficient energy use and improved *EI*. In the future, if reducing dependence on nuclear power and increasing the introduction of renewable energy remains a goal, then industrial energy prices may rise; thus, *EI* may improve further.

11.4 Conclusion

In light of Japan's energy and environmental problems, determining how to realize improved energy efficiency in the face of rising energy consumption is a critical issue. This study defined the role of population agglomeration in improving *EI* and conducted an empirical analysis of its impact on the residential and industrial sectors from a dynamic perspective.

Firms across Japan are now facing global competition, and, thus, they are pursuing greater energy efficiency through the development of energy-saving technologies. The result has been a continued lowering of *EI* in the industrial sector. On the other hand, the residential sector has not achieved much improvement in energy efficiency; therefore, enhancing it is a crucial task for Japan. Prior studies in Europe and the United States indicate that the more concentrated the population in a region, the smaller the energy consumption of households (Newman and Kenworthy 1989; Lariviere and Lafrance 1999; O'Neill and Chen 2002; Liddle 2004; Bento and Cropper 2005; Brownstone and Golob 2009; Karathodorou et al. 2010). The empirical analysis in this study also indicates the possibility of improving *EI* in areas with dense populations.

Furthermore, this study confirmed differences in the effect of population agglomeration on *EI* depending upon sectoral demand. The effects of population agglomeration were found to be larger in the residential sector than the industrial sector, and they were larger in the long term than the short term. Population agglomeration was definitely a contributing factor to the improvement of *EI* in large metropolitan areas, including the Greater Tokyo area and the Chubu and Kansai regions. On the other hand, *EI* worsened in other regions as a result of dispersed population; this may have impeded improvement in *EI*. In order to improve energy efficiency in these regions, a compact city policy that agglomerates populations in city centers may be effective. In addition, forming such population agglomerations will presumably lead to realizing further improvements in energy efficiency.

Unlike large metropolitan areas, which possess great diversity, other local regions are composed mostly of mid-sized cities with largely uniform industrial structures. These mid-sized cities are able to avoid the problems of congestion associated with agglomeration. Our next topic of analysis will be the relationship between urban scale and energy efficiency. To answer the question of what urban scale is most desirable in terms of achieving a low-carbon society, we must quantitatively ascertain the optimum population scale needed to increase energy efficiency from the perspective of sectoral demand. This future agenda will serve as yet another step toward understanding how best to create a more sustainable economy.

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Chapter 12
Can Japanese Economy Grow Under Population Decline? Evidence from Dynamic Spatial CGE Model with Endogenous Growth Mechanism

Yoji Kunimitsu

Abstract This chapter aims to evaluate the effects of research and development investment under population decline in a matured economy like Japan. Based on the endogenous growth theory, the spatial dynamic computable general equilibrium model (SD-CGE model) is used to concretely show the future situation of Japanese economy. The simulation results are as follows: (1) Japan's GDP will slightly grow owing to technological progress caused by the research and development (R&D) investment, but such technological progress is not strong enough to overcome the negative impacts of population decline in Japanese economy. (2) per-capita GDP becomes higher in the case of population decline than the case of constant population because of an increase in wage rate and labor participation rate. (3) future technological progress will widen regional economic disparities, because most industries in which technological progress is likely to occur are concentrated in the urban areas like Kanto area. Thus, government needs policy measures not only for suppressing population decline but also for revitalizing local economy.

Keywords Technological progress · Research and development investment · Labor participation rate · Regional economic disparity

JEL Classification: O41, R13, R15

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12.1 Introduction

Japanese government aims to achieve 600 trillion yen (5.5 trillion dollars) of gross domestic production (GDP) in 2020, which is 1.13 times higher than the present GDP level. A growth in GDP is not so difficult if population increases in the future, but Japanese population is now decreasing and total population will be 2/3 of present population in 2050. Hence, there are big questions on whether Japan can increase its GDP under population decline and whether such growth is sustainable or not. To answer such questions is important and interesting for policy making.

In general, one of the most effective measures to increase GDP under population decline is the policy to increase in efficiency of industrial production (Solow 1956; Swan 1956). Research and development (R&D) investment and public investment, such as road construction and irrigation and farmland consolidation, can contribute to such purpose (Yoshikawa 2016; Miyagawa 2018). Such a prescription is based on independency of population change and technological progress. If these two factors relate to each other, the optimal policy for matured economy under population decline would be different from common theory. There is no information on how much influences of such mutual dependency between factors can be in Japan. Furthermore, the R&D investment improves different industries, and industries that are influenced by the R&D investment are differently located in each region. Hence, regional impacts of R&D investment are probably different by regions, and growth rates of the regional economy would be different by regions and consequently, regional gaps in gross production would probably change. Based on such aspects of R&D investment, effects of R&D investment need to be evaluated with consideration of endogeneity and regionality.

To tackle these issues, this study aims to analyze the effects of R&D investment and future Japanese economic situation when R&D investment will stay at the present level or will change according to the economic situation. We use dynamic spatial, computable general equilibrium model (DS-CGE model) which endogenizes private R&D investment and simulates its effects of industrial production via total factor productivity of each industry.[1] We also simulate future economic growth in each region and measure regional differences in production by such DS-CGE model.

Following this section, Section 12.2 reviews the previous studies and Sect. 12.3 explains the structure of CGE model and the methods to combine policy measures with the CGE model. Section 12.4 presents the results of simulation by the model. Based on these results, Section 12.5 presents policy implications and concludes.

[1]The model in this paper is “spatial” rather than “regional” as it has a spatial linkage structure among multiple regions by considering the flexibility of inter-regional trade, which is primarily represented by spatial substitution elasticity (Miyagi 2012).

12.2 Literature Review and Scientific Questions

In the policy evaluation, it is important not only to measure the positive effects of the policy measure, but also to consider where to obtain funds for the policy measure. Unlike partial equilibrium analysis, CGE model analysis always assures the balance of supply and demand of goods and services traded in the market. In other words, in the CGE model, the balance between expenditure and procurement of funds moving along with transactions is always achieved. Therefore, the CGE model can evaluate the positive aspects of policy in addition to the negative aspects through financing of policy instruments.

Considering these advantages, there were many previous studies applying the CGE model to Japan's economic policy. For example, Miyata et al. (2018) analyzed the effects of subsidies for promotion of electric vehicles. Their results demonstrated that an improvement of electric vehicle use makes some industrial outputs larger, but total CO_2 emissions cannot be reduced because increased CO_2 emissions from EV manufacturing and nonferrous metal industries overcome reduced CO_2 emissions by EV transport. Furthermore, CGE model has been used for evaluation on intertemporal economic effects of promotion of waste recycling (Miyata and Shibusawa 2008), evaluation of adaptation technologies against global warming in agricultural sector (Tokunaga et al. 2017; Sakaue et al. 2015), mitigation policy against global warming in rice production (Kunimitsu 2015) and evaluation on natural disaster and its reconstruction (Kajitani et al. 2018; Kunimitsu 2018). However, these studies assumed that the improvement of electric car technology and agricultural technology were exogenously installed. With regard to R & D for producing those technologies, there were few studies that fully analyzed the relationship between the sources of the funds and the production.

Considering this point, practical CGE model needs to be modified to install endogenous growth mechanism that model the accumulation process of R&D investment and the knowledge capital stocks generated by R&D investment. Di Comite and Potters (2014) proposed a regional CGE model that endogenized R&D investment and the knowledge capital stocks based on the theory of endogenous economic growth. Similarly, Kristkova et al. (2016) and Kristkova and van Dijk (2017) used the regional CGE model with endogenous growth mechanism, and quantitatively showed the effects of R&D investment for improvement of food security.

As shown above, there were several studies that developed the CGE model with endogenous growth mechanism, but few previous studies, that adopted such model to the Japanese economy, were published as far as the author knows. In particular, when the future growth of the mature economy is taken into accounts, the issue "whether technological progress derived from R&D investment can overcome the negative impacts of population decline on the economy," is an interesting research subject.

12.3 Method

12.3.1 The Structure of DS-CGE Model

The model used here is the recursive-dynamic spatial CGE model (DS-CGE model) with multiple regions. The structure of our model is based on the work of Ban (2007), which uses GAMS (GAMS Development Corporation) and MPSGE (a modeling tool using the mixed complementary problem), as developed by Rutherford (1999). The basic model structure is as follows.

The cost functions derived from the production functions are defined as nested-type CES (constant elasticity of substitution) forms. The structure of production part is shown in Fig. 12.1. In this figure, degrees of spatial dependence among regional products for intermediate inputs are represented by spatial trade substitution elasticities (σ^r). Although empirical studies that measured the value of σ^r were few, Tsuchiya et al. (2005) showed that the values of σ^r used in the previous CGE models differed from 0.40 to 2.87 and were higher than substitution elasticities between

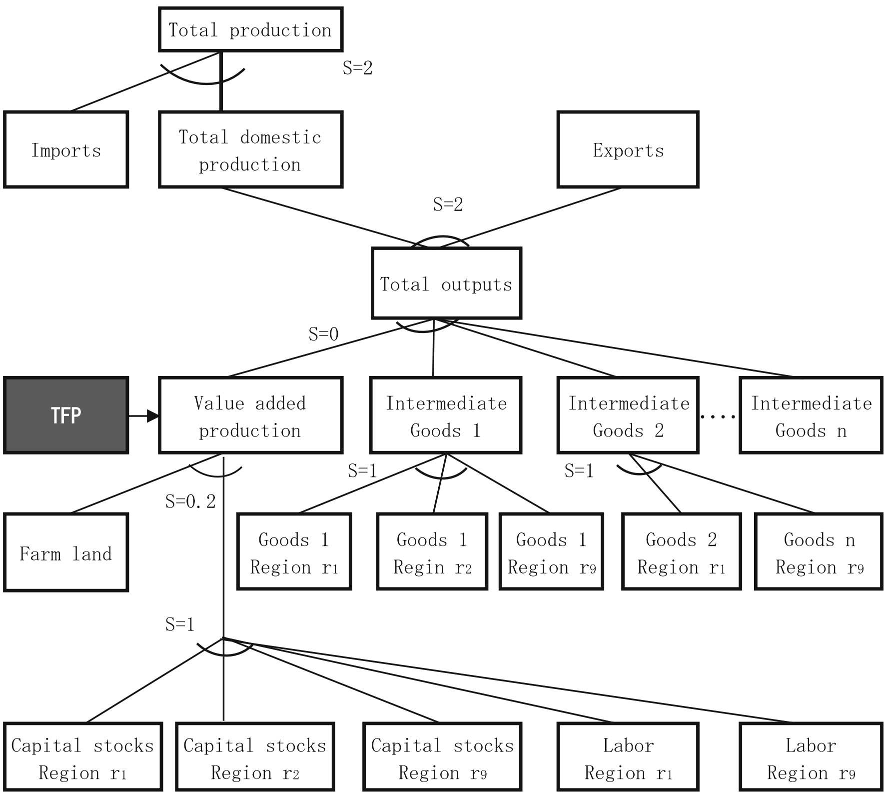

Fig. 12.1 Production structure of spatial dynamic CGE model

domestic goods and imported goods. These big differences are probably because of data used for estimation and the kinds of commodities that were focused on in the studies. Furthermore, spatial substitution elasticities differ according to time span considered in the study. In the long run, these values probably become higher than the case of short run. On the other hand, Koike et al. (2012) revised data used for Tsuchiya's estimations and showed σ^r was less than one, showing inelastic situation of spatial commodity flows and low spatial dependence.

As a matter of fact, suitable data, especially the price data that should be different from regions according to the flexibility of regional transactions were quite a few. Therefore, this study assumed the Cobb Douglas-type spatial substitution function and σ^r as 1, based on Koike's study after conducting sensitivity analysis regarding this value as well as other substitution elasticities.

The elasticity of substitution between farmland and other input factors, which was not used in Ban (2007), is assumed to be 0.2 for agriculture. This number means that farmland is a semifixed input for agricultural production and cannot be flexibly substituted by other factors. As pointed out by Egaitsu (1985), farmland relates to biological technology and is different from other input factors, such as labor and capital, relating to the mechanical technology. Hence, the substitutability of farmland against other input factors can be set as low, though the substitutability between capital and labor is high, according to empirical evidence on Japanese rice production from several studies.

Consumption is defined by the nested type function (Fig. 12.2). The first nest is defined by the linear expenditure system (LES) function derived from consumers' maximization assumption on utility with Stone–Geary form. The second nest shows spatial dependence among commodities produced in different regions. As is the case of intermediate inputs in the cost function, the spatial substitution elasticities take 1, showing middle degree of spatial dependency in economy. Other elasticity values of substitution in the consumption, import, and export functions are set to be the same as Kunimitsu's (2017) study and based on the GTAP 8 database. The Frisch parameter for the consumption structure is −1.2 based on Saito's (1996) empirical study.

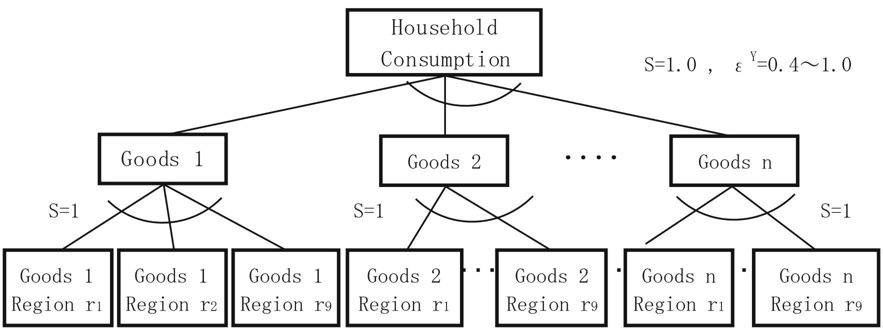

Fig. 12.2 Consumers' utility structure in the model

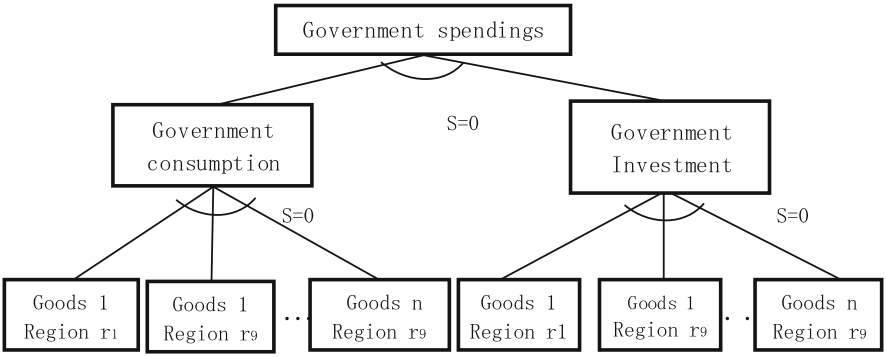

Fig. 12.3 Government spending

The government consumption and government investment are Leontief type fixed share function (Fig. 12.3). Of course, total government spending corresponds to the total public revenue collected through taxation.

12.3.2 Modification of CGE Model for Consideration of Endogenous Growth

Technological progress of each industry measured by the total factor productivity (TFP) is, in our model, assumed to occur based on knowledge capital stocks accumulated by the R&D investment. In addition the public capital stocks of infrastructure, such as agricultural base facilities like irrigation and drainage canals, and roads and management scale of agriculture farms are assumed to influence to TFP level as follows.

$$TFP_{i,r}(t)/TFP_{i,r}(t_0) = \left(KK_{i,r}(t)/KK_{i,r}(t_0)\right)^{\beta_i^K} \cdot \left(KG_{i,r}(t)/KG_{i,r}(t_0)\right)^{\beta_i^G} \times \left(MA_{i,r}(t)/MA_{i,r}(t_0)\right)^{\beta_i^M} \quad (12.1)$$

Here, subscripts *i* and *r*, respectively, show the industrial sector and region. t shows year and t_0 correspond to the initial year of the simulation. *KK*, *KG*, and *MA* are, respectively, knowledge capital stocks, public capital stocks of infrastructure and average management scale of agriculture farms representing economies of scale. β_i^K, β_i^G, and β_i^M are elasticities of TFP with regard to knowledge capital, public physical capital for infrastructure, and average management scale of agricultural farms, respectively. These elasticities are measured by the econometric estimation and statistic data and shown in Table 12.1.

Table 12.1 Elasticity values of TFP with respect to factors by industries

Sectors	Factors		
	Knowledge capital	Public infrastructure capital	Agriculture farm management scale
Paddy rice	0.1067	0.1067	0.1067
Dry field production	0.0451	0.0451	0.0451
Livestocks	0.1784	0.1784	0.0330
Transportation of communication	0.1992	0.1992	–
Electricity and gas	0.0750	0.0750	–
Chemical products	0.0888	–	–
Machine	0.0611	–	–
Electric equipments	0.4892	–	–
Other manufacturing	0.0543	–	–

Source: Kunimitsu (2017)

In the real economy, more than 70% of the R&D investment is conducted by private firms, and the lest 30% is invested by the public sector, such as government and university. This public R&D investment is exogenously provided, and, different from private R&D investment, allocated in public budget in our model.

The private and public knowledge capital stocks (KK^P and KK^G) are accumulated by the R&D investments as:

$$\begin{aligned} KK_{i,r}^{k}(t) &= IK_{i,r}^{k}(t - Lag) + IK_{i,r}^{k}(t - Lag - 1) + \cdots + IK_{i,r}^{k}(t - Lag - N) \\ &= \sum_{j=Lag}^{Lag+N} IK_{i,r}^{k}(t - j) \end{aligned} \tag{12.2}$$

Here, superscript k classifies private (P) or public (G), and j is the operation variable. Lag is the gestation period of R&D investment, and N is the lifespan of knowledge. Lag is assumed to be 3 years for private R&D investment and 7 years for public R&D investment, and N is 12 years for private sector and 8 years for public sector. These periods are based on the questionnaire research of Cabinet Office of Japan (2010) and National Institute of Science and Technology Policy (1999).

The level of private R&D investment (IK^P) is defined by the production level of related industry as:

$$IK_i^P(t) = rik_i \cdot X_i(t), \tag{12.3}$$

where rik is the rate of R&D investment spent by each industry in accordance with total production (X) of i-th sector and in year t. X is defined by the market equilibrium condition depicted by the CGE model. Public R&D investment increases in accordance with past increasing trend.

When total knowledge capital stocks are calculated and used in Eq. (12.1), agricultural sector adds up private and public knowledge capital stocks as; $KK_{i,r}(t) =$

$KK_{i,r}^{P}(t) + KK_{i,r}^{GAgri}(t)$. On the other hand, regarding the nonagricultural sectors, since public knowledge capital stocks by sectors are not obtained, private and growth level of total knowledge capital stocks in nonagricultural sectors are added by the growth rate of private and public knowledge capital stocks after taking logarithmic form as; $\ln\left(KK_{i,r}(t)\right) = \ln\left(KK_{i,r}^{P}(t)\right) + \ln\left(KK_{i,r}^{GWhole}(t)\right)$.

To form the recursive dynamic path, the private capital stocks (*KP*) are defined by the annual investment (*IP*) and depreciation rate ($\delta = 0.04$) as:

$$KP_{i,r}(t) = (1 - \delta)\, KP_{i,r}\,(t - 1) + IP_{i,r}(t) \tag{12.4}$$

In this equation, *IP* is endogenously defined by the CGE model corresponding to the total savings of households, government, and trade accounts as:

$$IP^{*}{}_{i,r}(t) = IP_{i,r}\,(t_0)\left(\frac{PK_{i,r}\,(t-1)}{\overline{PK}_r\,(t_0)}\right)^{0.5}, \tag{12.5}$$

$$IP_{i,r}(t) = \frac{IP^{*}{}_{i,r}(t)}{\sum_i IP^{*}{}_{i,r}(t)} IPS_r(t), \tag{12.6}$$

where $IP_{i,r}$ is the private investment in the i-th industry of the r-th region, IP^* is the ideal private investment, *PK* is the service price of capital stocks, $\overline{PK}_r$ is the average service price among industries. IPS_r is the total regional investment corresponding to the total savings in the *r*-th region, and is defined by the CGE model according to the rate of return on the private capital stocks by regions.

The public capital stocks (*KG*) of infrastructure at the end of the year, such as road facilities and agricultural base facilities like irrigation and drainage canals, are defined as:

$$KG_r^g(t) = KG_r^g\,(t - 1) + IG_r^g(t) - DG_r^g(t) \tag{12.7}$$

Here, g classifies the agricultural base facilities (g = A) and the road facilities (g = R), *IG* is the public investment, and *DG* is the depreciation value of stocks. The initial value of *KG* at year t_0, *IG* and *DG* are derived from actual data on public facilities (Cabinet Office of Japan 2012), and these values are exogenously defined in our CGE model.

Labor forces, as like the private physical investment which forms private capital stocks, are assumed to move among sectors and regions. In our model, labor supply is assumed to decrease according to the population changes, and regional labor supply considers the labor force which moves among regions based on wage differences as:

$$LS_r(t) = LS_r(t_0)\left(\frac{PL_r(t-1)}{\overline{PL}(t_0)}\right)^{0.5}\frac{POP_r(t)}{POP_r(t_0)}. \tag{12.8}$$

Here, *LS* is labor supply, *PL* is the wage rate, $\overline{PL}$ is whole country average wage rate, and *POP* is population. In Eq. (12.8), 1 year time lag is considered at wage rate change influencing participation rate in the labor market because job searchers can obtain information on wage rates of firms only after some while.

Different from labor and investment, farmland cannot move among regions. Hence, total farmland supply, *FS*, is assumed to decrease by *gr* which is set as −0.4% with consideration of actual decreasing tendency of farmland area in Japan and is almost the same as population growth rate as:

$$FS_r(t) = (1 + gr)\, FS_r(t-1). \tag{12.9}$$

12.3.3 Data

To calibrate the parameters of the CGE model, the social accounting matrix (SAM) in 2014 was estimated (Kunimitsu 2019) based on Japan's 2005 inter-regional input–output table published by the Ministry of Economy, Trade and Industry (http://www.meti.go.jp/statistics/tyo/entyoio/result/result_13.html). In order to analyze sectoral production more precisely, the rice sector, transportation sector, and research and development sector were separated from the aggregated sectors in the IO table by using regional tables (404 × 350 sectors). Subsequently, the sectors were reassembled into 16 sectors: (1) paddy (pady); (2) other agriculture, forestry, and fishery (oaff); (3) mining and fuel (minf); (4) food processing (food); (5) chemical products (chem); (6) general machine (mach); (7) electrical equipment and machine (elem); (8) other manufacturing (omfg); (9) construction (cnst); (10) electricity and gas (elga); (11) water (watr); (12) transportation (tpts); (13) research and development (rese); (14) wholesale and retail sales (trad); (15) financial services (fina); and (16) other services (serv). Regions consisted of nine regions: Hokkaido; Tohoku; Kanto including Niigata prefecture; Chubu; Kinki; Chugoku; Shikoku; Kyushu; and Okinawa.

The factor input value of farmland, not shown in the Japanese I/O table, was estimated using farmland cultivation areas (Farmland statistics, Ministry of Agriculture, Forestry, and Fishery, and every year) and multiplying the areas by farmland rents. The factor input value of farmland was subtracted from the operation surplus in the original IO table. The value of capital input was subsequently composed of the remaining operational surplus and the original depreciation value of capital.

Most elasticity values of substitution in the production, consumption, import, and export functions were set at the same values as Ban (2007), which were based on the GTAP database. In order to check the stability of our model, the sensitivity analysis on these substitution elasticities were conducted by changing these values as ±20%. Such sensitivity analysis showed that the simulation results shown in the latter section had the same tendency and took the same signs of change although the changed values were different.

12.3.4 Simulation Cases

In order to predict the future situation, the simulation is conducted for 37 years from 2014 to 2050. The five simulation scenarios are considered as follows:

Case 01 (Reference case under population decline) This case is used for the reference of other simulations, which consider population decline. Private and public knowledge capital stocks do not change ($KK(\text{t})/KK(t_0) = 1.0$ in Eq. (12.1)). Although knowledge capital will not contribute to the changes in TFP, it will change due to the changes in agricultural management scale and public investment for infrastructure. The future population is exogenously provided according to the prediction of National Institute of Population and Social Security Research (http://www.ipss.go.jp/).

Case 02 (Reference case under constant population) This case is used for the reference of Case 2, which assumes constant population. The knowledge capital stocks, public capital stocks, and agricultural management scale took the same levels as Case 01. Future population keeps constant level which is the same as in 2014 when the simulation starts.

Case 1 (Endogenous growth of private R&D investment under population decline) Private R&D investment is endogenously defined by the SD-CGE model according to Eq. (12.3), whereas public R&D investment keeps its level the same as the initial year (2014) for 37 years. Future population level is the same as Case 01.

Case 2 (Endogenous growth of private R&D investment under constant population) The same as Case 1, private R&D investment endogenously changes according to Eq. (12.3) and the levels of public R&D investment are also the same as Case 1. The future population is fixed at the same level as 2014 as Case 02.

Case 3 (endogenous growth of private R&D investment with increased public R&D investment under population decline) The settings for private R&D investment and population are the same as Case 2, but public R&D investment in every year is increased by 20% from the Case 2 level. The increase in public R&D investment is offset by the decrease in public investment other than roads and agricultural base infrastructure, in order to exclude productivity changes caused by changes in factors other than public R&D investment.

In all cases, government savings, international trade balance, and inter-regional money transfer are assumed to be fixed as the present level. Management scale (*MA*), which is only considered in paddy sector and other agricultural sectors, increases according to the past trend in all cases. Public investments for infrastructure (IG^A and IG^R) keep their level the same as initial year, because actual public investments have not increased under recent severe government's budget constraint.

12.4 Results

12.4.1 Prediction of Knowledge Capital Stocks

Figure 12.4 shows the prediction of public knowledge capital stocks by cases, based on the exogenous settings on public R&D investment as explained in the previous section. As expected, public knowledge capital stocks in Cases 1 and 2 are 16% larger than reference cases, and that in Case 3 is 38% larger than reference cases. Since R&D investment level is assumed to go flat after changing its level at the start year, the peak of knowledge capital stocks emerges 13 years after R&D investment's increase, then after that, it keeps flat level.

Figure 12.5 shows the prediction path of private R&D investment and private knowledge capital stocks by cases. As is clear from the comparison between (a) and (b) in this figure, the increase in private sector R&D investment is suppressed more in the case of population decline than the case of constant population. In particular, as shown by Case 1 in Figure (a), R & D investment will increase until the 2030s, but will decrease after that. In 2050, the level of private sector R & D investment is close

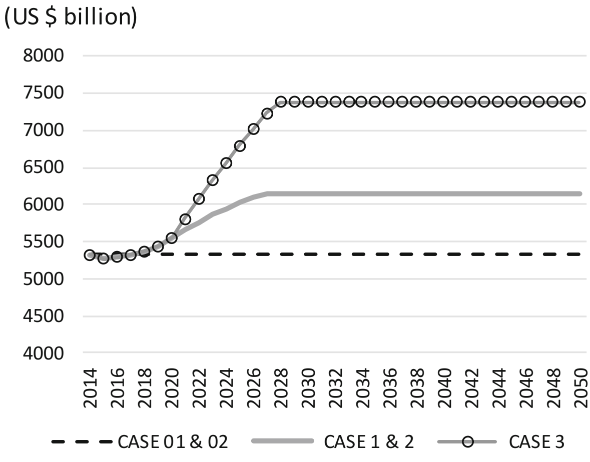

Fig. 12.4 Public knowledge capital stocks by simulation cases

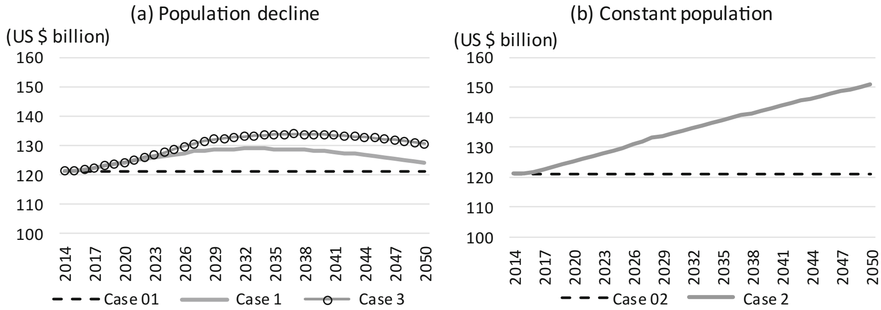

Fig. 12.5 Chronological change in private R&D investment by cases

Fig. 12.6 Private knowledge capital stocks by industrial sectors and cases at year 2050

to that of the reference case (Case 01). In the CGE model employed here, private R&D investment assumes the virtuous circle in which R&D investment improves gross production via TFP improvement and then improved gross production can increase R&D investment. However, the above results show that the effects of the virtuous circle are not strong enough to outweigh the negative effects of population decline.

Figure 12.6 shows the future private knowledge capital stocks by industrial sectors at the end of the simulation. Most of the private knowledge capital stocks are accumulated by the manufacturing sectors. Conversely, those levels in the agriculture and food sectors are low, because R&D investment in the agriculture and food sectors is occupied by the public R&D investment.

12.4.2 Prediction of GDP

Figure 12.7 depicts the transition of TFP in all industries for each case. Regarding the reference cases (Cases 01 and 02), The change in TFP is the same for both depopulation and constant population. However, TFPs at the BAU level in Cases 1 and 2 differ in their levels, because the level of R & D in the private sector is different. In the case of population decline (Case 01), the TFP level of the reference case at 2050 is 20% lower than the case of constant population (Case 02). In Case 3 where public R&D investment is increased, the TFP level becomes similar to that of the constant population case (Case 2). In other words, it is necessary to increase public R&D investment for overcoming the decline in productivity growth rate caused by a population decline.

Figure 12.8 shows the change in Japanese GDP for each case. Although the transition of TFP in the reference case is the same for both constant population and population decline, the GDP in the reference case showed little growth in the case of population decline and its level is much lower than the constant population case. Even so, there is a slight rise in GDP under population decline until the 2030s.

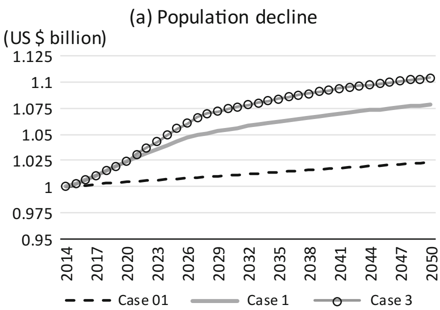

Fig. 12.7 TFP change by cases. Note: TFP in this figure is the weighted average of each industry's TFP by using the production as weight

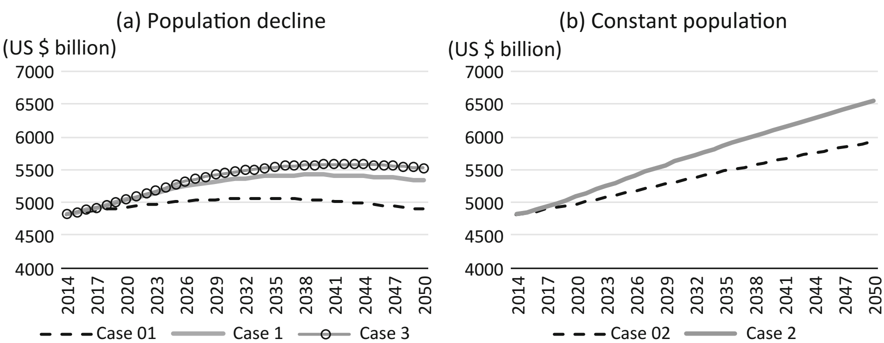

Fig. 12.8 GDP change by cases

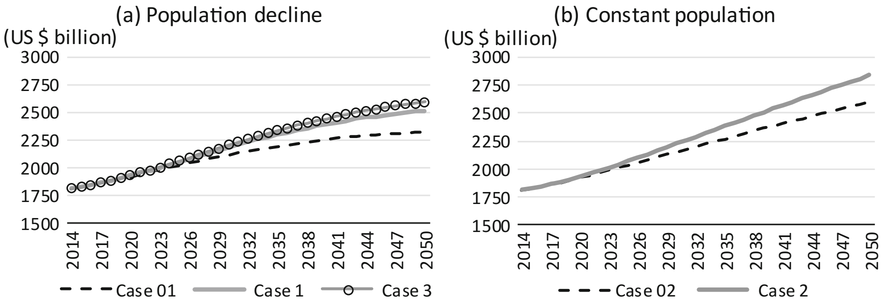

Fig. 12.9 Change in private physical capital stocks by cases

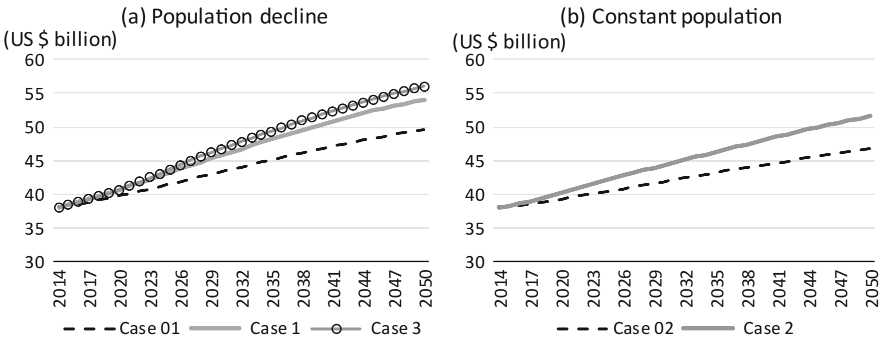

Fig. 12.10 Change in per-capita GDP by cases

However, since then, the growth rate turns negative, and the GDP level in 2050 is roughly the same as 2014 at the start of the simulation. Compared to the constant population, the GDP under the reference case's population decline in 2050 is about 20% lower.

The reason for the slight increase in GDP despite the negative impact of the population decline is that accumulated private capital stocks, such as factories and machines, through private investments contributed to the increase in GDP, in addition to the effects of the rise in TFP due to public investment for infrastructure development. Figure 12.9 shows the trend of private capital stock, and it continues to rise under the population decline, although the growth rate is lower than in the case of a constant population. In Japan, high levels of private investment based on high levels of private savings have a positive impact on GDP, suggesting that private capital stocks can substitute for labor as well as farmland in the future.

Figure 12.10 shows the transition of per-capita GDP. Unlike GDP in Fig. 12.8, per-capita GDP continuously increases in both the population decline case and constant population case. Also, interestingly, per-capita GDP reaches a high level under the population decline than constant population. This is because high labor supply causes a decrease in wage rate and labor participation rate in the case of constant population. As a result, the growth of household income is also suppressed, so the positive effects of population bonus are reduced.

12.4.3 Prediction of Regional Economy

Figure 12.11 shows the transition of GRP by region. Among the nine areas, six characteristic areas are picked up in this figure. It is added that the missing Tohoku, Kinki, and Chugoku are similar to Kyushu, Chubu, and Sikoku, respectively.

In Hokkaido and Shikoku, the percentage of service industry, which is a growing industry, is small, so GRP decreases consistently under the influence of population decline. In the Kanto region, on the other hand, GRP is continuously increasing, because many manufacturing and service industries are located and degree of population decline is small. However, even in the Kanto region, the rate of increase decreases since the 2030s. Okinawa's GRP tends to increase with a slight increase in population, but the amount of GRP is small, so the impact on Japan as a whole is small.

As such, there are differences in GRP trends by regions, and the regional GRP gap will widen by 2050. In Case 1, the coefficient of variation among the nine regions of GRP increases from 1.24 (in 2014) to 1.43 (in 2050). The coefficient of variation in per-capita GRP also rises from 0.19 (in 2014) to 0.22 (in 2050). Similar calculation in Case 2 (constant population) shows that the coefficient of variation about GRP in 2050 is 1.40, and that about per-capita GRP is 0.25. The coefficient of variation in 2014 is the same as in the case of population decline, so the coefficient in the case of a constant population increases after 37 years, as similar to the case of population decline. However, the degree of increase is moderated in the case of GRP and accelerated at per-capita GRP. From the GRP alone, the decline in population has the effect of expanding regional economic disparity.

12.5 Summary and Policy Implications as Conclusion

This chapter tried to measure influences of population decline in matured economy like Japan with consideration of mutual relations of technological progress and population growth. We used a dynamic spatial, computable general equilibrium model (DS-CGE model) to concretely show the future situation of economy.

The simulation results demonstrated the following points. First, if technological progress from R&D investment does not occur, Japan's GDP under population decline cannot grow and the GDP level in 2050 will be almost the same as 2014 level. Owing to technological progress caused by R&D investment, GDP in 2050 will be 11% higher than in 2014, even under population decline. However, GDP under population decline is 23% lower than the case of constant population. Therefore, it can be said that technological progress caused by R&D investment

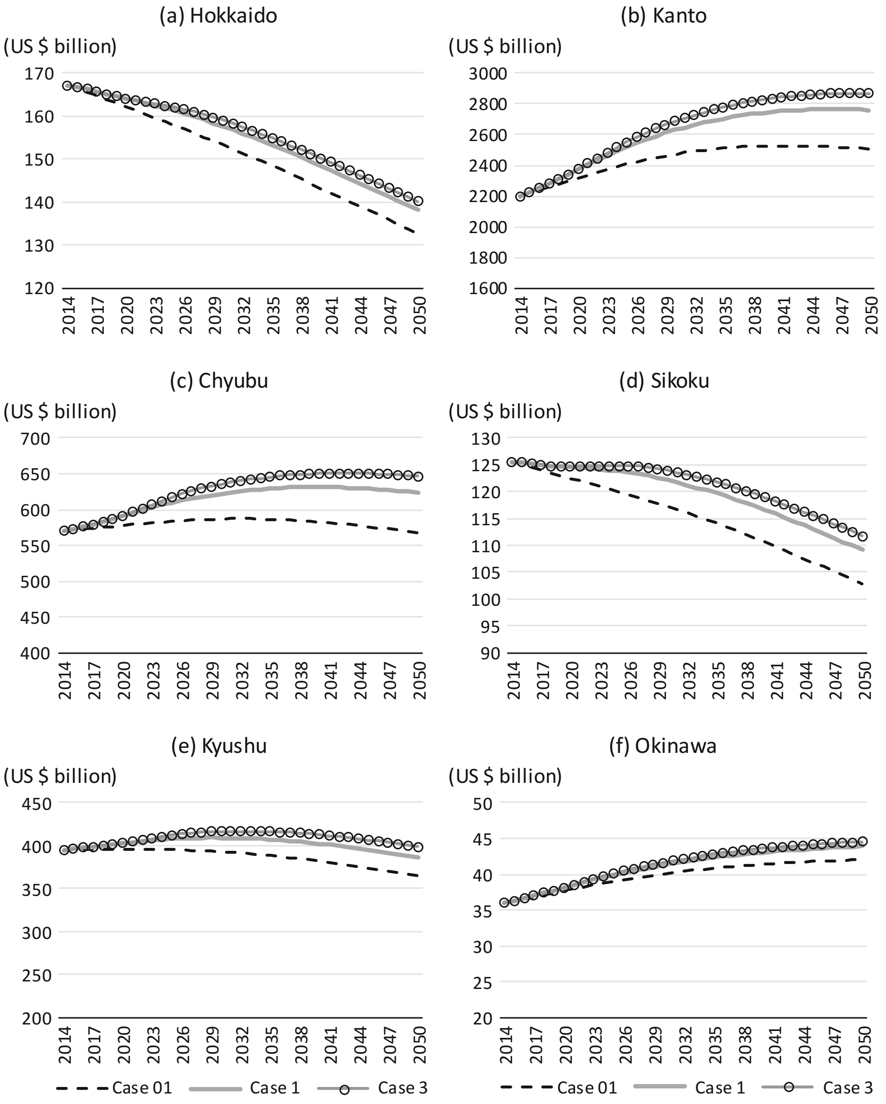

Fig. 12.11 Change in Gross Regional Production (GRP) by regions

is not strong enough to overcome the negative impacts of population decline in Japanese economy.

Previous studies (e.g., Yoshikawa 2016) often conclude that technological progress is the key to overcome population decline, and Japan's GDP can continue to grow. Unfortunately, the results of this research suggest that there would be an over expectation for technological progress and technological progress itself also may decline due to population decline.

Second, per-capita GDP becomes higher in the case of population decline than in the case of a constant population. This is because population decline increases wage rate, raises labor participation rates and increases household income. These influences bring about an increase in both supply and demand of the market. Although the suppression of population decline is indispensable for GDP growth, there is a good point in the population decline in terms of increasing per-capita GDP. Nevertheless, if the population decline continues, the country itself will disappear, and per-capita GDP will also disappear. In order to avoid this, policies that suppress a decline in population (e.g., an increase in child support subsidy) and policies that fully transfer economic growth outcomes to labors' disposable income in order to enhance household's consumption are required.

Third, future technological progress will widen regional economic disparities, because most industries in which technological progress is likely to occur are concentrated in the urban areas. In addition, the progress of substitution from labor to capital due to population decline probably widens disparities among individuals. This happens for the increase of the capital income, and for the decrease in labor income. The expansion of the income disparity generally leads to social unrest and lowers the life satisfaction of the majority. Therefore, it is needed to revitalize the local economy where the population decline is faster and to enhance policies on social welfare improvement such as rise in the minimum wage.

Thus, the simulation by the CGE model enables analysis of comprehensive ripple effects including side effects. Therefore, CGE analysis is effective as a tool when examining future economic policy.

Finally, the remaining issues are considered as follows. First, the model of this research is built based on the interregional input–output table in 2005, and the economic structural change after the 2011 Great East Japan Earthquake is not fully considered. Since inter-regional input–output table has not been released since 2005, updating data is a major challenge, although it is not easy. Second, although the model of this research assumes that the effects of public R & D investment are equally applicable to all industries, it is important to further verify the validity of this assumption. In this regard, the estimation of public knowledge capital stocks by sectors is an important issue. Third, this study focused on the future economic situations in Japan as a result of endogenous economic growth, so no analysis has been conducted on the specific policy effects. Analyzing the effects of public investment for infrastructure and labor productivity improvement policy by the CGE model developed here is the remaining issue.

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Chapter 13
The General Perspective of Japanese Agricultural Policy That Appears from Rice Riots and Artificial Intelligence

Hideji Isomae

Abstract The general perspective of Japanese agricultural policy can be roughly understood when we focus attention on the rice riots. The Taisho rice riots (1918) changed the agricultural land improvement project from one that had been, until then, led by landowners to one led by the national government, and promoted by large sums of subsidy investments. This was because of a sudden change in popular opinion saying that landowners cannot be counted upon any longer and the national government should be the one to which one turns. The movement of this regulation enhancement spread not only in the production aspects but also in distribution. And after decades from that time, the "Heisei rice riots" (1993–1994) occurred. The public opinion quickly changed to one that the government cannot be counted upon, and the market is to be relied upon. It changed from regulation tightening to regulation loosening. Would not the future rice riots change the direction of agricultural policy? And would not the rapid development of artificial intelligence change the direction of agricultural policy? After some deliberation, we can envisage that the realization of high labor productivity that, so far, could not be recognized by large-scale agricultural management focusing on land use, will become possible through the development of artificial intelligence and efficiency-improved batteries in a way so as to reduce the environmental burden.

Keywords Rice riot · Artificial intelligence (AI) · Japanese agricultural policy · General perspective · Large-scale agricultural management · Labor productivity · Environmental burden

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13.1 Issues

In Japan, the era of "Heisei" (1989–2019.4) is over and the new era of "Reiwa" (2019.5-) has begun. Let us review the era of Heisei based on the GDP trend. As of the first year of Heisei (1989), China's GDP was far below that of Japan. But by the end of Heisei, China's GDP grew to more than two times that of Japan. This was not simply due to the rapid economic growth of China, but also because Japan's economic growth rate was way too low. Japan could only slightly increase its GDP during the Heisei era. "Heisei" means "Please flatten". As the name "Heisei" indicates, its GDP growth, as a trend, was almost flat during this period.

The voices of the United States, which continues to experience sustained economic growth at a high rate, and of China, which rapidly developed its economy, grew larger in the international community. Japan's influence in the international community, on the other hand, became relatively weaker. In the background, there was a huge fluctuation like this in terms of economic power. In the Reiwa era, Japan should not be satisfied with the low economic growth it experienced during the Heisei era, so that it can overcome the challenges of restructuring the public pension system in light of an aging population combined with the diminishing number of children as well as of establishing Japan as a peaceful nation by reinforcing its voice in the international scene. For that purpose, advanced economic policy geared toward value-added creation should be envisaged, prepared, and implemented.

In the field of agriculture, advanced agricultural policy needs to be envisaged, prepared, and implemented. Having said this, agricultural policy requires a long-term sustained perspective, and advanced agricultural policy must be based upon a general perspective. In other words, it must be based on a sweeping trend. This chapter will first (1) describe that the sweeping trend of Japanese agricultural policy in the past can be seen by focusing on rice riots. Then, based on (1), this chapter will (2) consider the focal points of Japan's agricultural policy in the future from a broader perspective while also taking note of the impact on large-scale land-focused agricultural management by artificial intelligence (AI), which has seen rapidly evolving research and development.

13.2 Rice Riots and Japanese Agricultural Policy

13.2.1 Rice Riots of Taisho and Strengthening of Regulations

From the Meiji era onward until today, a general perspective of Japanese agricultural policy can be seen by paying attention to rice riots. Incidentally, rice riots in this chapter will be interpreted extensively and defined as nationwide or cross-regional socioeconomic confusion caused by a sharp increase in the price of rice. The most representative rice riot prior to World War II was the Taisho rice riot, while, post-war, it was the Heisei rice riot. This section will discuss the Taisho rice riot.

Before the start of World War I (1914–1918), agricultural land improvement projects (agricultural civil engineering works) such as the building of irrigation systems and construction of agricultural roads were primarily carried out by village landowners. These landowners undertook the repair of community roads broken by heavy rains or of the roofs of shrines and temples damaged by typhoons, for example, thus giving back a significant portion of the farm rents collected from the communities. These community contribution functions by landowners were highly valued by the local villagers.

The outbreak of World War I, however, totally changed the situation. Much of the farmland rent income of landowners was now directed toward direct investment in larger cities enjoying the wartime economic boom and toward the purchase of shares of large corporations. This substantially reduced the amount given back to their agricultural communities, such as the fund for agricultural land improvement projects. It then weakened the infrastructure of agricultural production, leading to the stagnation of productivity of rice cultivation. Irrigation waterways with significant leakages that were left unrepaired can be cited as an example.

In contrast, demand for rice in large cities in the booming wartime economy rapidly expanded, helped by the increase in the urban population. The rapidly expanding demand for rice at a time when the rice supply was stagnant led to a sharp increase in rice prices. Added to this was the speculative investment that expected that troops would be deployed in the Siberia intervention. Thus, the rice prices soared, leading to the Taisho rice riot.

The Taisho rice riot occurred from July to September in the 7th year of Taisho (1918) (Note 1). The inception was the activities to bar the shipment of locally produced rice to outside Toyama prefecture and rice price negotiation by the women groups of the fishing community of Uozu-machi, Toyama prefecture that took place on July 23. Incidentally, Uozu-machi had experienced several rice riots after the rice safety net structured under the feudal system of the Tokugawa shogunate disappeared in the Meiji era (Note 2). The behavior "pattern" of the rice riot conventionalized through these experiences seems to have been practiced at the Taisho rice riot, which was by no means a haphazard and emotional demonstration activity.

It is also worth noting why the rice riot started with the fisherwomen in Toyama prefecture. The reason cannot be due to low income, as rice riots seldom occurred in locations such as Hokkaido, Aomori, Iwate, and Akita, where many low-income people lived at the time. Rather, it was because the fishermen and women in Uozu-machi and its neighboring fishing cities and harbor cities lost their capabilities or qualifications, namely their entitlements to lawfully obtain and consume rice (Note 3).

The rice riots that started at fishing cities in Toyama prefecture spread nationwide and led to a situation that eventually required even the army to be mobilized. Then, the Taisho rice riot came to a halt, at least for a while, due to the conflict at Mitsui Mining. The Taisho rice riot was such a social event that it led to the ousting of the Terauchi cabinet and made way for the cabinet of Hara of Seiyukai.

The Taisho rice riot drastically changed public opinion. It led the public to believe that landowners could not be relied upon and that the state (national government) should be relied on instead. With the Russian revolution in 1917, people's expectations toward the state increased amid the societal turmoil. The government's engagement in agriculture started with the production aspect. That is, it was a conversion from the agricultural land improvement projects led by landowners to the state-led agricultural land improvement projects promoted by the investment of large subsidies. The mechanism of the state-led agricultural land improvement projects that appeared on the scene at this time was passed on until after World War II and, to this day, with modifications necessitated by the times.

In addition, the government also started to increase its involvement in the distribution stage of rice and other products; in other words, this led to the enforcement of the Staple Food Control Act (1942–95). This mechanism of state control in the distribution of rice and other grains was also passed on to the post-World War II period. It should be noted that many aspects of the agricultural policy prior to and after the war are not decoupled but continuous. As seen here, we can say that the rice riots of Taisho changed the direction of agricultural policy from deregulation to re-regulation, or accelerated the changes.

13.2.2 The Heisei Rice Riots and Deregulation

The Heisei rice riots took place from September of the 5th year of Heisei (1993) to March of the 6th year of Heisei (1994), consisting of the first phase of rice riots from September to November of the 5th year of Heisei and the second phase of rice riots from February to March of the 6th year of Heisei (Note 4). The primary cause of the rice riots was the cold summer of the 5th year of Heisei. Other causes include insufficient fertility management due to the aging of agricultural labor, but this would be a secondary factor. The crop situation index of paddy-field rice harvested in the 5th year of Heisei was 74 on a nationwide basis, an unprecedentedly poor crop. This level was such that it required an urgent import of as much as 1.58 million tons of rice. Crop situation index refers to an index wherein the expected harvest level that is forecast, considering technological progress, is taken as 100.

There were large variances in the crop situation index from region to region. According to the crop statistics of the Ministry of Agriculture, Forestry and Fisheries, they were 40 for Hokkaido, 56 for Tohoku, 88 for Hokuriku, 85 for Kanto/Tosan, 91 for Tokai, 92 for Kinki, 85 for Chugoku, 89 for Shikoku, 76 for Kyushu, and 108 for Okinawa, indicating significant damage in northern Japan. The crop situation indices for Aomori, Iwate, and Miyagi, in particular, were among the lowest levels in the country at 28, 30, and 37, respectively.

The first phase of rice riots occurred in northern Japan where the cold summer was particularly severe. The primary cause was the large-scale rice purchase activity by rice-growing farm households for the purpose of securing rice for their own consumption and for gifts. In other words, rice producers who could foresee the cold weather damage set off a panic (Note 5).

The second phase of rice riots, on the other hand, was caused by the consumers who expected that the purchase of domestically grown rice would become more difficult. The transaction price of freely distributed rice at the Tokyo market for 60 kilograms of *Koshihikari* produced in Niigata prefecture shot up approximately 2.3 times from JPY 22,750 in July of the 5th year of Heisei to JPY 52,500 in March of the next year. The area of the second phase of rice riots, unlike the first phase of rice riots, spread nationwide, causing a short-lived but serious food problem.

In light of the above, public opinion changed completely. The public wondered why there was such severe cold summer crop damage in the post-war period, despite heavy agricultural subsidies, why there was such a significant increase in the rice prices with only this level of cold summer weather, thought that they could no longer rely on the government, and that they would like to rely on the market, etc. In short, they were looking for a change to deregulation. The necessity of deregulation was talked about in many fields, and agricultural policy, was also about to turn toward deregulation.

Deregulation was first strengthened in terms of distribution. The newly effected Staple Food Act (1995–) came about, replacing the Staple Food Control Act that was valid until then. The official name of the Staple Food Act is the Act for Stabilization of Demand, Supply and Prices of Staple Food. Under this law, wholesale and retail businesses of rice changed from an approval system with stringent conditions upon new entry to a registration system. This also prompted competition between foreign-produced rice and low-price domestically produced rice.

Further, deregulation was also strengthened on the production side. The most noticeable among them was the effectuation of the Revised Agricultural Land Act (December 2009) that was based on the performance experience of the special zones for structural reform under the Koizumi administration. This allowed general corporations such as joint-stock corporations to engage in agricultural business anywhere in the country as long as the farmlands they cultivated were rented. At the same time, the maximum rental period of farmlands was increased from 20 to 50 years, and the maximum penalty in case of violation of diversion of farmlands was raised from JPY 3 million to JPY 100 million.

Measures aimed at deregulation have been implemented after this, too. These include, among others, assistance in making agriculture a so-called senary sector (diversifying agriculture into a secondary as well as a tertiary sector business), promotion of agriculture=commerce=industry alignment, cessation of the production adjustment of rice, agricultural management by agricultural corporations of prefectures, and raising of the maximum equity ratio of private enterprises in agricultural production corporations (less than 50%). While other measures, with the central and local governments playing their roles in the forefront, were taken, such as encouraging agricultural land to be amassed in the hands of leaders in agriculture by activating agricultural land intermediate management organizations (Note 6), on a macro basis, deregulation is still the direction in which the agricultural policy is heading.

(Note 1) See Inoue/Watanabe ed., (1962) pp. 5–6 for details.
(Note 2) See Inoue/Watanabe ed., (1962) pp. 313–380 for details.
(Note 3) See Amartya Sen (2000) for a detailed explanation of entitlement and food procurement power.
(Note 4) See Higuchi et al. (2001) p.2.
(Note 5) See Higuchi et al. (2001) pp. 69–92 for details.
(Note 6) Also called agricultural land banks. Reliable intermediate receptacle organizations of agricultural lands established in 2014 in all the prefectures in Japan.

13.3 Future Rice Riots and Japanese Agricultural Policy

Would rice riots occur in the near future? This is a rather vague question but it is something worth giving consideration. The production adjustment of rice ceased as of 2018. On the other hand, the subsidy for conversion to feedstuff rice has been raised. Thus, the actual revenue level for farmers became much the same, be it staple food rice or feedstuff rice. In other words, the willingness of agricultural managers to produce staple food rice is surmised to have fallen in a relative sense. This being the case, if abnormal weather hits again, as it did in 1993, the likelihood of rice riots will be heightened. If a rice riot should occur in the future, agricultural policy will be significantly impacted, as past agricultural history shows.

There is a view that the presence of rice will decrease more and more, so the impact of rice riots on agricultural policy should weaken, but this view is not necessarily correct. This is because the measurement results show that the income elasticity of demand for rice since the 1970s is continually increasing as a trend (Note 1). In other words, the presence of rice for consumers can be described as steadily strengthening despite the fact that its nature as necessities remains unchanged (Note 2). Therefore, if a rice riot occurs, shouldn't the impact on agricultural policy be something that cannot be ignored after all? Agricultural policy based upon a general perspective must be envisaged and planned in preparation for the rice riots in the near future.

(Note 1) See Fujii (2015). Here, Fujii writes about the measurement result: "... income elasticity of demand for rice that was falling precipitously turned to recover upon entering the 1970s, and is stably trending between 0.5 and 0.6 since the 1990s. At one time, from the mid-1960s to the 1970s, its income elasticity fell to a negative figure, or it became inferior goods, but other than that, it can be observed that rice remains necessities." By the way, necessities mean goods whose income elasticity of demand is greater than 0 but smaller than 1.
(Note 2) Measured values of income elasticity of demand vary depending upon what kind of measurement model is used. Attention must be given to such points.

13.4 Artificial Intelligence and Japanese Agricultural Policy

Although rice riots cannot be disregarded as a factor regulating the macro trend of agricultural policy going forward, the impact of artificial intelligence (AI) that is making rapid progress in terms of R&D is also important. The impact of AI on Japanese agricultural policy is considered in this section. To do so, we must first understand the major challenge for Japan's agriculture, especially the challenges to large scale agricultural businesses focusing on land use. In Japan's agricultural business focusing on land use, the fact that the expansion of business scale does not lead to an improvement of profitability still remains a problem.

An expense-related problem associated with the expansion of the business scale, or the expansion of cultivated lands under management, is the noticeable increase in travel time and travel cost due to the higher degree of dispersion of cultivated lands under management, although this may not apply to some areas of Hokkaido. In the case of paddy-field rice, the average cost reduction effect becomes almost nonexistent once the cultivation area exceeds 10 hectares for this reason.

The issue on the revenue side as the business scale expands is that the revenue does not increase in parallel with the scale. One can point out a few causes for this: as the business scale expands, we must give up high unit price products that require rigorous fertility management; even if the product grown is the same, expansion of the business scale makes fertility management difficult, causing quality deterioration and a decrease in the unit price; and as the scale expands, fertility management to secure a target harvest per unit area becomes difficult, and the harvest per unit area actually declines.

Further, roughly speaking, when the land area under cultivation increases n times, necessary labor input and machinery work also become n times. That is, labor productivity, meaning the value added generated by one person, does not increase under large-scale agricultural business focusing on land use; therefore, "economies of scale" does not materialize. Researchers of the agricultural economics like us have long been taught to take this as an implicit assumption.

The development of AI, however, raises the possibility that this implicit assumption may be negated. The development of AI has the potential to make a profound change in agriculture, not just in Japan but in the whole world. The introduction of low-cost automatic equipment in agriculture, made possible by the development of AI, would drastically reduce the incremental labor input required for scale expansion. If the power source of such equipment is switched from an internal combustion engine, which entails labor input, to a small, high-quality battery, incremental labor input required for scale expansion would be further reduced. In addition, the introduction of an optimal fertility management system would lead to an increase in the sales unit price realized by quality improvement.

Thus, the implementation of AI to large-scale agricultural business would enhance expectations regarding the effects of drastically reducing labor input, increasing the sales unit price, and rapidly reducing the average fixed costs due to sales increases brought about by high quality. As a result, the expectations of a leap in the labor productivity in large-scale agricultural businesses will increase. With the advent of AI, Japan's agricultural business focusing on land use will now be able to envision a situation where the "economies of scale" actually operates.

The Taisho rice riots changed the key player of agricultural policy from the landowner to the state. The Heisei rice riots changed the key player of agricultural policy from the state to the market. Looking beyond to the future, then, would not AI coupled with the rice riots change the key player of agricultural policy from the market to large-scale agricultural businesses? The rapidly declining rural population in Japan increases the need for scale expansion of agricultural businesses. Should not the focal point of Japanese agricultural policy based on a general perspective be calibrated to match the mechanism buildup that would allow large-scale agricultural business equipped with AI to make sufficient investments?

Mechanisms worth considering would include (1) allowing general corporations like joint stock companies to purchase agricultural lands when they wish to do so for the purpose of making sufficient investments, as long as the local areas (including cases involving multiple municipalities) also wish or approve of it, just like the case of Yabu City, Hyogo Prefecture, a national strategic special zone (Note 1), and (2) improvement of creation/control/operation system of intellectual properties related to agricultural production technology incorporating AI.

As mentioned above, I have searched the general perspective of Japanese agriculture and agricultural policy that show themselves through rice riots and artificial intelligence. After consideration, I came to surmise that the key players of Japanese agricultural policy could be large-scale agricultural businesses that actively utilize AI. Of particular note is that the thoroughly labor-saving system that such key players, expected to bring about sufficient profitability, equip themselves with will be driven by small but high-performance lithium-ion batteries with a low environmental burden. We finally came to be able to envision agriculture in which economic efficiency and environmental protection are compatible with each other.

I believe that Dr. Yuzuru Miyata, professor of the Toyohashi University of Technology, in his research on environmental economics, always paid strong attention as a constraint to the compatibility between economic efficiency and environmental protection/creation. I pray for the repose of professor Miyata's soul who always remained a pioneer of environmental economics and regional science.

(Note 1) See Isomae (2006) for the basic studies on land rental periods in relation to optimal agricultural investments.

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Chapter 14
Recovery Process of Municipal Economies After a Tsunami in Aichi Prefecture, Japan: A Dynamic Input–Output Approach

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Abstract Japan is susceptible to earthquakes and tsunamis. This study investigates how production activities in 54 municipalities of Aichi Prefecture recovered from a tsunami which will be caused by the Nankai megathrust earthquakes in near future. We propose a dynamic bottleneck model that uses the inter-regional input–output tables of the 54 municipalities. By applying a sequential, hypothetical extraction method and simulation analysis, we clarify the recovery process of municipal economies after the stoppage and subsequent resumption of production activities in the coastal area of Aichi Prefecture. We also focus on the surrounding disaster areas of Mikawa Port and the flooded areas in the hazard map published by Aichi Prefecture.

Keywords Tsunami · Economic damage · Resilience · Input–output analysis

14.1 Introduction

In various locations around Japan, large-scale earthquakes have occurred in recent years, including the Great East Japan Earthquake in March 2011 and the Kumamoto and Oita Earthquake in April 2016. However, the Nankai Trough megathrust earthquakes are considered the most serious in near future, with the economic damage estimated to be approximately 220 trillion yen (Cabinet Office Central Disaster Management Council (2013)).

Aichi prefecture locates in the center of Japan, and its manufacturing output is the highest of all of Japan's prefectures. Important international ports locate in Aichi Prefecture, such as Nagoya Port and Mikawa Port, where many automobile-related

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industries are located. It is expected that these ports will suffer serious direct damage from earthquakes and tsunamis in the future.

Input–output analysis is a powerful tool for evaluating economic impacts at the national and regional levels (Isard (1951), Miller and Blair (2009), Shishido (2010)). Natural disaster impacts are also estimated using extended input–output/CGE models (Rose et al. (1997), Rose and Liao (2005), Okuyama (2007), Kajitani and Tatano (2014), Koks et al. (2015), Tokunaga and Okiyama (2017), Tokunaga and Okiyama (2017), Tokunaga and Resodudarmo (2017), Shibusawa and Miyata (2017a, b), Miyata et al. (2018), Kunimitsu (2018)). Shimoda and Fujikawa (2012) used the Leontief model, Ghosh model, demand and supply hybrid model, and bottleneck model to estimate indirect supply constraints from the Great East Japan Earthquake. They also estimated the impact of decreasing demand and decreased production activities in upstream and downstream industries for certain regions and sectors. Shigeta (2014) estimated the impact of the disruption of food imports in Japan on downstream industries using the bottleneck model, which measures forward linkage effects. This method is more suitable as a pricing model than the earlier Ghosh Model (which substituted input goods) and its interpretation. However, these models estimate the ripple effects from the indirect damage as a long-term impact. The indirect damage and the recovery process of regional economies in the wake of the earthquakes and the tsunami have not been adequately considered.

In this study, we construct a sequential dynamic bottleneck model by combining forward linkage and production technology for 54 municipalities in Aichi Prefecture. By applying the hypothetical extraction method sequentially (Miller and Lahr (2001), Miller and Blair (2009), Dietzenbacher and Lahr (2013)) on the basis of the initial direct damage in each industry affected by the tsunami, as well as recovery scenarios for the Nankai megathrust earthquakes, we estimate regional economies' recovery process, where goods and services are traded among sectors and regions. In addition, to assess additional supply conditions, such as supplementary goods from outside the target areas, we use a noncompetitive, import-type, inter-regional input–output table that disaggregates imports. We analyze the recovery's impact on the regional economy caused by changes in the recovery rate of the value added for each industrial sector in municipalities affected by the disaster and consider additional supply flows from outside the target areas.

14.2 Method

In this study, we construct a sequential, dynamic bottleneck model that considers the supply flow conditions of imported goods using a noncompetitive, import-type, inter-regional input–output table based on input–output tables for Aichi Prefecture. First, we show an inter-regional input–output table and define each coefficient used for this analysis. Next, we explain the static Ghosh model. We then define survival rates of the value added, which change with time after the disaster, and formulate a sequential, dynamic bottleneck model based on Leontief's production technology. Furthermore, we specify the dynamics of supply support from outside the region. Finally, we explain the data used for this analysis for the targeted affected areas using cases and scenarios in the simulation analysis.

14.2.1 Model

14.2.1.1 Inter-Regional Input–Output Table

Table 14.1 shows the model with two production sectors, whose economy consists of Region *r*, Region *s*, and other regions. Regional goods and imported goods inputted to each industrial sector are noncompetitive.

14.2.1.2 Coefficients

From Table 14.1, we define the coefficients used for this analysis: $\mathbf{A^d}$ is the input coefficient matrix for regional goods, $\mathbf{A^m}$ is the input coefficient matrix for imported goods, and $\mathbf{v}$ is the value-added coefficient column vector. These equations have the following elements: $\mathbf{X}$ is the production amount column vector, $\mathbf{Z^d}$ is the regional goods input matrix, $\mathbf{Z^m}$ is the imported goods input matrix, and $\mathbf{V}$ is the value added column vector. ^ denotes a diagonal matrix.

$$\mathbf{A^d} = \mathbf{Z^d}\left(\widehat{\mathbf{X}}\right)^{-1} \tag{14.1}$$

$$\mathbf{A^m} = \mathbf{Z^m}\left(\widehat{\mathbf{X}}\right)^{-1} \tag{14.2}$$

$$\mathbf{v} = \left(\widehat{\mathbf{X}}\right)^{-1}\mathbf{V} \tag{14.3}$$

In addition, we define the output coefficient matrix for regional goods $\mathbf{B^d}$ and the import coefficient matrix for imported goods $\mathbf{B^m}$ as follows, where $\mathbf{IM}$ is the import amount column vector.

$$\mathbf{B^d} = \left(\widehat{\mathbf{X}}\right)^{-1}\mathbf{Z^d} \tag{14.4}$$

$$\mathbf{B^m} = \left(\widehat{\mathbf{IM}}\right)^{-1}\mathbf{Z^m} \tag{14.5}$$

Table 14.1 Skeleton of an inter-regional input–output table

		Intermediate demand				Domestic Demand		Export	Import	Output
		Region *r*		Region *s*						
		Sec 1	Sec 2	Sec 1	Sec 2	Reg *r*	Reg *s*			
Region *r*	Sec 1	Z_{11}^{rr}	Z_{12}^{rr}	Z_{11}^{rs}	Z_{12}^{rs}	F_1^{rr}	F_1^{rs}	EX_1^r		X_1^r
	Sec 2	Z_{21}^{rr}	Z_{22}^{rr}	Z_{21}^{rs}	Z_{22}^{rs}	F_2^{rr}	F_2^{rs}	EX_2^r		X_2^r
Region *s*	Sec 1	Z_{11}^{sr}	Z_{12}^{sr}	Z_{11}^{ss}	Z_{12}^{ss}	F_1^{sr}	F_1^{ss}	EX_1^s		X_1^s
	Sec 2	Z_{21}^{sr}	Z_{22}^{sr}	Z_{21}^{ss}	Z_{22}^{ss}	F_2^{sr}	F_2^{ss}	EX_2^s		X_2^s
Rest of the world	Sec 1	Z_{11}^{mr}	Z_{12}^{mr}			F_1^{mr}			IM_1^r	
	Sec 2	Z_{21}^{mr}	Z_{22}^{mr}			F_2^{mr}			IM_2^r	
	Sec 1			Z_{11}^{ms}	Z_{12}^{ms}		F_1^{ms}		IM_1^s	
	Sec 2			Z_{21}^{ms}	Z_{22}^{ms}		F_2^{ms}		IM_2^s	
Value added		V_1^r	V_2^r	V_1^s	V_2^s					
Output		X_1^r	X_2^r	X_1^s	X_2^s					

14.2.1.3 The Ghosh Model with Imports

The balance formula of production and cost (summed in the direction column of Table 14.1) is as follows (Ghosh 1958):

$$\mathbf{X} = \left(\mathbf{Z^d}\right)^{\mathrm{t}}\mathbf{i} + \left(\mathbf{Z^m}\right)^{\mathrm{t}}\mathbf{i} + \mathbf{V} \tag{14.6}$$

where $\mathbf{i}$ is the column vector of 1 for obtaining a row sum. By multiplying the output coefficient by the production amount, and the import coefficient by the import amount, the distribution of input goods in production is as follows:

$$\mathbf{Z^d} = \widehat{\mathbf{X}}\mathbf{B^d} \tag{14.7}$$

$$\mathbf{Z^m} = \widehat{\mathbf{IM}}\mathbf{B^m} \tag{14.8}$$

By substituting these into Eq. (14.6) and rearranging them, the production amount can be obtained from the value added and the import amount as follows:

$$\mathbf{X} = \left(\mathbf{I} - \left(\mathbf{B^d}\right)^{\mathrm{t}}\right)^{-1}\left(\mathbf{V} + \left(\mathbf{B^m}\right)^{\mathrm{t}}\mathbf{IM}\right) \tag{14.9}$$

In Eq. 14.9, it is assumed that production uses input goods under perfect substitution technology.

14.2.1.4 Recovery Scenarios

We assume that factories were damaged by the tsunami. In our model, it is represented by declines in the value added (labor and capital). After a natural disaster, this recovers over time. The survival rates of the value added during period t are defined as follows:

$$\boldsymbol{\lambda}(t) = \left[\lambda_1^r(t), \lambda_2^r(t), \lambda_1^s(t)\lambda_2^s(t)\right]^{\mathrm{t}} \tag{14.10}$$

where $0 \le \lambda_i^z(t) \le 1\ (i = 1, 2; z = r, s)$. The damage rate is calculated as $1-\lambda_i^z(t)$. $\lambda_i^z(t)$ is the survival rate of sector i in region z during period t.

The survival rate of the value added immediately after the disaster (the first period) is given from the tsunami's damage reports, and later survival rates of the value added are increased based on the recovery scenarios and given exogenously. We assume that human and physical capital stock (value added) accumulates with the lapse of time through public funds. That is, the survival rate of the value added during period t is expressed as a function of the survival rate in the previous period.

$$\boldsymbol{\lambda}(t) = \mathbf{f}(\boldsymbol{\lambda}(t-1)) \quad (t = 1, 2, 3, \cdots) \tag{14.11}$$

14.2.1.5 The Dynamic Bottleneck Model

In this study, we use a bottleneck model with input goods distributed to the industrial sector after the disaster. However, production levels in the disaster areas drop because of the shortage of input goods. Here, we assume that production is measured based on the Leontief production function, using input goods and value added. Input goods are distributed within and outside the regions. We assume that input goods from different industrial sectors cannot be substituted but that input goods from the same industrial sectors in multiple regions can be perfectly substituted.

Before the disaster, $\mathbf{Z^d}(0)$ denotes input goods from within regions, $\mathbf{Z^m}(0)$ denotes imported goods from outside regions, $\mathbf{V}(0)$ is the value added, and $\mathbf{X^F}(0)$ is the normal production amount. Then, the survival rate of the value added, $\hat{\boldsymbol{\lambda}}(0)$, is 100%. Next, goods produced during normal times are distributed to each industrial sector in the first period. By multiplying the production amount $\mathbf{X^F}(0)$ by the domestic output coefficient $\mathbf{B^d}$, input goods in the first period, distributed to industrial sectors within regions $\mathbf{Z^d}(1)$, are defined by the following equation. With $t = 0$,

$$\mathbf{Z^d}(t+1) = \widehat{\mathbf{X^F}}(t)\mathbf{B^d}. \tag{14.12}$$

Similarly, we assume that imported goods from outside regions in normal times are distributed to each industrial sector in the first period. By multiplying the import amount $\mathbf{IM}(0)$ by the import coefficient $\mathbf{B^m}$, imported goods in the first period distributed to industrial sectors are defined by the following equation. With $t = 0$,

$$\mathbf{Z^m}(t+1) = \widehat{\mathbf{IM}}(t)\mathbf{B^m}. \tag{14.13}$$

Here, it is assumed that natural disasters occur and the value added declines. Let the survival rate of the value added be $\hat{\boldsymbol{\lambda}}(1)$ in the disaster year. The production $\mathbf{X^F}(1)$ of each industrial sector relies on the input goods $\mathbf{Z^d}(1)$, the imported goods $\mathbf{Z^m}(1)$, and the survival rate of the value added $\hat{\boldsymbol{\lambda}}(1)\mathbf{V}(0)$ under the Leontief production function. With $t = 1$, the production function in region $k(=r, s)$ and industrial sector $j(=1, 2)$ is given by the following:

$$X_j^{Fk}(t) = \min\left\{\frac{\sum_{z=r,s} Z_{1j}^{zk}(t) + Z_{1j}^{mk}(t)}{\sum_{z=r,s} a_{1j}^{zk} + a_{1j}^{mk}}, \frac{\sum_{z=r,s} Z_{2j}^{zk}(t) + Z_{2j}^{mk}(t)}{\sum_{z=r,s} a_{2j}^{zk} + a_{2j}^{mk}}, \frac{\lambda_j^k(t)V_j^k(0)}{v_j^k}\right\} \tag{14.14}$$

Immediately after stopping production, the input goods can be secured as they would be secured in normal times; hence, the production amount $X_j^{Fk}(1)$depends only on the survival rate of the value added (survival labor and capital). Therefore, in region k,

$$X_j^{Fk}(1) = \lambda_j^k(1) X_j^{Fk}(0) = \frac{\lambda_j^k(1) V_j^k(0)}{v_j^k} \tag{14.15}$$

In other words, the decline in production due to disasters in the first period is explained by a decline in the value added (labor and capital). After the second period, the reduced production is distributed to each industrial sector. We repeat the above calculation until the eleventh period.

14.2.1.6 Supply Support from Surrounding Regions

In the restoration and reconstruction process, additional supplies from outside regions are provided in addition to existing imports. When the value added of the affected industrial sectors is restored, production capacity in the industry expands. However, since there is a time lag before the recovery of production activity in the surrounding regions, it takes more time for all affected regions to recover. Therefore, to recover quickly, it is necessary to supply additional imported goods from outside regions. We consider that the additional supply of imported goods has a mitigating effect on production bottlenecks.

In this analysis, if production in the recovery period does not reach normal production levels, we consider that imported goods from outside regions are insufficient. In each period, we calculate the difference (shortfall) between production amounts in each industrial sector and production amounts in normal times, which are added to the imports distributed as the next input goods. The import amount $\mathbf{IM}(t)$ in period t and the distributed import goods $\mathbf{Z^m}(t+1)$ are defined as follows:

$$\mathbf{IM}(t) = \mathbf{IM}(0) + \left(\mathbf{X}(0) - \mathbf{X^F}(t-1)\right) \tag{14.16}$$

$$\mathbf{Z^m}(t+1) = \widehat{\mathbf{IM}}(t)\mathbf{B^m}. \tag{14.17}$$

14.2.2 Data and Area

We construct a noncompetitive, import-type, inter-municipal input–output table for 54 municipalities in Aichi Prefecture on the basis of the 2011 Aichi Prefecture Input–Output table using various socioeconomic statistical data (for example Aichi Prefecture (2016); Japan Statistics Research Institute of Hosei University (2017)); a gravity model; and the RAS method (Yamada and Owaki (2012), Shibusawa and Miyata (2017a), Shibusawa and Hanaoka (2018), Shibusawa et al. (2019)). The industries are classified into four sectors: (1) agriculture, forestry, and fisheries, (2) mining and manufacturing, (3) construction, and (4) services.

We assume two disaster areas: (a) the coastal area of Mikawa Port and (b) the tsunami-flooded areas of Aichi Prefecture, as shown Fig. 14.1. The tsunami-flooded areas are based on a hazard map published by Aichi Prefecture (2014) and selected

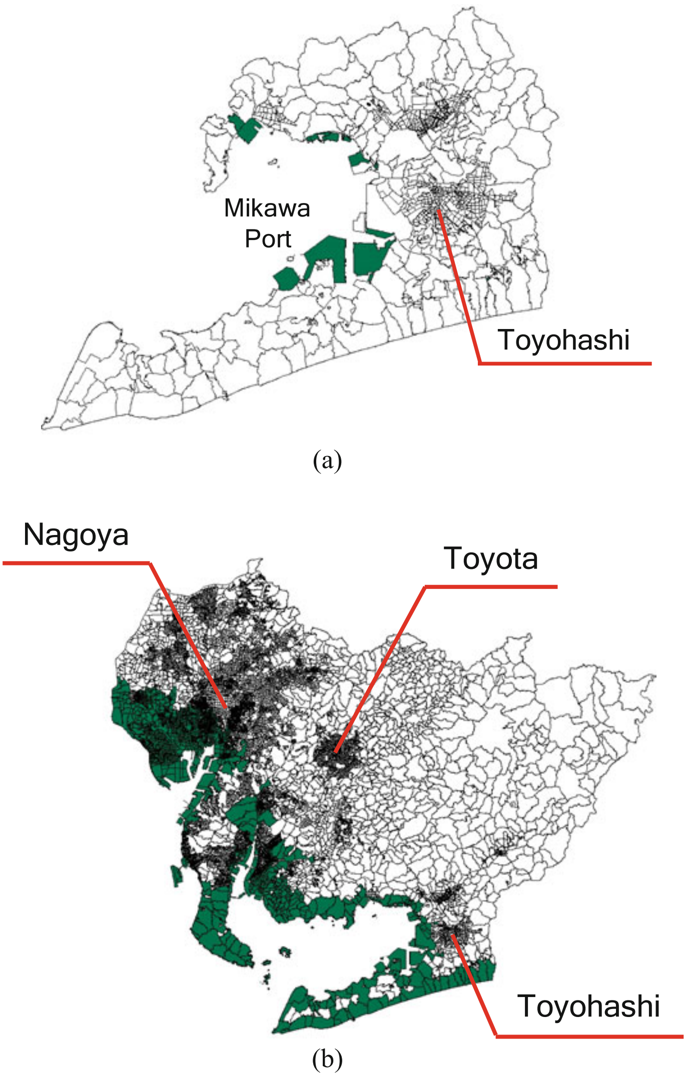

Fig. 14.1 Disaster areas. (**a**) Coastal area of Mikawa port. (**b**) The flooded areas in aichi prefecture

using a small district unit and ArcGIS's space selection feature. The coastal area of Mikawa Port is included in the tsunami-flooded areas; however, we focus on the coastal area because it is an important area where the manufacturing industries of the East Mikawa area in Aichi Prefecture are concentrated. This area is the subject of our analysis.

Immediately after the disaster (the first period), we assume that production activities in all industrial sectors end in the selected area. The damage rate for each municipal industrial sector is given by the proportion of the number of employees in affected areas to the number of employees in the "2014 Economic Census (Ministry of Internal Affairs and Communications of Japan 2016)." Figure 14.2 shows the number of employees by each municipal industrial sector in normal times.

14.2.3 Cases and Scenarios

We assume that two areas in the coastal area of Mikawa Port are damaged and that the tsunami also damaged areas in Aichi Prefecture. We set three scenarios for each case and analyze what kind of recovery takes place in the affected areas and surrounding regions. The outline of each scenario is as follows. We define the restoration process by the following equation, with an upper limit of 100%:

$$\lambda_j^k\,(t+1) = \lambda_j^k(1) + \alpha \bullet t \;\; (t = 1, 2, 3, \cdots)\,. \tag{14.18}$$

Basic Scenario
The damage rate recovers by 10% every period ($\alpha = 0.1$).
Optimistic Scenario
The damage rate recovers by 20% every period ($\alpha = 0.2$).
Pessimistic Scenario
The damage rate does not change (does not recover) ($\alpha = 0$).

14.3 Results

As the initial condition immediately after the disaster, the damage rate is given by *the number of employees in the assumed area affected ÷ by the number of employees in normal times × 100*.

In addition, the production amount in the first period is derived by multiplying the value added by the survival rate *(1—damage rate)* and dividing the result by the coefficient of the value added. The change rate of production amount within a municipality is given by the *(the production amount at the time of the disaster - the production amount in normal times) ÷ by the production amount in normal times × 100).*

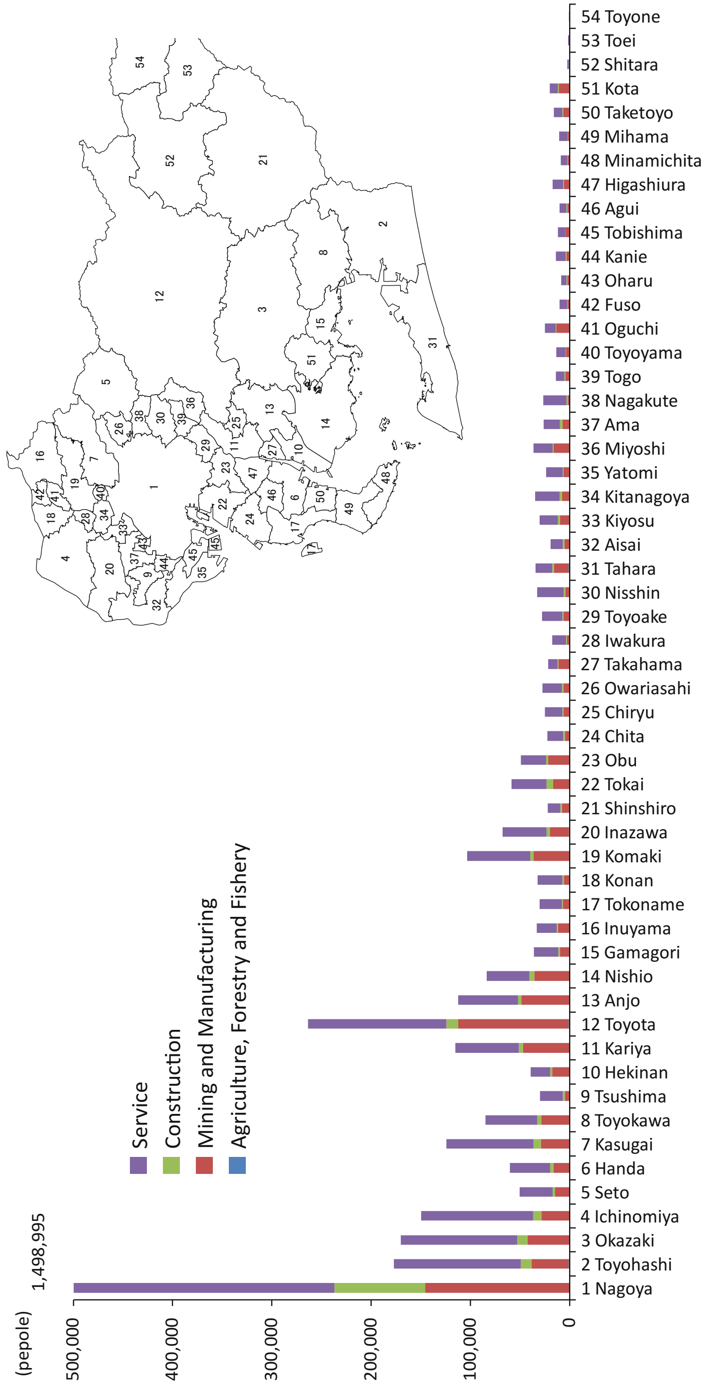

Fig. 14.2 Number of employees in normal times

14.3.1 The Coastal Area of Mikawa Port

Our simulation is based on the initial damage rate immediately after the disaster, using the dynamic bottleneck model, while reducing the damage rate to the value added (increasing the survival rate) based on three scenarios for eleven periods. Figure 14.3 shows the reduction rate of production for each scenario in the damaged coastal area of Mikawa Port.

Basic Scenario
In the four municipalities surrounding Mikawa Port (Toyohashi City, Toyokawa City, Gamagori City, and Tahara City), production dropped sharply immediately after the disaster (the first period), but tended to recover over time. In other municipalities, from the second period, production amounts declined because of negative supply chain constraints in the affected areas and production technology bottlenecks. However, recovery occurred after the third period. In the eleventh period, the change rates of production in all municipalities were almost 0%, and consequently, they recovered to normal production amounts.

Optimistic Scenario
In a manner similar to the basic scenario, production amounts in the four municipalities surrounding Mikawa Port greatly declined in the first period; however, they recovered faster than in the basic scenario. In Tahara City, which was the most damaged area, production recovered to its normal levels as early as the fourth period. Other municipalities' production amounts indirectly began to decline because of a negative forward linkage during the second period. This decline of several percentage points recovered over time.

Pessimistic Scenario
In a manner similar to both the previous scenarios, production amounts in the four municipalities surrounding Mikawa Port greatly declined in the first period. However, in this case, since the value added of the four municipalities had not recovered, other municipalities also began to be negatively influenced during the second period because later production continued to remain flat.

14.3.2 Tsunami-Flooded Areas in Aichi Prefecture

Our simulation is based on the initial damage rate conditions immediately after the disaster using the dynamic bottleneck model. We reduced the rate of damage to the value added (the survival rate increased) based on three scenarios until the eleventh period. Figure 14.4 shows the reduction rate in production for each scenario where tsunami-flooded areas in Aichi Prefecture were damaged. Figure 14.5 shows the spatial impacts of the basic scenario.

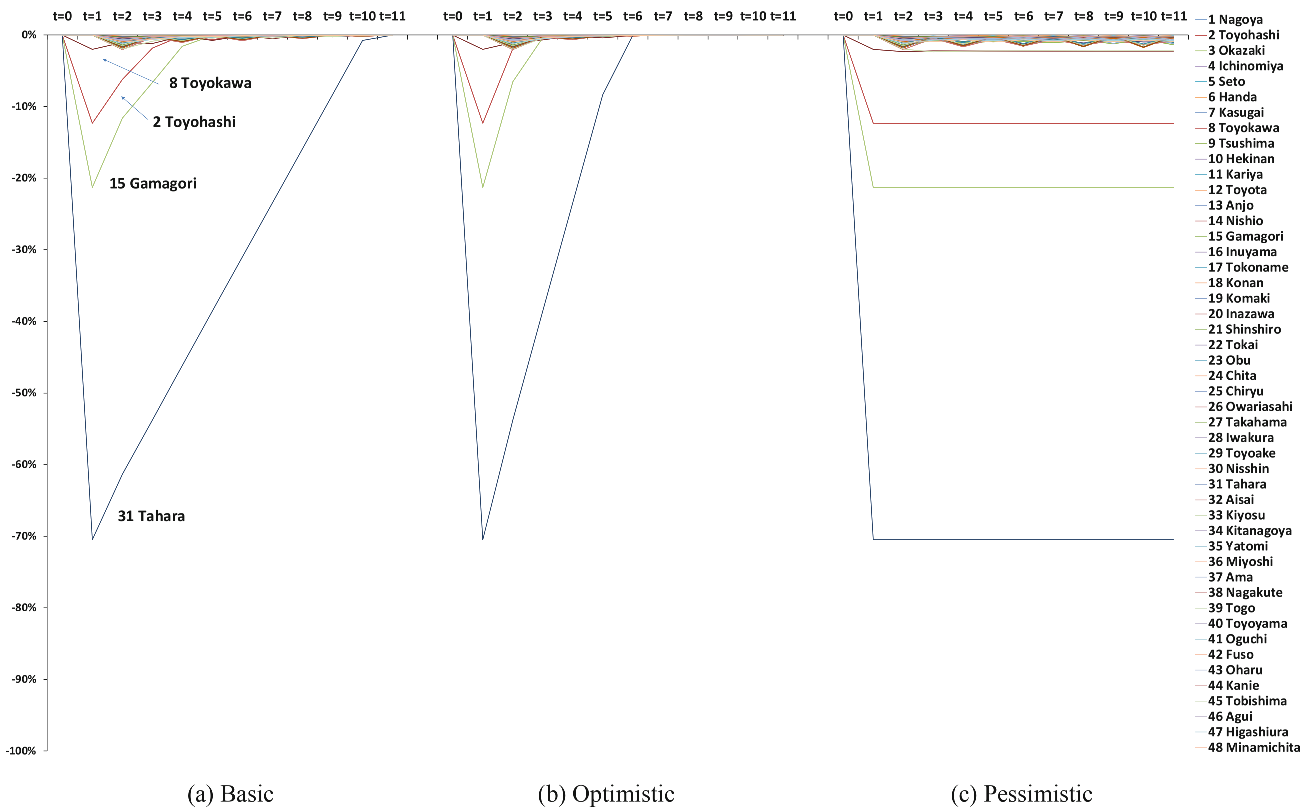

Fig. 14.3 Reduction rates in production in the coastal area of Mikawa Port. (**a**) Basic. (**b**) Optimistic. (**c**) Pessimistic

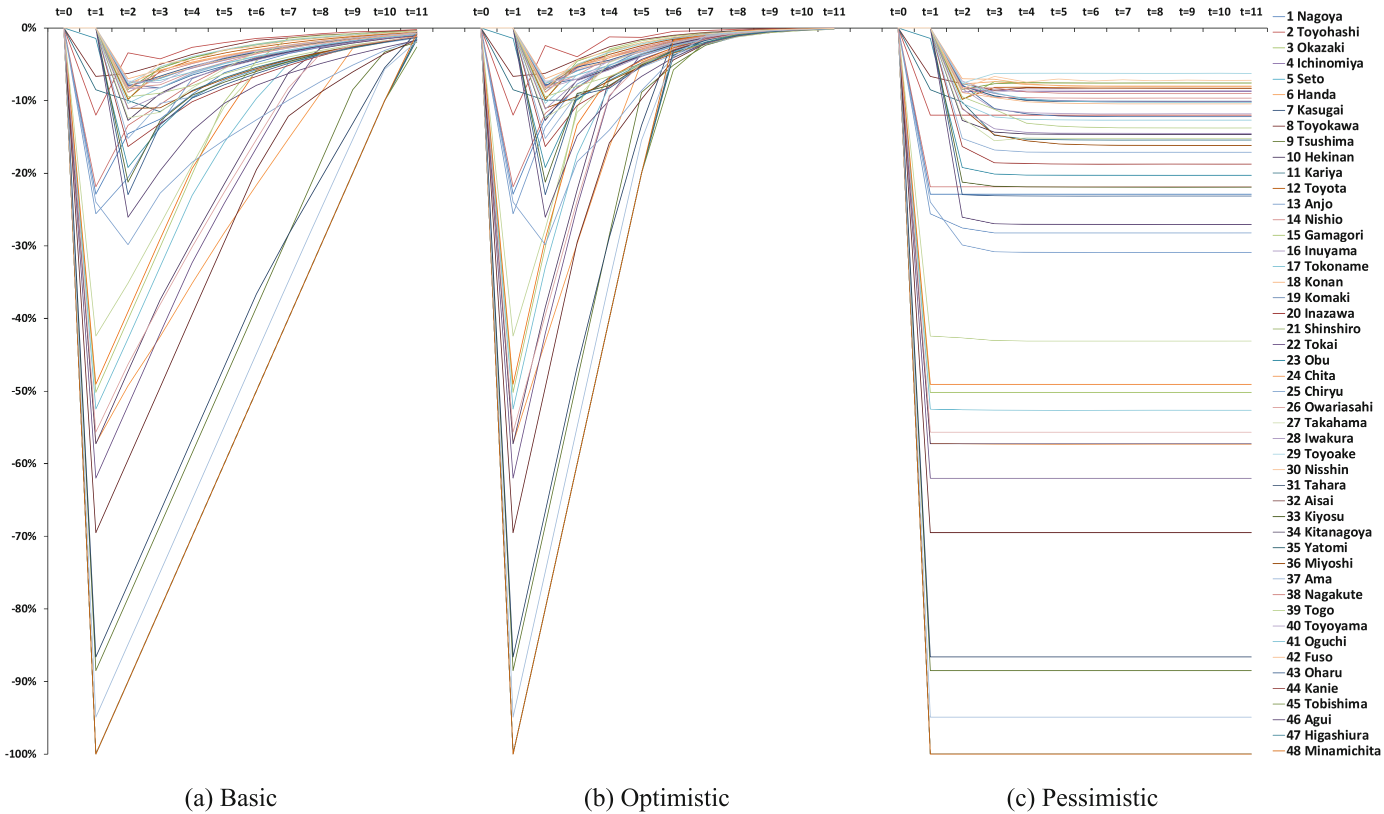

Fig. 14.4 Reduction rates in production for each scenario. (**a**) Basic. (**b**) Optimistic. (**c**) Pessimistic

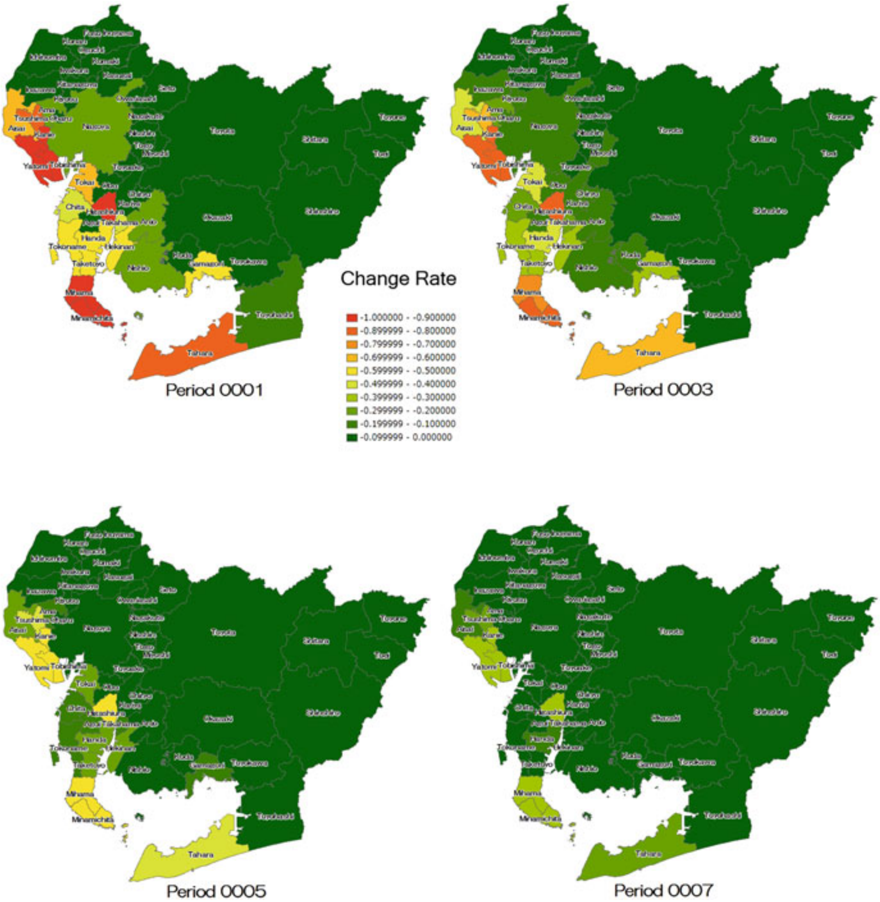

Fig. 14.5 Spatial impacts of disaster

Basic Scenario
In the affected municipalities, production greatly declined in the first period but recovered over time. In municipalities that did not suffer from the disaster, production amounts declined because of the affected municipalities. Finally, in each municipality, changes in the rate of production recovered to -1% but did not recover completely during the eleven periods.

Optimistic Scenario
Production in the optimistic scenario was similar to that of the basic scenario; however, it recovered more quickly, with each municipality returning to normal production levels during the eleven periods. Consequently, this scenario showed the largest production recovery.

Pessimistic Scenario
Recovery in the affected municipalities did not occur after the production decline in the first period, and the situation remained flat. In municipalities that did not suffer from the disaster, production declined after the second period because of the influence of the affected municipalities. Thereafter, though, there was still no recovery, and the situation continued to remain flat.

14.3.3 Sectoral Recovery Process After the Tsunami

Figure 14.6 shows the sectoral recovery process in certain municipalities in terms of output reduction rate after the disaster in the case of the tsunami-flooded areas in Aichi Prefecture. To observe the sectoral impacts, we chose Toyohashi City, Toyokawa City, Gamagori City, Tahara City, Nagoya City, Kariya City, Toyota City, and Agui Town in Aichi Prefecture. In this figure, a red bar means the direct damage in the first period.

Nagoya City and Kariya City are located in the coastal area and are directly damaged by the disaster. Nagoya City is the capital city in Aichi Prefecture, and it has Nagoya Port. In Kariya City, there are many automotive-related companies are located in the area. Toyota City is located inland and has a concentration of major automotive companies. Agui Town is located between Ise Bay and Kinuura Bay. Both Toyota City and Agui Town are indirectly affected by the disaster.

14.4 Conclusion

We simulated the recovery process of municipal economies in Aichi Prefecture based on the stoppage and subsequent restoration of production activity in the coastal area of Mikawa Port and the tsunami-flooded areas using a sequential, dynamic input–output model. For the basic and optimistic scenarios in the coastal area of Mikawa Port, all municipalities recovered to normal production levels, even in tsunami-flooded areas.

Regarding the transition of production amounts, production declines generally tended to converge during the simulated periods. Regions with relatively high damage rates were strongly affected by direct damage and restoration scenarios, whereas regions with relatively low damage rates and those without disasters were only indirectly negatively impacted by the affected regions. It was also shown that the former occurs immediately after the disaster and the latter tends to occur with a time lag.

In this study, we focused on the four municipalities surrounding Mikawa Port, distinct from the coastal port of Mikawa, where the tsunami flooded a total of 25 municipalities. In the latter case, even if individual industrial sectors had been restored, the overall regional economy would not have recovered fully because of

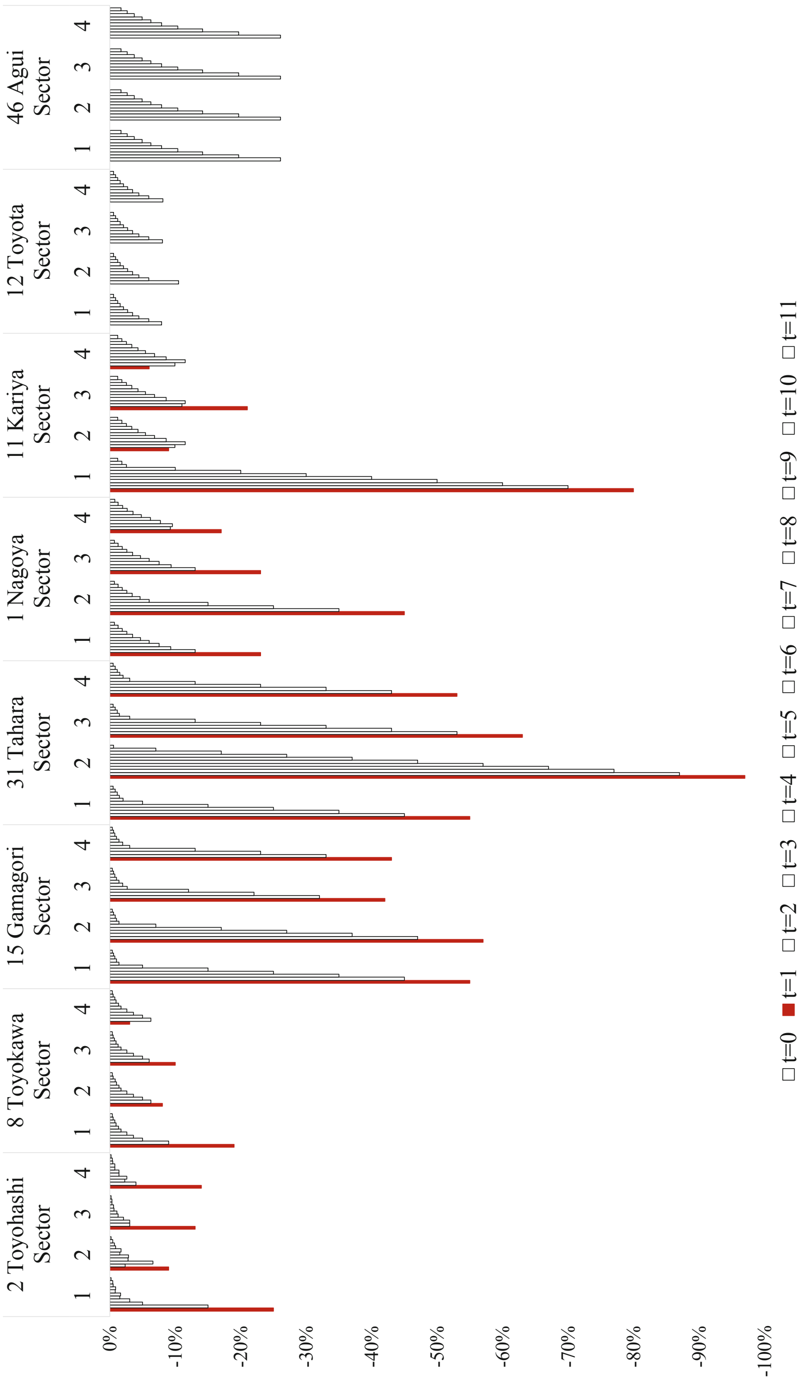

Fig. 14.6 Reduction rates in production by sector

supply restrictions and linkages in bottleneck production technology. A simulation was conducted in this chapter under the condition that input goods were supplied from outside the target regions, allowing regional economies to recover relatively quickly. However, large-scale disasters also affect surrounding regions; hence, a steady supply from these regions cannot be expected.

As a task for the future, we will design various policy scenarios, timed at earlier stages of disasters, in the event supplies from outside regions to affected regions, are not sufficient (e.g., labor and capital movement from outside the prefecture, efficient methods of distributing imported goods, and dealing with stock). We will then compare this scenario with the present one. This type of analysis can be applied to other types of natural disasters that are accompanied by time lag as seen in the Kumamoto-Oita Earthquake.

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Chapter 15
Spatial Analysis of Climate Change Impacts on Regional Economies Through Japan's Rice Production Changes and Innovative Food Industry Cluster: Using the Nine Interregional CGE Model

Suminori Tokunaga, Mitsuru Okiyama, and Maria Ikegawa

Abstract Based on the assumption that only rice is affected by global warming-induced climate change, the present study measures the impact of climate change on regional economies through changes in Japan's rice production and economic effects of innovative food industry clusters to recover from climate change. Our findings show that global warming has different impacts on each region and expands regional economic disparities. For example, global warming has a positive impact on regional economies in Hokkaido and Tohoku. Meanwhile, global warming has negative impacts on Chugoku, Shikoku, and Kyushu. Moreover, in most regions, the food and beverage industries will have a negative impact by global warming except the case that the production of agricultural food products will be positively affected in Hokkaido. Also, assuming that adaptive technologies such as high-temperature-tolerant rice varieties are developed in each region, the impact on climate change on rice production will be reduced. However, regional economies other than Hokkaido and Tohoku will continue to be negatively affected, and regional disparities are not completely resolved. Considering this result, we carried out the simulation to form the food industry cluster that links cooperation agriculture and food processing industry. As a result, we found that innovative food industry cluster is worth considering as measures against global warming to each regional economy.

Keywords Climate change impacts · Regional economy · Japan's rice production · Innovative food industry cluster · Nine interregional CGE model

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15.1 Introduction

There is ongoing scholarly debate on the problem of global warming since the 1980s. In the midst of the debates, "Intergovernmental Panel on Climate Change" (IPCC) was set up in 1988 as a forum to study global warming and review measures to reduce greenhouse gas (GHG) emissions, a major cause of global warming. It is believed that agriculture production would be most affected by climate changes induced by global warming. This, in turn, would affect the food and beverage industries that depend on the agriculture industry for the inputs. In 2017, the Japan Meteorological Agency (JMA) projected climate change in Japan based on the non-hydrostatic regional climate model using IPCC GHG emission scenario RCP8.5. The projection reveals that the annual mean temperature might increase by about 4.5 °C in the national average by the late twenty-first century (2076–2095 average), based on the average from the late twentieth century (1980–1999 average). This scenario depicts the highest GHG emissions and the rise in temperature are predicted based on the assumption that no policies will be implemented to curb GHG emissions that exceeds the present time. For example, Tokyo's current annual average temperature (from 1981 to 2010) is 15.4 °C. In this scenario, Tokyo's temperature will rise further by 4.3 °C by the late twenty-first century, which will be close to the current annual average temperature of Yakushima (19.4 °C).

The impact of climate change on the production of agricultural products in Japan has been studied earlier (Nishimori and Yokozawa 2001; Shimono 2008; Yokozawa et al. 2009). Most of these studies have focused on rice production and derived their findings based on models reflecting the actual rice growth conditions, variations in annual yield, and regional differences in climate conditions. These studies identified the consequences of climate change on rice yield and its quality as well as regional differences using chronological regional panel data including climate variables, such as specific periods after the rice-heading season, minimum and maximum daily temperatures, and solar radiation. For example, Yokozawa et al. (2009) approximated that the average national rice yield was expected to increase slightly or stay constant until the temperature rose by approximately 3 °C during the warm season from May to October. Moreover, if the temperature rise were to exceed 3 °C, the rice yield might reduce in various regions, except in Hokkaido and Tohoku. These forecasts are based on crop models among others, and the studies do not consider the impact on the macro-economy. But, Hasegawa et al. (2012) and Fujimori et al. (2018) analyze the impact on macroeconomics through a change in yield of agricultural crop due to future climate change using both the crop model and the CGE model across the world including Japan. Conversely, Kunimitsu (2015) and Tokunaga et al. (2017b) analyzed the impact on the regional economy of Japan through variations in rice production due to future climate change using the CGE model. Tokunaga et al. (2017b) found that a global warming will increase rice production in Hokkaido and Tohoku, production will decrease in the west of Kanto, with a 0.29–1.04% national decline. Meanwhile, production in Hokkaido will see a double-digit increase of 13.99% in case of the maximum value and an

8.16% increase in case of the minimum value. In addition, production in Tohoku, the largest producer of rice, will increase by 2.46–3.25%.

In the present study, Tokunaga et al. (2017b) have extended at three following points. First, a CGE model for nine regions (we call 9SCGE model) is developed instead of a CGE model for six regions. Second, The JMA's projections in 2017 are used instead of that in 2013. Thirdly, a scenario setting of global warming simulation with adaptation technology is carried out under assumption that development of high-temperature-tolerant rice varieties has resulted in curbing global warming-induced productivity decline. Fourthly, a scenario setting of global warming simulation with adaptation technology and food industry cluster is carried out under assumption that the west of Kanto will form an innovative food industry cluster that uses rice as a raw material whose value as a product is lost as a result of this decline in quality due to global warming in addition to the developing adaptation technology for global warming.

This chapter is organized as follows. Section 15.2 presents the estimated results of the rice yield production function, which includes climate variables using panel data for nine regions and studies the regional changes in the rice yield based on the JMA's future temperature projections (2017). Section 15.3 provides an overview of the nine regional SAMs and the 9SCGE model. Section 15.4 explains the data that includes the premise of simulations, and analyzes the results, especially the economic effects of innovative food industry cluster. Finally, Section 15.5 presents the conclusion and the policy implications.

15.2 Estimation of Regional Rice Yield and Prediction of Future Temperature

15.2.1 Estimation of Regional Rice Production Function

In this section, we conduct a panel data analysis to examine the impact of long-term climate change on rice production in Japan and add the lagged output and temperature variables. We estimate the dynamic panel data model for the rice yield, which is the production per cultivated land in the nine regions (Hokkaido, Tohoku, Hokuriku, Kanto-Tosan, Tokai, Kinki, Chugoku, Shikoku, and Kyushu) for a sample period from 1996 to 2009. These regional data were used by Okiyama et al. (2013) and Tokunaga et al. (2015, 2017b). We formulated the production function for rice yield by incorporating the point at which the temperature exceeds a certain level and the impact of high-temperature injury becomes larger and, as pointed out by Yokozawa et al. (2009), "yield decreases when temperature exceeds a certain point."

We then estimated the production function for rice yield with the mean temperature using the GMM. The results are shown Eq. (15.1) in Table 15.1. All variables are explained as follows. Y_{it} and Y_{it-1} represent the production of region i in year t and year $t-1$, respectively (unit in tons); $Land_{it}$ and $Land_{it-1}$ represent the

Table 15.1 Estimated production function for rice yield

Variables	Equation (15.1) ln (Y_{ti}/$Land_{ti}$)
ln ($Y_{t-1,i}$/$Land_{t-1,i}$)	0.1099 (4.21)$_{***}$
ln (K_{ti}/$Land_{ti}$)	0.0515 (2.21)$_{**}$
$terms_{ti}$	0.1429 (2.65)$_{***}$
$(tems_{ti})^2$	−0.0037 (−2.63)$_{***}$
D2003	−0.1614 (−3.16)$_{***}$
Constant term	0.1043 (0.20)
Wald χ^2	67.90
Prob > χ^2	0.000
Current sample period	1995–2009
Number of regions	9
Number of observations	117

Note 1: $_{***}$<0.001, $_{**}$<0.05, $_{*}$<0.1, *z*-statistics in parentheses

Note 2: Arellano-Bond dynamic panel-data estimation. Instruments for differenced equation are GMM-type: L(2/6).y_land, standard: D.capital_land D.tems D.tems_2 D.D2003

Source: Tokunaga et al. (2017b), Table 1b in p.564

cultivated area of region i in year t and year $t - 1$, respectively (unit in hectares); K_{it} represents the total real amount of fixed capital expended by all rice-farming households in region i in year t (unit in million yens); $tems_{it}$ represents the mean temperature from April to October for region i in year t; and D_{2003} is a dummy variable for 2003 given that it was a lean year in all areas of Japan. $temp_{it}^2$ represents the square of the temperature variable and is reflected in high-temperature injuries. For the Eq. (15.1), the coefficients of the variables for capital stock per cultivated land and lagged rice production per cultivated land are positive and statistically significant. The coefficient of the variable for the mean temperatures from April to October is positive and statistically significant, whereas the coefficient of the variable for the square of the mean temperature from April to October is negative and statistically significant. These results show that the impact of high-temperature injury becomes larger and "yield decreases when temperature exceeds a certain point," as pointed out in previous studies. Figure 15.1 presents the changes in rice yield using this elasticity for every 0.5 °C increase in the 1995–2009 mean temperature. This figure also points out that while yield growth slows down in Hokkaido as temperature increases, growth does not turn negative even if the temperature increases by 4 °C. However, in Tohoku, growth turns negative when the temperature increases by approximately 2.0 °C and the yield decreases when the temperature increase exceeds 4 °C. In the other regions, the yield decreases when the temperature increases by 0.5 °C from the 1995–2009 mean temperature and decreases exponentially when the temperature increases even further.

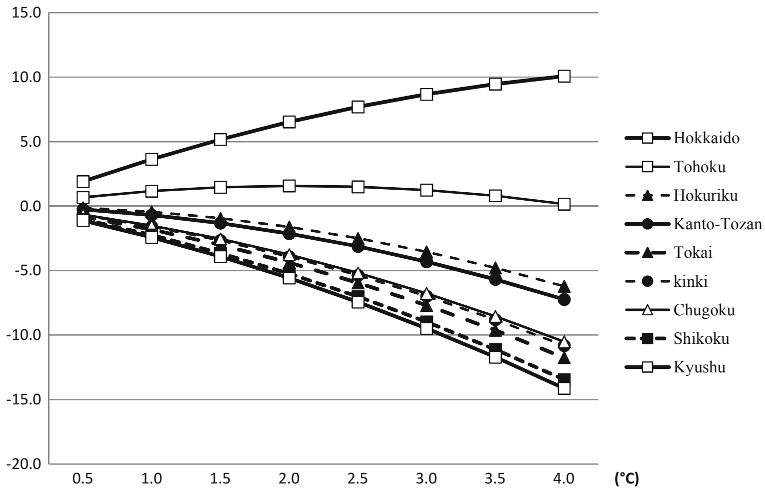

Fig. 15.1 Changes in the regional rice yield by rise in temperature. Source: Tokunaga et al. (2017b), Fig. 2 in p. 565

15.2.2 Prediction of Future Temperature and Regional Rice Yield

Next, we estimate the maximum, mean, and minimum values of the April–October mean temperatures for the future climate (2076–2095 average) based on the present climate (1980–1999 average) of the nine regions and the future climate (2076–2095 average) predicted by the JMA (2013) and the regional changes in mean temperature and standard deviation. The results are shown in column (b) of Table 15.2. Future temperatures in Hokkaido will increase up to a level that was slightly lower than Tohoku's 1990–2009 mean temperature, whereas future temperatures in Tohoku will increase up to a level that is on par with the 1990–2009 mean temperature of Kanto-Tosan. Whereas future temperatures in Tokai and the region west of Tokai will increase to 23–24 °C in terms of the April–October mean temperature, they will not reach Okinawa's 1990–2009 mean temperature (26.7 °C for April–October). Column (d) of Table 15.2 presents the results of the estimation of the regional rice yield growth rate calculated from the rate of increase in the regional future temperature shown in column (c) of Table 15.2. The following points were reviewed based on this table. Rice yield in Hokkaido and Tohoku will not become negative even if future temperatures increase to the maximum value. In the other regions, rice yield is negatively affected even if the future climate remains at the minimum value. In particular, rice yield will decrease by 3.89% in Kyushu and 6.18% in Shikoku. The regional differences in the yield growth rate show that, unlike Hokkaido, which will be most positively affected by temperature increases,

Table 15.2 Regional future temperature increase rate and regional prediction of the rice yield growth rate

Region %	(a) Current (1990–2009) average temperature during April–October	(b) Future (2076–2095) average temperature during April–October			(c) Changes in average temperature during April–October from 2005 to 2076–2095			(d) Changes by a rise in temperature from 2005 to 2076–2095: Rice production per land		
		Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
Hokkaido	14.0	19.2	18.4	17.6	36.9	31.3	25.7	12.10	11.84	11.06
Tohoku	17.2	22.0	21.2	20.5	27.9	23.5	19.0	−1.52	0.01	1.06
Hokuriku	19.2	23.9	23.1	22.4	24.6	20.7	16.9	−9.22	−6.53	−4.31
Kanto-Tozan	19.6	24.1	23.3	22.6	22.9	19.1	15.3	−9.98	−7.17	−4.81
Tokai	20.9	25.1	24.4	23.7	20.3	16.9	13.5	−13.22	−9.91	−7.02
kinki	20.5	24.9	24.2	23.5	21.2	17.8	14.3	−12.41	−9.26	−6.52
Chugoku	20.4	24.5	23.8	23.1	20.0	16.7	13.4	−10.43	−7.71	−5.37
Shikoku	22.0	26.4	25.7	25.1	20.2	17.1	14.1	−18.98	−15.14	−11.68
Kyushu	21.5	25.5	24.9	24.3	18.5	15.6	12.7	−13.49	−10.37	−7.57

Shikoku—the most negatively affected—will see a 21.6%-point difference for the maximum value and a 14.3%-point difference for the minimum value.

15.3 Structure of the Nine Regional Computable General Equilibrium Model

This section explains the framework of analysis to simulate the effects of global warming on regional economies through rice production. First, the database used for the 9SCGE model is the nine interregional SAM, which includes the interregional input–output table of competitive imports for the nine regions of Hokkaido, Tohoku, Kanto (the seven prefectures of the Kanto area in addition to the four prefectures of Niigata, Nagano, Yamanashi, and Shizuoka), Chubu (the five prefectures of Toyama, Ishikawa, Gifu, Aichi, and Mie), Kinki (the six prefectures of the Kinki area plus Fukui prefecture), Chugoku, Shikoku, Kyushu, and Okinawa. The data sources for the SAM include the input–output tables of the 2005 Ministry of Internal Affairs and Communications report for Japan; the 2005 Ministry of Economy, Trade, and Industry's nine interregional input–output table and its nine intraregional input–output tables of competitive imports; and the Cabinet Office's fiscal 2005 Prefectural Accounts for 47 prefectures.

Next, the 9SCGE model, which comprises 20 agents (one household, 16 industries, one company, one regional government, and one investment bank) in the nine regions, is developed.[1] Two agents, that is, the central government and overseas sector, are added. In addition, the marker includes 16 commodity markets; three production factor markets of agricultural land, labor, and capital in the five agriculture sectors (rice, wheat and potatoes, vegetables, fruit trees, and livestock); and two factor markets of labor and capital in the nonagricultural sectors.[2] Then, each endowment of agricultural land, labor, and capital is exogenously fixed, and it is assumed that there are no transfers outside the region, although agricultural land can shift between agriculture sectors and both labor and capital can move between industries within the region.

Next, the main structure of domestic production and households in the 9SCGE model is elucidated.

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[1]For the static spatial CGE model, see Tokunaga et al. (2003), Ban (2007), EcoMod Modeling School (2012), Okiyama and Tokunaga (2016), and Tokunaga et al. (2017).

[2]"Agriculture land" means "the total amount of rent." We calculate land rent and owned land rent per cultivated land and owned land rent per farmer based on the "Statistics on Production Cost," the "Report of Statistics Survey on Farm Management and Economy," and the "Statistics on Crops" by the Ministry of Agriculture, Forestry, and Fisheries. The total amount of rent can be found by multiplying the rent per cultivated land or farmer by the total cultivated land or total farmers. Therefore, we can obtain the capital in agriculture sectors by deducting the total amount of rent from the sum of operation surplus and compensation of capital stock in the SAM. In addition, the households in the SAM can provide the total amount of rent as household income.

1. Domestic production sector

The domestic production sector includes the nested production structure (Fig. 15.2a). Each production sector $a(a \in A)$in region $o(o \in S)$is assumed to produce XD_a^o of one commodity $c(c \in C)$, maximize their profits, and face a multilevel production function. First, the structure of agriculture production on the left is explained. In Level 1 (A1), an industry in sector a constrained by Leontief technology takes the production function using each intermediate input good XC_{ca}^o aggregated from the 16 commodities and the added value RKL_a^o as demand of an agricultural land–capital–labor bundle by the firms. Because the producer price PD_a^o of sector a in region o holds true for the "zero-profit condition," it follows that income equals production costs. In Level 2 (A2) on the right, we derive the intermediate goods aggregated for the 16 commodities from the composite commodity according to the Armington assumption XX_{ca}^{do} input from origin $d \in R$ in region d under the constraint of constant returns-to-scale CES technology and the o intraregional composite commodity according to the Armington assumption XX_{ca}^{oo}. In addition, we derive PXC_{ca}^o, the price of the intermediate goods aggregated from sector a of region o, by the income definition, considering the zero-profit condition

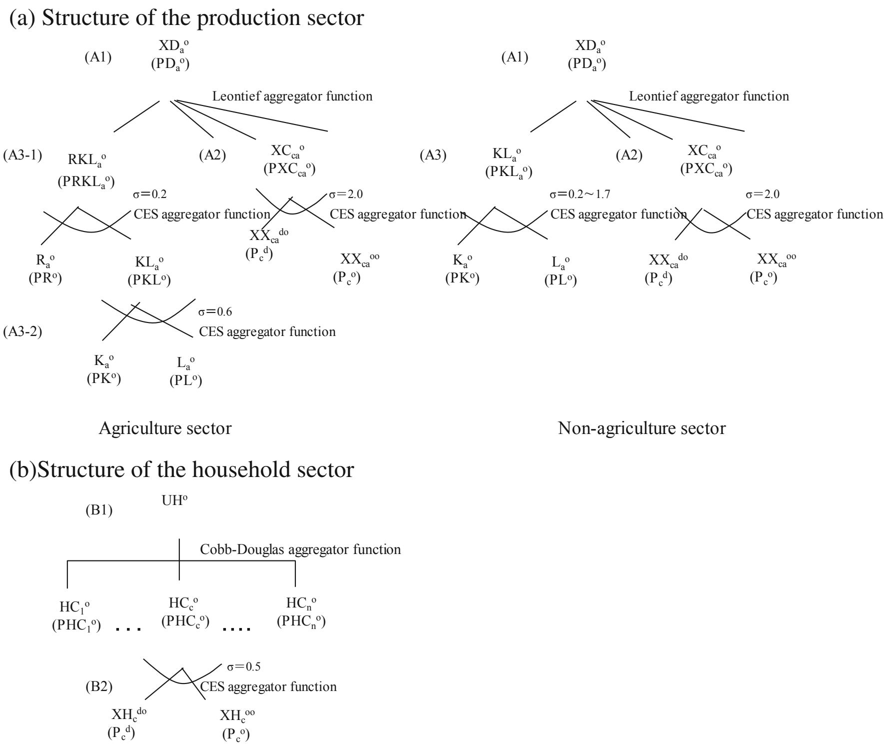

Fig. 15.2 (**a**) Structure of the production sector. (**b**) Structure of the household sector

for intermediate goods. By contrast, in Level 2(A3), the added-value portion consists of two levels. In Level 1 (A3–1), we derive RKL_a^o from agricultural land R_a^o and the capital–labor bundle by the firms $\left(KL_a^o\right)$ from sector a of the destination region o under the constraint of constant returns-to-scale CES technology. Furthermore, in Level 2 (A3–2), we derive KL_a^o from capital K_a^o and the labor L_a^o under the constraint of constant returns-to-scale CES technology. Then, each price level of $PRKL_a^o$ and PKL_a^o holds true for the zero-profit condition. Since there can be variation in the use of agricultural land, the rent PR^o is identical for agriculture sectors, and the return to capital PK^o and wage rate PL^o are identical for all industries in region o because they can shift between industries within region o.

Next, the structure of nonagricultural production on the right is elaborated. In Level 1 (A1), an industry in sector a constrained by the Leontief technology takes the production function using each intermediate input good XC_{ca}^o aggregated from the 16 commodities and the added value KL_a^o. In Level 2 (A2) on the right, we derive the intermediate goods aggregated for the 16 commodities from the composite commodity in line with the Armington assumption XX_{ca}^{do} input from origin $d \in R$ in region d under the constraint of constant returns-to-scale CES technology and the o intraregional composite commodity based on the Armington assumption XX_{ca}^{oo}. In addition, even the added-value portion (A3) is derived from capital K_a^o and labor L_a^o from sector a of destination region o under the constraint of constant returns-to-scale CES technology similarly as the intermediate goods sector. As the producer price PD_a^o of sector a in region o holds true for the zero-profit condition, it follows that income equals production costs. Finally, we arrive at PXC_a^o, the price of the intermediate goods aggregated from sector a in region o(by the income definition), considering the zero-profit condition for intermediate goods.

2. Household sector

In the household sector, we derive the behavior maximizing the level of household utility UH^o (Fig. 15.2b). At Level 1 (B1), households in the destination region o maximize the linear-homogeneous Cobb-Douglas utility function for goods HC_c^o aggregated under budgetary constraints $CBUD^o$. In addition, at Level (B2), we obtain the aggregated goods from the composite commodity consistent with the Armington assumption XH_c^{do} imported from region d in origin region $d \in R$ under the constant returns-to-scale CES technology constraint and the intraregional o composite commodity based on the Armington assumption XH_c^{oo}. Furthermore, we derive the price PHC_c^o of aggregated goods c (by the income definition), considering the zero-profit condition for such goods. Household income comprises employment income, capital income, social security benefits, property income, and receipts from other current transfers. Household budget $CBUD^o$ comprises payments of income tax from household income, household savings, social contributions, and payments from property income as well as other current transfers. Household savings are calculated from household income, assuming the fixed propensity to save.

3. Other sectors

The savings and investment sector has a similar structure to the household sector. The 9SCGE model is closed to prior savings, and in terms of investment, an agent called a "bank" allots savings S^o to investment demand IC_c^o from 16 goods in accordance with the linear-homogeneous Cobb–Douglas utility function. The savings here include the savings of household SH^o, company SN^o, regional government SLG^o, and central government SCG^o, in addition to income transfers SDB^o and overseas savings SF^o to offset the interregional current account balances. Hayashiyama et al. (2011), Okiyama and Tokunaga (2016), and others used a static interregional CGE model to indicate that income transfers are positive for savings in each region. In the structure of the trade sector, although it includes exports and imports between each region and the foreign sector, trade also occurs through imports and exports between regions. Finally, the relationship between regional and central governments, which coexist, is elucidated. The central government itself does not engage in spending. Instead, its function is to reallocate the taxes it collects to the nine regional governments and to create savings by taking a fixed proportion of the tax revenue and allocating it to the savings sector of the nine regions. Meanwhile, the governments in the nine regions have budgets that contain the differences between the revenues generated from tax receipts and regional allocation tax grants, among others, and the subsidies disbursed to each production sector. These budgets are then multiplied by a fixed ratio to create savings, and the expenditures comprise social security benefits to the household sector and transfers to other institutional sectors.

4. Setting the elasticity of substitution and other parameters

The function parameters for each sector were estimated with a calibration method that used the nine interregional SAM data with 2005 as the benchmark year. However, in order to estimate these function parameters, one of the parameters must depend on an external database. Thus, when describing the setting of these parameters, we referenced the values used in GTAP7.1 for the elasticity of substitution for labor and capital in the production sector and that for the CES-type (Armington) function of the trade sector. Then, with reference to previous studies by Ban (2007), Hayashiyama et al. (2011), and Tanaka and Hosoe (2009), we set the interregional elasticity of substitution for the production sector, for the household and investment sectors, and the elasticity of substitution of the CET-type function for the trade sector, and the elasticity of agricultural land and the capital–labor bundle (Table 15.3).

Table 15.3 List of the elasticity of substitution setup in the 9SCGE model

Production activities	Elasticity of substitution between land and capital–labor bundle in the CES function	Elasticity of substitution between capital–labor in the CES function	Elasticity of transformation in CET function	Elasticity of substitution of ARMINGTON function	Elasticity of substitution between intermediate goods of different origin in the CES function
Rice	0.2	0.6	2.0	5.0	2.0
Wheat and potatoes	0.2	0.6	2.0	3.0	2.0
Vegetables	0.2	0.6	2.0	2.0	2.0
Fruit trees	0.2	0.6	2.0	2.0	2.0
Livestock	0.2	0.6	2.0	2.0	2.0
Fisheries	0.2	0.6	2.0	1.2	2.0
Slaughtering and dairy products	–	1.2	2.0	4.0	2.0
Processed seafood	–	1.2	2.0	2.0	2.0
Grain milling and agricultural food stuffs	–	1.2	2.0	3.0	2.0
Other foods, beverage, and tobacco	–	1.2	2.0	2.0	2.0
Mining and manufacturing products	–	1.3	2.0	3.2	2.0
Construction	–	1.4	2.0	1.9	2.0
Electricity, gas, and water supply	–	1.3	2.0	2.8	2.0
Commerce	–	1.3	2.0	1.9	2.0
Transport	–	1.7	2.0	1.9	2.0
Services	–	1.3	2.0	1.9	2.0

15.4 Results of the Simulation Analysis

15.4.1 Setting Simulation Datum

This section demonstrates the setting of simulation data related to the changes in the production of rice caused by climate change-induced by global warming.

Before setting the simulation data for this section, we explain how the results obtained from rice production function (estimated in Sect. 15.2) were reflected in the 9SCGE model. As shown in Fig. 15.2a, the function for the production block in the 9SCGE model cannot be used to directly indicate the impact of global warming-induced temperature rise on regional production of rice. Therefore, the present study adopts a method to reflect the results of the rice-yield growth rate obtained from the production function, which indicates the temperature variables shown in Sect. 15.2. The panel data in Sect. 15.2 (designed to estimate the production function and the nine regional SAM, a database for the 9SCGE model) differ extensively in terms of data-set timing, volume/amount unit, and regional classification. In addition, the production functions in Sect. 15.2 and the 9SCGE model do not match in terms of the production function premises and explanatory variables (excluding temperature variables). While these two models differ vastly, the present study interpreted the rice-yield growth rate calculated by the rise of the temperature shown in Table 15.2 as the impacts of global warming on regional production of rice. Moreover, each regional rice-yield growth rate was matched, which was obtained from the rate of change of rice production, and agricultural land as the initial value of the impact of global warming on rice (not affected by rice in other regions) in regions corresponding to the 9SCGE model. Even if the initial value is obtained using the results obtained in Sect. 15.2, it is essential to develop methods to eliminate any doubts with regard to the credibility of the simulation results obtained by combining the results of one model with another model's simulation premises. The present study addresses this point by using the JMA's future temperature prediction ranges (maximum and minimum values).

Next, specific steps to obtain the parameters for simulation conditions are elaborated as follows. This study focuses on the efficiency parameter aF_a^o obtained from a calibration with regard to the rice production function, as shown in Eq. (15.2):

$$XD_a^o = \frac{1}{b_a^o} \cdot \left(\alpha_a^o \cdot aF_a^o\right) \left(\gamma F_a^o \cdot R_a^{o\,\frac{-(1-\sigma F_a)}{\sigma F_a}} + \left(1 - \gamma F_a^o\right) KL_a^{o\,\frac{-(1-\sigma F_a)}{\sigma F_a}}\right)^{\frac{-\sigma F_a}{1-\sigma F_a}} \tag{15.2}$$

where α_a^o represents the parameter (i.e., global warming parameter) that changes the productivity of rice production in each region due to climate change; b_a^o represents the efficiency parameter for the agricultural land–capital–labor bundle in sector

a's production function of region o; σF_a represents the elasticity of substitution between agricultural land and the capital–labor bundle in the CES function; and γF_a^o represents the CES distribution parameter for the capital–labor bundle in sector a's production function of region o.

However, an alternative approach is used to change this efficiency parameter because it cannot be directly altered using the information discussed in Sect. 15.2. This approach determines a global warming parameter, which changes the efficiency parameter (i.e., this parameter's default gives a value of "1.0" to the rice production activities in the nine regions) from the 9SCGE model simulations. Under this approach, simulations were run to determine a global warming parameter, which can reproduce the rice-yield growth rate obtained in Sect. 15.2 in the 9SCGE model, for 24 cases (rice in eight regions, except Okinawa, for the maximum, mean, and minimum values, respectively). In order to reproduce the yield growth rate in the 9SCGE model, in addition to the rice production in the regions that are to be changed, all endogenous variables in all regions will be changed. Consistent with the changes in rice production, agricultural land, labor, and capital variables, which are rice-production factors, will also be changed. Therefore, the changed agricultural land and capital variables were included into the yield production function in Eq. (15.1) to recalculate the said rice-yield growth rate and reproduce it in the 9SCGE model. By repeating these processes, a global warming parameter was obtained in which the results of Eq. (15.1)'s production function nearly matched those of the 9SCGE model. Tables 15.4 and 15.5 show the results. The numerical values of center part in Table 15.4 are the results of each simulation by region using 9SCGE model; in other words, the result of rice production that some region is only affected by global warming and other regions is not affected by global warming. On the other hand, the numerical values of the right-hand side in Table 15.4 are the results of production of rice including the changes in land obtained in an earlier simulation by 9SCGE model using Eq. (15.1). The search frame mentioned earlier is shown in Fig. 15.3.

Next, three settings are made. First, by inserting the global warming parameters of the nine regions in Table 15.5 into the 9SCGE model, "global warming simulations without adaptation technologies" were performed using three scenarios: when future temperature becomes (1) the maximum value; (2) the mean value; and (3) the minimum value. This was used to measure the impact of each scenario on regional economies and the economic welfare for each region as well as the economic spillover effects on the agriculture, forestry, fishery, and food and beverage industries. Second, it was assumed that the "development of high-temperature tolerant rice varieties has resulted in curbing global warming-induced productivity decline" (with adaptation technologies, mean value) for regions whose global warming parameter when future temperature has a mean value of 1 or below. These global warming parameters were calculated on the basis of the assumption

Table 15.4 Comparison of the results of rice production in Eq. (15.1) with the result of the 9SCGE model

Rice changes in base value (2005), %	Simulation results to obtain a global warming parameter through the repetition of these processes									The result of Eq. (15.1) by GMM estimation		
	Changes in land			Changes in capital			Changes in production			Changes in production		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
Hokkaido	−2.43	−2.35	−2.20	−2.96	−2.87	−2.69	9.71	9.42	8.84	9.67	9.49	8.86
Tohoku	0.12	0.00	−0.08	0.53	0.00	−0.35	−1.41	0.00	1.01	−1.40	0.01	0.98
Kanto	1.91	1.40	0.95	5.39	3.91	2.64	−7.92	−5.69	−3.80	−7.89	−5.64	−3.78
Chubu	1.67	1.25	0.89	4.12	3.07	2.18	−10.30	−7.56	−5.29	−10.26	−7.59	−5.30
Kinki	1.60	1.22	0.88	3.59	2.71	1.95	−10.30	−7.61	−5.37	−10.34	−7.65	−5.34
Chugoku	2.81	2.10	1.48	6.73	4.99	3.50	−7.58	−5.58	−3.89	−7.62	−5.61	−3.88
Shikoku	2.71	2.23	1.76	5.56	4.56	3.59	−16.26	−12.90	−9.97	−16.27	−12.92	−9.92
Kyushu	4.56	3.54	2.62	7.90	6.10	4.50	−8.92	−6.81	−4.96	−8.94	−6.83	−4.94

Table 15.5 Setting of the nine regions' global warming parameters with/without adaption technologies

	Adaptation technologies does not exist			Adaptation technologies exist
	A maximum rise in temperature	A mean rise in temperature	A minimum rise in temperature	A mean rise in temperature
Hokkaido	1.129	1.125	1.117	1.125
Tohoku	0.982	1.000	1.013	1.000
Kanto	0.881	0.913	0.941	0.957
Chubu	0.867	0.901	0.930	0.951
Kinki	0.869	0.902	0.930	0.951
Chugoku	0.872	0.904	0.932	0.952
Shikoku	0.800	0.839	0.874	0.920
Kyushu	0.850	0.883	0.913	0.942
Okinawa	1.000	1.000	1.000	1.000

that productivity decline will improve by 50%.[3] This parameter was also used to run "global warming simulations with adaptation technologies" based on the 9SCGE model to measure the degree to which the negative economic impact can be mitigated by comparing the results of the former. Thirdly, the influence of global warming on rice is known from previous studies to reduce the quality of rice, in addition to reducing the amount of rice production. This is the case where productivity of the food processing industry improves by forming a new food industry cluster that uses rice as a raw material whose value as a product is lost as a result of this decline in quality, even if the amount of production of rice that keeps up quality decreases.[4] In this case, "there is adaptation technology and food industry cluster." As there are no previous studies on how much productivity of the formation of such cluster improves, the setting of productivity in the production activity of "Grain milling and agricultural food stiffs" in this model is such that Chugoku, Shikoku, and Kyushu where economic welfare declines significantly compared to other regions are raised by 0.5%, respectively, as shown in Table 15.6. This is the reason that these productivities in the Shikoku and Kyushu are considered to rise to the productivity level of Chugoku obtained by calibration, and

[3]The Yomiuri Shimbun on May 62,015, reports that "the Ministry of Agriculture, Forestry and Fisheries will strengthen research to make agricultural products strong against heat and water shortage as a measure against global warming from 2015." Assuming that the annual average temperature rises by 2 °C in that, predicting to what extent crop yield and quality will decline for domestic major agricultural crops, with the aim of suppressing such damage to less than half.

[4]It has been pointed out from previous studies that a large amount of cloudy rice is produced due to the future global warming. However, this model cannot distinguish rice by the quality difference between first grade rice and second grade rice, so such rice cannot be accurately reflected in the production amount on the model. Therefore, in the present study, we decided to treat such rice whose value as a product is lost.

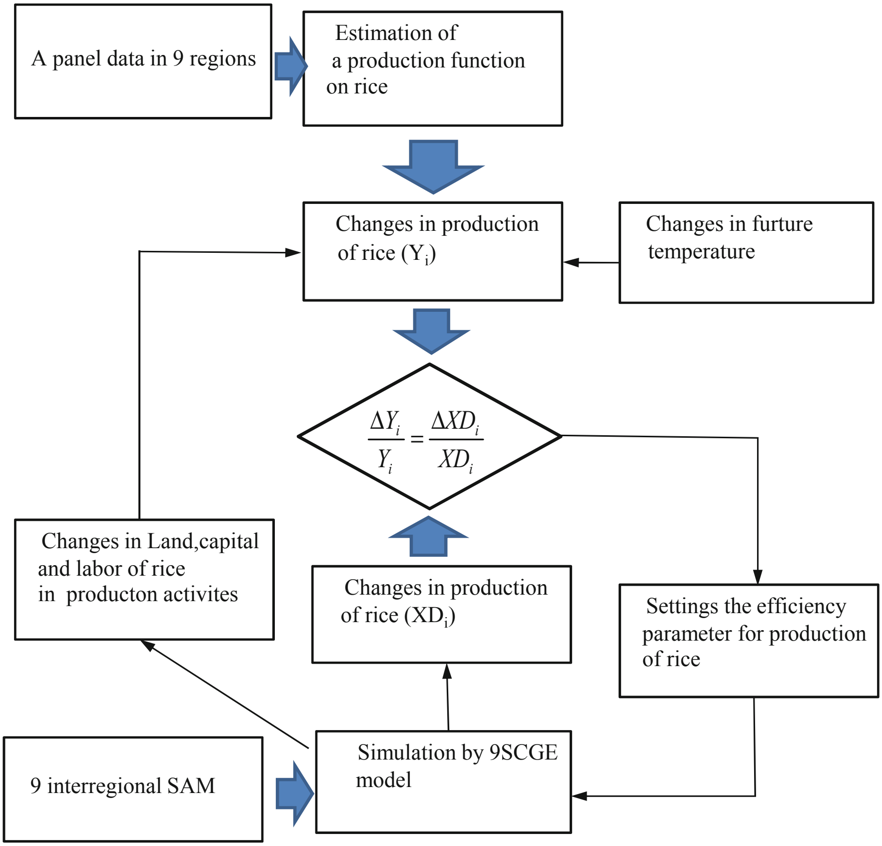

Fig. 15.3 Search frame for global warming parameter

Chugoku is considered to rise to the productivity level of Okinawa. In addition, regarding productivity improvement in the Kanto, Chubu, and Kinki regions where the decrease in economic welfare was smaller than in the above three regions, these efficiency parameters in these regions are increased by 0.25% as shown in Table 15.6.

15.4.2 Simulation Results

Table 15.7 reveals the following six points. First, in the simulations assuming alterations in regional rice production owing to Japan's rise in temperature over the next 60–80 years (global warming simulations without adaptation technologies), the national equivalent variation (economic welfare) will decline by 54.16 billion yen when the impact of global warming is minimum and by 131.93 billion yen when the

Table 15.6 Setting of the nine regions' efficiency parameter of the 9SCGE production function

		The efficiency parameter of CES production function of nonagricultural sector								
		Hokkaido	Tohoku	Kanto	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
Grain milling and agricultural food stuffs	(1) Value calculated by Calibration method	6.857	8.256	6.289	6.066	6.198	7.204	6.789	6.725	7.533
	(2) Case for Food industry cluster	6.857	8.256	6.447	6.218	6.353	7.564	7.128	7.062	7.533
	(2)/(1)	1.000	1.000	1.025	1.025	1.025	1.050	1.050	1.050	1.000

Table 15.7 Simulation results using the 9SCGE model

Changes in the output of base value (2005)			Economic welfare		Main index (unit: %)			Direct and indirect effect by global warming (unit: %)					Spillover effect to nonagricultural output (unit:%)					
Region	With/Without adaptation technologies	Degree of a rise in temperature	Equivalent variation unit: billion yen	E.V. per capita unit:yen	Real GRP	Total Output	Farmer household's sales	Total crops	Rice	Wheat and potatoes	Vegetables	Fruit trees	Livestock	Slaughtering and dairy products	Grain milling and agricultural foodstuffs	Other foods, beverage and tobacco	Mining and manufacturing products	Services
Whole country	Without adaptation technologies	Max	−131.93	−1038	−0.02%	−0.03%	2.55%	−1.69%	−2.41%	−3.10%	−0.62%	−1.70%	−0.36%	−0.32%	−2.32%	−0.23%	0.02%	0.00%
		Mean	−88.42	−696	−0.02%	−0.02%	1.69%	−1.13%	−1.60%	−2.07%	−0.41%	−1.20%	−0.23%	−0.20%	−1.56%	−0.15%	0.01%	0.00%
		Min	−54.16	−426	−0.01%	−0.01%	1.03%	−0.68%	−0.96%	−1.25%	−0.24%	−0.72%	−0.13%	−0.11%	−0.96%	−0.09%	0.01%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−36.96	−291	−0.01%	−0.01%	0.71%	−0.46%	−0.66%	−0.83%	−0.17%	−0.50%	−0.08%	−0.07%	−0.66%	−0.06%	0.01%	0.00%
		Added import policy	−11.05	−87	−0.01%	0.00%	−1.79%	−1.74%	−5.11%	0.86%	0.17%	0.52%	0.06%	0.12%	−0.01%	0.02%	0.06%	−0.01%
		Added innovation food industry cluster	24.70	194	0.01%	0.01%	1.15%	−0.23%	−0.04%	−0.75%	−0.17%	−0.61%	−0.06%	−0.05%	0.10%	−0.01%	0.01%	0.01%

Hokkaido	Without adaptation technologies	Max	0.68	127	0.05%	0.03%	3.30%	4.34%	20.26%	−0.86%	−0.50%	−0.59%	−0.31%	−0.22%	0.34%	−0.11%	−0.03%	0.03%
		Mean	1.39	259	0.04%	0.04%	2.38%	3.68%	16.45%	−0.42%	−0.27%	−0.28%	−0.15%	−0.11%	0.61%	−0.05%	−0.03%	0.02%
		Min	1.87	348	0.04%	0.04%	1.65%	3.07%	13.12%	−0.11%	−0.10%	−0.07%	−0.04%	−0.03%	0.77%	0.00%	−0.02%	0.01%
	With adaptation technologies (Mean value)	Only adaptation technologies	2.11	391	0.04%	0.04%	1.42%	3.06%	12.69%	0.04%	−0.01%	0.02%	0.03%	0.02%	0.89%	0.02%	−0.02%	0.01%
		Added import policy	0.97	181	0.04%	0.05%	0.04%	2.18%	7.74%	0.49%	0.32%	0.45%	0.07%	0.21%	1.26%	0.10%	0.05%	0.00%
		Added innovation food industry cluster	2.20	408	0.04%	0.04%	1.73%	3.27%	13.19%	0.26%	−0.03%	−0.05%	0.06%	0.03%	0.68%	0.03%	−0.02%	0.02%
Tohoku	Without adaptation technologies	Max	1.19	132	−0.02%	−0.05%	4.51%	0.90%	2.44%	−6.07%	−0.52%	−1.25%	−0.33%	−0.32%	−2.70%	−0.21%	0.00%	0.04%
		Mean	1.36	152	0.00%	−0.02%	3.14%	1.28%	2.79%	−3.81%	−0.32%	−0.77%	−0.19%	−0.19%	−1.50%	−0.12%	0.00%	0.03%
		Min	1.51	169	0.01%	0.00%	2.05%	1.47%	2.87%	−2.04%	−0.16%	−0.41%	−0.09%	−0.09%	−0.61%	−0.05%	0.00%	0.02%
	With adaptation technologies (Mean value)	Only adaptation technologies	0.36	40	0.00%	−0.01%	1.26%	0.53%	1.15%	−1.57%	−0.13%	−0.31%	−0.09%	−0.08%	−0.65%	−0.05%	0.00%	0.01%

(continued)

Table 15.7 (continued)

Changes in the output of base value (2005)			Economic welfare		Main index (unit: %)			Direct and indirect effect by global warming (unit: %)					Spillover effect to nonagricultural output (unit:%)					
Region	With/Without adaptation technologies	Degree of a rise in temperature	Equivalent variation unit: billion yen	E.V. per capita unit:yen	Real GRP	Total Output	Farmer household's sales	Total crops	Rice	Wheat and potatoes	Vegetables	Fruit trees	Livestock	Slaughter{-}ing and dairy products	Grain milling and agricultural foodstuffs	Other foods, beverage and tobacco	Mining and manufacturing products	Services
		Added import policy	−2.33	−259	−0.01%	0.01%	−0.91%	−0.40%	−0.81%	0.83%	0.04%	0.19%	0.01%	0.08%	0.26%	0.03%	0.08%	−0.01%
		Added innovation food industry cluster	0.71	79	0.00%	−0.01%	1.60%	0.68%	1.43%	−1.86%	−0.11%	−0.32%	−0.07%	−0.06%	−0.88%	−0.03%	0.00%	0.02%
Kanto	Without adaptation technologies	Max	−50.31	−969	−0.02%	−0.02%	1.78%	−2.91%	−6.14%	−5.12%	−0.67%	−0.81%	−0.16%	−0.22%	−2.02%	−0.18%	0.02%	0.00%
		Mean	−33.16	−638	−0.02%	−0.02%	1.07%	−2.14%	−4.68%	−3.42%	−0.44%	−0.50%	−0.10%	−0.14%	−1.34%	−0.12%	0.01%	0.00%
		Min	−19.66	−379	−0.01%	−0.01%	0.53%	−1.49%	−3.41%	−2.06%	−0.25%	−0.26%	−0.06%	−0.07%	−0.81%	−0.07%	0.01%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−13.82	−266	−0.01%	−0.01%	0.36%	−1.09%	−2.50%	−1.48%	−0.18%	−0.19%	−0.05%	−0.05%	−0.58%	−0.05%	0.00%	0.00%

		Added import policy	−5.05	−97	−0.01%	0.00%	−1.85%	−2.13%	−6.53%	1.35%	0.19%	0.25%	0.01%	0.08%	−0.05%	0.02%	0.06%	−0.01%
		Added innovation food industry cluster	12.16	234	0.01%	0.01%	0.75%	−0.90%	−1.90%	−1.59%	−0.20%	−0.22%	−0.02%	−0.02%	0.21%	0.00%	0.01%	0.01%
Chubu	Without adaptation technologies	Max	−17.42	−1286	−0.03%	−0.02%	2.56%	−3.93%	−6.25%	−7.94%	−0.65%	−5.37%	−0.21%	−0.29%	−2.65%	−0.29%	0.03%	0.00%
		Mean	−11.94	−881	−0.02%	−0.02%	1.64%	−2.91%	−4.75%	−5.51%	−0.44%	−3.69%	−0.13%	−0.18%	−1.83%	−0.19%	0.02%	0.00%
		Min	−7.66	−565	−0.01%	−0.01%	0.90%	−2.09%	−3.55%	−3.56%	−0.28%	−2.35%	−0.07%	−0.10%	−1.19%	−0.12%	0.01%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−5.35	−395	−0.01%	−0.01%	0.66%	−1.43%	−2.41%	−2.51%	−0.19%	−1.64%	−0.04%	−0.06%	−0.82%	−0.08%	0.01%	0.00%
		Added import policy	1.38	102	−0.01%	0.00%	−2.62%	−3.00%	−7.44%	1.97%	0.15%	1.61%	0.05%	0.10%	−0.11%	0.01%	0.02%	−0.01%
		Added innovation food industry cluster	1.58	116	0.01%	0.01%	1.17%	−1.19%	−1.74%	−2.78%	−0.20%	−2.09%	0.00%	−0.02%	0.00%	−0.02%	0.01%	0.01%

(continued)

Table 15.7 (continued)

Changes in the output of base value (2005)			Economic welfare		Main index (unit: %)			Direct and indirect effect by global warming (unit: %)					Spillover effect to nonagricultural output (unit:%)					
Region	With/Without adaptation technologies	Degree of a rise in temperature	Equivalent variation unit: billion yen	E.V. per capita unit:yen	Real GRP	Total Output	Farmer household's sales	Total crops	Rice	Wheat and potatoes	Vegetables	Fruit trees	Livestock	Slaughter{-}ing and dairy products	Grain milling and agricultural foodstuffs	Other foods, beverage and tobacco	Mining and manufacturing products	Services
Kinki	Without adaptation technologies	Max	−25.10	−1167	−0.02%	−0.02%	2.07%	−3.56%	−5.79%	−5.18%	−1.14%	−1.88%	−0.55%	−0.33%	−1.77%	−0.30%	0.02%	0.00%
		Mean	−16.58	−771	−0.01%	−0.02%	1.20%	−2.72%	−4.68%	−3.42%	−0.74%	−1.21%	−0.34%	−0.21%	−1.18%	−0.20%	0.01%	0.00%
		Min	−10.02	−466	−0.01%	−0.01%	0.53%	−2.06%	−3.79%	−2.06%	−0.44%	−0.70%	−0.19%	−0.12%	−0.72%	−0.13%	0.01%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−7.01	−326	−0.01%	−0.01%	0.42%	−1.39%	−2.53%	−1.50%	−0.31%	−0.51%	−0.13%	−0.07%	−0.50%	−0.09%	0.01%	0.00%
		Added import policy	0.84	39	−0.01%	0.00%	−3.67%	−3.79%	−9.81%	2.60%	0.52%	1.03%	0.28%	0.17%	0.06%	0.02%	0.05%	−0.01%
		Added innovation food industry cluster	3.02	140	0.01%	0.01%	0.90%	−1.11%	−1.80%	−1.54%	−0.33%	−0.66%	−0.12%	−0.06%	0.32%	−0.02%	0.01%	0.01%

Chugoku	Without adaptation technologies	Max	−13.44	−1806	−0.04%	−0.05%	4.02%	−2.92%	−3.83%	−9.48%	−0.95%	−2.15%	−0.80%	−0.62%	−3.55%	−0.43%	0.01%	0.00%
		Mean	−9.63	−1295	−0.03%	−0.03%	2.87%	−2.11%	−2.79%	−6.87%	−0.67%	−1.53%	−0.58%	−0.43%	−2.54%	−0.30%	0.01%	0.00%
		Min	−6.55	−880	−0.02%	−0.02%	1.93%	−1.46%	−1.93%	−4.73%	−0.46%	−1.03%	−0.40%	−0.28%	−1.73%	−0.20%	0.01%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−4.43	−596	−0.01%	−0.02%	1.27%	−1.04%	−1.41%	−3.21%	−0.31%	−0.69%	−0.27%	−0.18%	−1.17%	−0.14%	0.00%	0.00%
		Added import policy	−1.93	−259	−0.02%	0.01%	−3.64%	−4.08%	−8.59%	3.01%	0.31%	0.73%	0.14%	0.19%	−0.17%	0.01%	0.09%	−0.02%
		Added innovation food industry cluster	1.35	182	0.01%	0.01%	2.12%	−0.54%	−0.29%	−3.81%	−0.38%	−0.89%	−0.28%	−0.18%	0.13%	−0.04%	0.01%	0.01%
Shikoku	Without adaptation technologies	Max	−6.81	−1771	−0.05%	−0.07%	1.09%	−3.67%	#####	−4.02%	−0.28%	−2.48%	−0.36%	−0.31%	−4.76%	−0.34%	0.06%	0.00%
		Mean	−4.97	−1291	−0.04%	−0.05%	0.57%	−3.04%	#####	−3.04%	−0.21%	−2.31%	−0.27%	−0.22%	−3.55%	−0.24%	0.04%	0.00%
		Min	−3.53	−919	−0.03%	−0.04%	0.36%	−2.29%	−8.05%	−2.22%	−0.15%	−1.34%	−0.20%	−0.15%	−2.56%	−0.16%	0.03%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−2.20	−572	−0.02%	−0.03%	0.30%	−1.39%	−4.77%	−1.48%	−0.10%	−0.88%	−0.14%	−0.10%	−1.61%	−0.10%	0.02%	0.00%

(continued)

Table 15.7 (continued)

Changes in the output of base value (2005)			Economic welfare		Main index (unit: %)			Direct and indirect effect by global warming (unit: %)					Spillover effect to nonagricultural output (unit:%)					
Region	With/Without adaptation technologies	Degree of a rise in temperature	Equivalent variation unit: billion yen	E.V. per capita unit:yen	Real GRP	Total Output	Farmer household's sales	Total crops	Rice	Wheat and potatoes	Vegetables	Fruit trees	Livestock	Slaughter{-}ing and dairy products	Grain milling and agricultural foodstuffs	Other foods, beverage and tobacco	Mining and manufacturing products	Services
		Added import policy	−1.95	−508	−0.03%	−0.01%	−1.79%	−2.17%	#####	0.64%	−0.01%	0.60%	−0.08%	0.05%	−0.46%	0.00%	0.08%	−0.02%
		Added innovation food industry cluster	1.03	267	0.00%	0.00%	0.70%	−1.22%	−3.93%	−1.44%	−0.04%	−1.06%	−0.10%	−0.08%	−0.21%	−0.03%	0.03%	0.01%
Kyushu	Without adaptation technologies	Max	−18.82	−1446	−0.05%	−0.07%	1.73%	−2.66%	−6.45%	−2.81%	−0.51%	−2.14%	−0.52%	−0.51%	−3.73%	−0.26%	0.04%	0.00%
		Mean	−13.68	−1051	−0.04%	−0.05%	1.18%	−2.07%	−5.17%	−2.07%	−0.37%	−1.55%	−0.38%	−0.36%	−2.74%	−0.18%	0.03%	0.00%
		Min	−9.43	−724	−0.03%	−0.04%	0.74%	−1.56%	−4.02%	−1.46%	−0.25%	−1.07%	−0.26%	−0.23%	−1.92%	−0.12%	0.02%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−6.08	−467	−0.02%	−0.02%	0.49%	−1.01%	−2.59%	−0.97%	−0.17%	−0.70%	−0.16%	−0.14%	−1.25%	−0.08%	0.01%	0.00%

		Added import policy	−3.24	−249	−0.03%	0.00%	−1.85%	−2.29%	−8.97%	0.31%	0.06%	0.66%	0.10%	0.15%	−0.42%	0.01%	0.09%	−0.01%
		Added innovation food industry cluster	3.24	249	0.01%	0.01%	1.03%	−0.70%	−1.52%	−0.71%	−0.12%	−0.91%	−0.16%	−0.15%	0.06%	−0.01%	0.03%	0.01%
Okinawa	Without adaptation technologies	Max	−1.91	−1329	0.00%	−0.01%	0.50%	0.28%	10.08%	−1.04%	−0.03%	0.02%	−0.05%	−0.10%	−2.64%	−0.16%	0.06%	0.00%
		Mean	−1.22	−854	0.00%	−0.01%	0.33%	0.19%	6.30%	−0.64%	−0.01%	0.05%	−0.03%	−0.06%	−1.68%	−0.11%	0.04%	0.00%
		Min	−0.70	−487	0.00%	0.00%	0.19%	0.12%	3.50%	−0.32%	0.00%	0.05%	−0.02%	−0.03%	−0.94%	−0.06%	0.02%	0.00%
	With adaptation technologies (Mean value)	Only adaptation technologies	−0.53	−371	0.00%	0.00%	0.13%	0.07%	2.66%	−0.32%	−0.01%	0.02%	−0.02%	−0.03%	−0.74%	−0.04%	0.02%	0.00%
		Added import policy	0.26	183	0.00%	0.00%	−0.88%	−0.48%	#####	0.40%	0.21%	0.50%	0.01%	0.05%	0.11%	0.00%	0.00%	−0.01%
		Added innovation food industry cluster	−0.59	−410	0.00%	0.00%	0.20%	0.14%	3.08%	−0.32%	0.04%	0.08%	0.00%	−0.03%	−0.92%	−0.02%	0.02%	0.00%

impact is maximum (compared to the 2005 standards). When this is converted into per capita value, a decline will be in the range of 426 yen to 1038 yen. Region-wise data show that the residents in Hokkaido and Tohoku will be positively affected by global warming, while the west of Kanto will be negatively affected. When Chugoku is affected the maximum by global warming, the decline will be up to 1806 yen per person, creating a gap of 1933 yen with Hokkaido, which will see a 127 yen increase. Similarly, considering the impact of global warming on regional economies, while the real GRP will increase by 0.04% to 0.05% in Hokkaido, a decline in the real GRP will be the largest in Shikoku and Kyushu at −0.03% to −0.05%. Meanwhile, the real GRP in Tohoku with the maximum value and the west of Kanto except Okinawa will be negatively affected by global warming.

Second, while global warming will increase rice production in Hokkaido and Tohoku, production will decrease in the west of Kanto except Okinawa, with a −0.96% to −2.41% national decline. Meanwhile, production in Hokkaido will witness an increase of 20.26% in case of the maximum value and 13.12% increase in case of the minimum value. In addition, production in Tohoku, the largest producer of rice, will increase by 2.44% to 2.87%. By comparing this rate of increase with the simulation results (Table 15.4), assuming that only Tohoku will be positively affected by global warming, the mean value will increase from 0.0% to 2.79%. In case of the maximum value, the rate of increase in production will grow +2.44% from −1.4%. This is because the outflow from Tohoku will rise due to the differences in prices of rice with western Japan, where rice production will decrease. In addition, the region will witness a production increase beyond the positive impact of global warming. A similar situation is pointed out in Hokkaido.

Thirdly, through changes in regional rice production, we find that the production of other agricultural products will be affected negatively. This is because the three production factors of agricultural land, capital, and labor will shift from other agricultural products to rice in both Hokkaido/Tohoku region and the west of Kanto. As a result, other agricultural products will decrease in both regions. However, the cause that shifts the production factors to rice from other agricultural products is different. It is that in the west of Kanto, as the productivity of rice declines due to global warming, the production factors are introduced into rice to mitigate a decline in rice production as possible. As a result, the production factors of other agricultural products shift to rice, and the production volume of other agricultural products decreases. On the other hand, in Hokkaido and Tohoku, the productivity of rice due to global warming have a positive effect, so there is no shift in the production factor for rice due to global warming. However, as rice production in the west of Kanto decreases, rice exports from Hokkaido and Tohoku to the west of Kanto increase due to the differences in price of rice between regions as mentioned earlier. As a result, the production factor shifts from other agricultural products to rice in order to increase rice production, and the production volume of other agriculture products decreases even in this region. By considering the production value of agricultural products in each region as farmers' sales and focusing on the change, while the production volume of agricultural products will decrease in regions other than Hokkaido, Tohoku, and Okinawa due to global warming, producer prices will increase in these regions. While the regional production of agricultural products throughout the nation will decrease by 0.68 to 1.69%, farmers' sales will increase by 1.03% to 2.55%. Moreover, when the impact of global warming is the maximum value, farmers' sales in Kanto, Chubu, Kinki, Chugoku, Shikoku, and Kyushu will increase by 1.78%, 2.56%, 2.07%, 4.02%, 1.09%, and 1.73%, respectively. That levels in Chubu and Kinki will be almost on par with farmers' sales in Tohoku when the impact of global warming is the minimum value. And the farmers' sales in Chugoku for the case of the maximum value will be above that in Hokkaido for the case of the mean value. As shown earlier, while the production volume of agricultural products will decrease in the west of Kanto due to global warming, an increase in producer prices for agricultural products will ensure the level of farmers' sales.

Fourth, we consider the spillover effects on other industries impacted by global warming on the production of agricultural products. Livestock production will be negatively affected in all regions. This is due to reasons similar to agricultural products other than rice. In case of the food and beverage industries, the production of agricultural food products in Hokkaido will be positively affected but other food and beverage industries will have a negative impact. However, in any case in Tohoku and the west of Kanto, the food and beverage industries will have a negative impact by global warming. Given the production in the mining and manufacturing industries as well as in the service industry, the mining and manufacturing industries in all regions except Hokkaido will be positively affected and the service industry will be positively affected in Hokkaido and Tohoku. Meanwhile, in other regions service industries will remain nearly constant.

Fifth, assuming that "a range of global warming-induced decline in productivity has increased by 50%," due to the adaptation technologies for rice in regions affected by global warming, the positive impact on the production of rice in Hokkaido and Tohoku will be lower than in the range of increase "when the impact of global warming without adaptation technologies is the minimum value." While the negative impact on the production of rice in the west of Kanto will be lower than in the range of decline. Consequently, the rate of decline in national rice production improves by 0.30% points from −0.96% in the minimum value. Moreover, the national equivalent variation will recover from −88.42 billion yen to −36.96 billion yen. It falls below 17.20 billion yen when "the impact of global warming without adaptation technologies is the minimum value." Given the differences between Hokkaido, which is most positively affected by global warming, and Shikoku/Kyushu, which is most negatively affected, a regional gap in the real GRP will slightly reduce from 0.08% to 0.06%. The present study also found that the equivalent variation gaps between Hokkaido and Chugoku will reduce from 1554 yen to 987 yen per person. In terms of farmers' sales, the national mean value with adaptation technologies will increase by 0.71%, a 0.98% decline from the mean value without adaptation, which will increase by 1.69%.

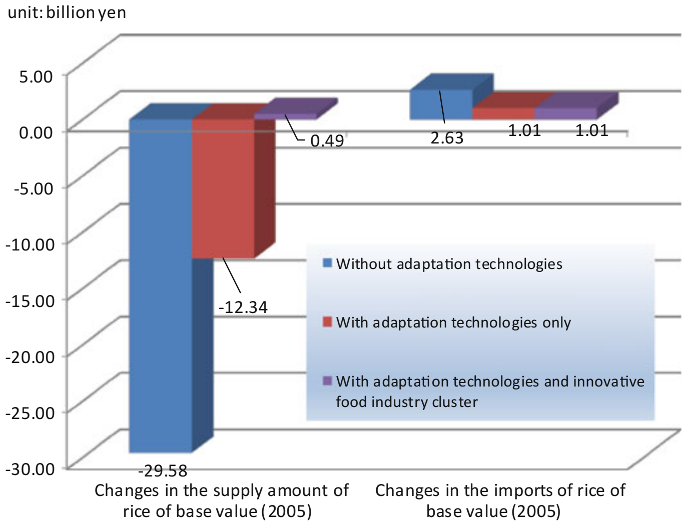

Fig. 15.4 Changes in the supply amount and in the imports of rice of base value (2005)

Finally, we consider the simulation result with the mean value of "with adaptive technology and food industry cluster."[5] In the cases, the supply of rice to the market will increase by about 0.49 billion yen compared with the base value (2005), as shown in Fig. 15.4. In addition, both the production of rice and the farmers' sales in all nine regions will improve compared with only adaptation technology (Table 15.7). There are things that need to be noted about this result. The reason for the increase in rice production in Hokkaido, Tohoku, and Okinawa is due to the increase in demand for rice due to the recovery of economic welfare of the whole country. On the other hand, the reason why rice production in other regions is further increased beyond the recovery of production due to adaptation technology is presumed that the food industry cluster will add rice which has lost its value as a product due to the declining quality to the portion supplied to the market as a raw material to the food processing industry. Considering the whole country, the rice as a whole will recovery by −0.04%, a 0.62% points increase from 0.66% decrease with only adaptation technology. Moreover, farmers' sales increase by 1.15%. By region, farmers' sales are positive in all the nine regions, and farmers' sales in Chubu, Chugoku, and Kyushu will increase by 1.17%, 2.12%, and 1.03%, respectively, more than in other regions of the west of Kanto. Therefore, equivalent variations in the west of Kanto are improved and are changed from negative to positive in regions where are negatively affected the impact of global warming. In particular, Chugoku and

[5]For the food industry cluster, see Sect. 2.5.3 and 6.2 in (eds.) Tokunaga and Resosudarmo (2017). There are already regional food clusters (rice-cosmetic cluster in Kanazawa and rice-based bioethanol at Chikujou town in Fukuoka Prefecture etc.)

Kyushu will be negative (4.43 billion yen and 6.08 billion yen) from positive (1.35 billion yen and 3.24 billion yen), respectively. Consequently, the national equivalent variance shows an increase of 24.70 billion yen from a decrease of 36.96 billion yen with only adaptation technology, and the per capita value is up to 194 yen from −291 yen, and equivalent variations per capita in the west of Kanto are changed from negative to positive in regions, as shown in Fig. 15.5. As a result, the gap per capita between Hokkaido and other regions has shrunk. Next, considering the changes in the real GRP and the total output, the real GRP and the total output in the west of Kanto have improved from a 0.01–0.02% decline to a 0.0–0.01%. As a result, the real GDP and the total output in whole country have improved from a 0.01% decline to a 0.01%, respectively. This is due to the increase in the production of "Grain milling and agricultural food stuffs" which is increased by 0.10% from −0.66%, in addition, the production of "Other foods, Beverage and Tobacco" also reduced to −0.01% from −0.06%. Based on these results, food industry cluster is worth considering as measures against global warming to each regional economy.

15.5 Conclusion and Policy Implications

Based on the assumption that only rice is affected by global warming, this study presented the impact of global warming on regional economies through spillover effects from rice and other agricultural products and the industrial section having an input–output relationship with agriculture. Therefore, this study found that global warming-induced climate change has different influences in each region and expands regional economic disparities. For example, global warming has a positive impact on regional economies in Hokkaido and Tohoku. In addition to increasing rice production, gaps in rice prices in the west of Kanto will increase outflow, which in turn further increases such production. Meanwhile, global warming will reduce rice production in Chugoku, Shikoku, and Kyushu, which will have a negative impact on regional economies. Moreover, in almost regions, the food and beverage industries will have a negative impact by global warming except the case that the production of agricultural food products will be positively affected in Hokkaido. Also, assuming that adaptive technologies such as high-temperature-tolerant rice varieties are developed in each region, the impact on climate change on rice production will be reduced. However, regional economies other than Hokkaido and Tohoku will continue to be negatively affected, and regional disparities are not completely resolved. Considering this result, we carried out the simulation to form the food industry cluster that links cooperation agriculture and food processing industry. As a result, we found that equivalent variations in the west of Kanto are improved and are changed from negative to positive in regions where are negatively affected the impact of global warming. Therefore, if we can form a food industry cluster, it is essential to draw the aggressive policy to promote the food industry cluster that is worth considering as measures against global warming to each regional economy.

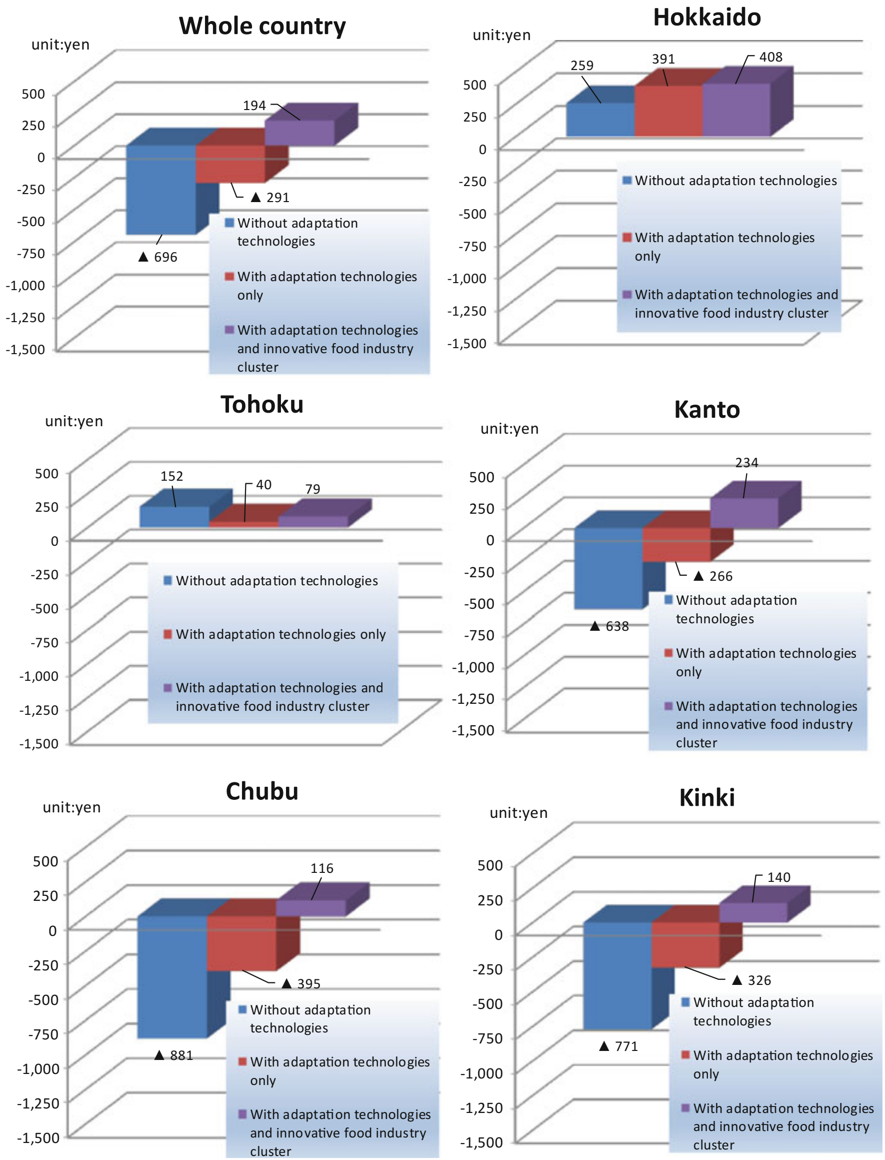

Fig. 15.5 Equivalent Variation per capita by regions in three cases with the mean value

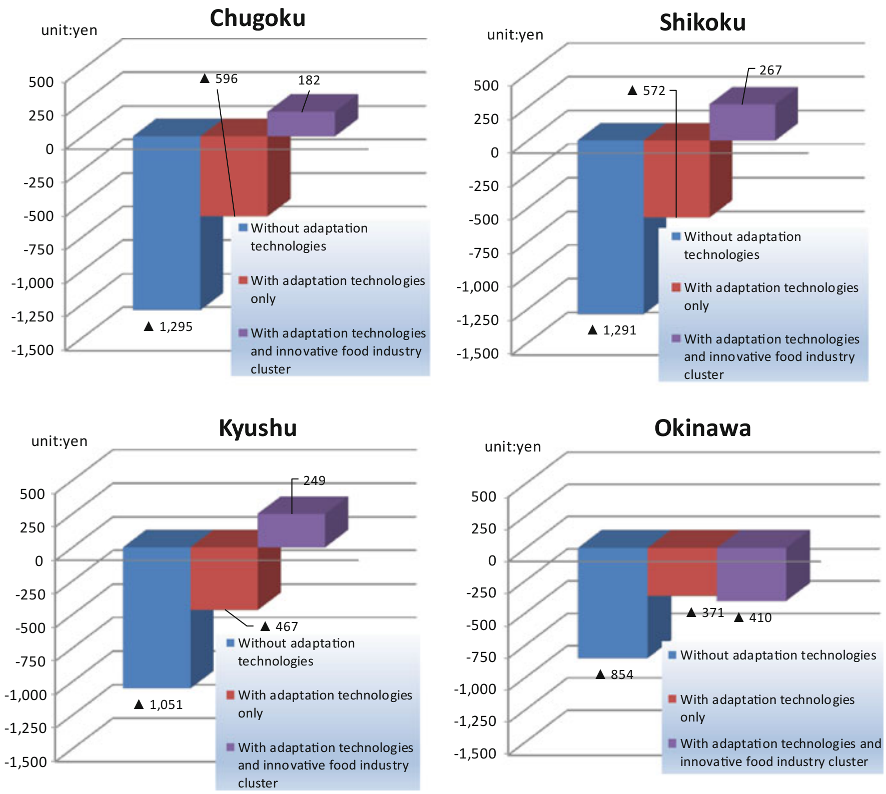

Fig. 15.5 (continued)

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Chapter 16
Environmental Regulation for Non-point Source Pollution in a Cournot Three-Stage Game

Akio Matsumoto, Keiko Nakayama, Makoto Okamura, and Ferenc Szidarovszky

Abstract A regulator can observe the total concentration of non-point source (NPS) pollution, however, cannot monitor individual emissions with low cost and high enough accuracy. This information asymmetry makes adequate standard instruments of environmental policy impossible. This paper constructs a simple Cournot competitive model and considers how much the ambient charge tax can control NPS pollution in a three-stage game. It is shown that the sub-game perfect equilibrium is obtained in which the optimal tax is determined to maximize the social welfare at the first stage; the profit maximizing firms adopt the optimal abatement technologies at the second stage and the optimal productions at the third stage. It is also demonstrated that an increase of the ambient tax can decrease the total concentrations not only at the second stage but at the third stage as well.

Keywords Non-point source pollution · Ambient charges · Abatement technology · Three-stage game · Cournot competition · Sub-game perfect equilibrium

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16.1 Introduction

To date, non-point source (NPS) pollution is widely dispersed in the environment such as farm field surface runoff; water pollution contaminating river, lake, and underwater; air pollution that may arise health problems for humans. It is also called diffused pollution or surface pollution and its prominent feature is the diffuse sources with which it is not easy to identity emissions of individual polluters. Consequently, the design of efficient environmental policy is hampered by informational problems associated with the inability to observe individual contribution to the ambient concentration. Due to informational asymmetries, the regulator or the policy-maker cannot use standard environmental policy instruments including emission taxes, tradable permits, subsidies for emission reductions, deposit system, Pigouvian tax, etc. In order to control NPS pollution, Segerson (1988) proposes monitoring ambient concentrations of pollutants. In this approach, the regulator first determines an environmental standard level and then, imposes uniform tax on the pollutants if the concentration is above the standard level and pays uniform subsidies if it is below.

Ganguli and Raju (2012) show a "perverse" effect of the ambient charges on the total pollution in the Bertrand duopoly, that is, an increase in the ambient charge tax could lead to larger pollution. Further, Raju and Ganguli (2013) consider the ambient charge effect in a Cournot duopoly and numerically show the effectiveness of the ambient charge to control NPS pollution under a two-stage game. Sato (2017) analytically shows that a higher ambient charge reduces pollutant emissions in a Cournot duopoly market. Some n-firm extensions from a duopoly setting have already started. Matsumoto et al. (2018) construct an n-firm Cournot model and reexamine those static results in a dynamic framework in which an equilibrium can lose stability. Ishikawa et al. (2019) turn attention to the ambient charge effect in a n-firm Bertrand model and show that the sign of the effect depends on the number of the firms, the degree of substitutability, and the heterogeneity of abatement technology. One important point that the literature has largely left unaddressed is how the regulator determines the ambient charge tax. Although the analysis is limited to a duopoly framework, this paper focuses on this issue in a three-stage Cournot game.

The rest of the paper is organized as follows. Section 16.2 provides a base model and solves a three-stage game. Accordingly, this section is divided into three subsections. Section 16.2.1 determines the optimal output levels, given the abatement technologies and the ambient tax rate. Section 16.2.2 selects the optimal technologies, given the ambient tax rate. Section 16.2.3 determines the optimal tax rate that maximizes the social welfare. The final section summarizes the results and presents further research directions.

16.2 Three-Stage Game

There are two firms in the duopoly market in which Cournot competition takes place and NPS pollutions are emitted. Firm k produces an amount q_k of homogenous goods for $k = i, j$. The price function is assumed to be linear,

$$p = a - (q_i + q_j). \tag{16.1}$$

Each firm produces output as well as emits pollutions and it is assumed that one unit of production emits one unit of pollution. However, using an abatement technology ϕ_k, the firm can reduce the actual amount of pollution to $\phi_k q_k$ by abating $(1 - \phi_k)q_k$. The technology is subject to $0 \leq \phi_k \leq 1$ with a pollution-free technology if $\phi_k = 0$ (i.e., no pollution) and a fully-discharged technology if $\phi_k = 1$ (i.e., no abatement). The regulator can measure the total emission quantity[1] $\sum_k \phi_k q_k$ but cannot identify individual contributions to the total quantity. To control the ambient concentrations, it enforces the environmental policy that has an exogenously determined environmental standard E and imposes uniform ambient tax rate θ on the polluted emissions, $\sum_k \phi_k q_k$. This θ is measured in some monetary unit per emission and assumed to be positive but is not necessarily less than unity. The regulator will, according to θ times the difference between $\sum_k \phi_k q_k$ and E, levy the penalty if the difference is positive and award the subsidy if negative.[2]

There are three decision variables, the regulator imposes an ambient charge tax with rate θ while firm k makes choices of the abatement technology, ϕ_k and production of output, q_k. In this paper, under the following time structure, three variables are determined one by one in a three-stage Cournot game. At the first stage, the regulator determines the tax rate of ambient charges to maximize the welfare of the people involved in the market. Having known the tax rate, the firms sequentially take actions in two steps. Each firm determines its optimal abatement technology at the second stage. Then it chooses a production level so as to maximize profit at the third stage, using the optimal technology obtained at the second stage and having the ambient tax rate. As usual, solving this three-stage game backwardly, we derive the sub-game perfect equilibrium of the game, that is, we determine first the optimal output levels, given the level of the abatement technologies and the tax rate, then the optimal technologies, given the tax rate and finally the optimal rate that maximizes the social welfare. Before proceeding we make two assumptions only for the sake of analytical simplification.[3]

Assumption 1. (1) $a = 1$; (2) the firms have zero production costs.

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[1]"total quantity of pollutions," "total pollutions," and "ambient concentrations" are synonymous in this paper.

[2]Since E is exogenously given, it can be mentioned that firm i receives subsidy θE and pays taxes of $\theta(\phi_i q_i + \phi_j q_j)$.

[3]In a future study, we will consider the similar game without this assumption.

16.2.1 Third Stage

Under Assumption 1, firm i determines production of output to maximize its profit defined as

$$\pi_i(q_i) = pq_i - \theta(\phi_i q_i + \phi_j q_j - E). \tag{16.2}$$

Substituting the price function (16.1) into the profit function and differentiating the resultant profit function present the first-order condition for an interior solution,

$$\frac{\partial \pi_i}{\partial q_i} = 1 - 2q_i - q_j - \theta\phi_i = 0, \tag{16.3}$$

where the second-order condition (SOC) is satisfied (i.e., $\partial^2\pi_i/\partial q_i^2 = -2 < 0$). The first-order condition for firm j is similarly obtained. The optimal levels of output can be obtained by solving simultaneously these two first-order conditions, which can be rewritten as

$$\begin{aligned} 2q_i + q_j &= 1 - \theta\phi_i \\ q_i + 2q_j &= 1 - \theta\phi_j. \end{aligned} \tag{16.4}$$

The optimal production levels of outputs at the third stage are

$$\begin{aligned} q_i^*(\theta, \phi_i, \phi_j) &= \frac{1}{3}\left(1 + \theta\phi_j - 2\theta\phi_i\right), \\ q_j^*(\theta, \phi_i, \phi_j) &= \frac{1}{3}\left(1 + \theta\phi_i - 2\theta\phi_j\right). \end{aligned} \tag{16.5}$$

For the non-negativity of output, the levels of the abatement technology should satisfy the following inequalities:

$$\phi_i \geq 0,\ \phi_j \geq 0 \text{ and } \frac{1}{2}\phi_i + \frac{1}{2\theta} \geq \phi_j \geq 2\phi_i - \frac{1}{\theta}. \tag{16.6}$$

We graphically construct the feasible region of ϕ_i and ϕ_j satisfying the conditions in (16.6) in Fig. 16.1. Zero-production loci of $q_i^* = 0$ and $q_j^* = 0$ are, from (16.5),

$$\phi_j = 2\phi_i - \frac{1}{\theta} \text{ and } \phi_j = \frac{1}{2}\phi_i + \frac{1}{2\theta}$$

where the former is a straight line with a steeper slope and a horizontal intercept $1/2\theta$ and the latter is also a straight line with a flatter slope and a vertical intercept $1/2\theta$. The two lines cross the diagonal at $(1/\theta, 1/\theta)$. In the region surrounded by

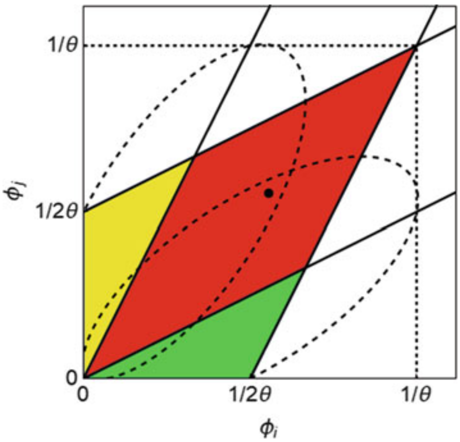


Fig. 16.1 Feasible region of ϕ_i and ϕ_j

these two lines and parts of the horizontal and vertical axes (that is, red-, yellow-, and green-colored regions), the conditions (16.6) are fulfilled and thus $q_i^* \geq 0$ and $q_j^* \geq 0$. (Ignore the dashed curves, two straight lines starting at the origin, and the black dot for now).

The total quantity of pollutions at the Cournot equilibrium is

$$E^*(\theta, \phi_i, \phi_j) = \phi_i q_i^*(\theta, \phi_i, \phi_j) + \phi_j q_j^*(\theta, \phi_i, \phi_j) \tag{16.7}$$

for which we have the following result[4]:

Theorem 1 *Given non-negative abatement technology,* ϕ_k for $k = i, j$, *increasing the policy parameter* θ *decreases the total concentrations,*

$$\frac{\partial E^*(\theta, \phi_i, \phi_j)}{\partial \theta} \leq 0.$$

Proof *Substituting* q_i^* *and* q_j^* *into equation (16.7) and then differentiating it give*

$$\frac{\partial E^*(\theta, \phi_i, \phi_j)}{\partial \theta} = -\frac{2}{3}\left(\phi_i^2 - \phi_i\phi_j + \phi_j^2\right)$$

$$= -\frac{2}{3}\left[\left(\phi_i - \phi_j\right)^2 + \phi_i\phi_j\right] \leq 0$$

where the equality holds only for $\phi_i = \phi_j = 0$. ■

Although individually emitted pollutions are non-observable, we are interested in how much each firm responses to the policy change. First, differentiating $\phi_i q_i^*$

[4]This is already shown by Sato (2017).

for $k = i, j$ with respect to θ gives

$$\frac{\partial}{\partial\theta}\left(\phi_i q_i^*\right) = \frac{1}{3}\phi_i\left(\phi_j - 2\phi_i\right) \text{ and } \frac{\partial}{\partial\theta}\left(\phi_j q_j^*\right) = \frac{1}{3}\phi_j\left(\phi_i - 2\phi_j\right).$$

Zero-responses loci of each firm's pollution are described by

$$\phi_j = 2\phi_i \text{ and } \phi_j = \frac{1}{2}\phi_i.$$

These fomulas are illustrated as straight lines passing through the origin in Fig. 16.1. It is also obtained

$$\frac{\partial}{\partial\theta}\left(\phi_i q_i^*\right) \gtreqless 0 \text{ according to } \phi_j \gtreqless 2\phi_i$$

and

$$\frac{\partial}{\partial\theta}\left(\phi_j q_j^*\right) \gtreqless 0 \text{ according to } \phi_j \lesseqgtr \frac{1}{2}\phi_i.$$

Both responses are negative in the red-colored parallelogram surrounded by four solid lines. Firm i's response is positive and firm j's response is negative in the yellow-colored triangle in the lower-left. Roughly speaking, if an abatement technology of firm i is more efficient than that of firm j, then firm i emits more pollutions and firm j abates more pollutions when the value of θ increases. However, decreases in pollutions dominate increases in pollutions, leading to the result that the total concentrations decrease. Responses between the firms are interchanged in the green-colored triangle in the lower-right when firm j with efficient technology emits more pollutions.

We also examine how firm's profit varies as the ambient charge varies. Now ϕ_i and ϕ_j are considered fixed. The maximized profit is obtained by substituting the optimal outputs in (16.5)

$$\bar{\pi}_i(\theta) = p(\theta)\bar{q}_i(\theta) - \theta(\phi_i\bar{q}_i(\theta) + \phi_j\bar{q}_j(\theta) - E), \tag{16.8}$$

where the optimal output is simplified as $\bar{q}_i(\theta)$ and $\bar{q}_j(\theta)$ and the corresponding price is denoted by $p(\theta) = 1 - \bar{q}_i(\theta) - \bar{q}_j(\theta)$. Differentiating (16.8) with respect to θ gives

$$\frac{\partial\bar{\pi}_i(\theta)}{\partial\theta} = \frac{1}{9}\left\{2\theta\left(4\phi_i^2 - 7\phi_i\phi_j + 7\phi_j^2\right) - \left(4\phi_i + \phi_j\right)\right\}. \tag{16.9}$$

In the same way, the marginal profit of firm j is obtained,

$$\frac{\partial\bar{\pi}_j(\theta)}{\partial\theta} = \frac{1}{9}\left\{2\theta\left(4\phi_j^2 - 7\phi_i\phi_j + 7\phi_i^2\right) - \left(4\phi_j + \phi_i\right)\right\}. \tag{16.10}$$

The zero-marginal profit of firm i is illustrated as the dotted elliptical shape curve close to the horizontal axis in Fig. 16.1. The marginal profit of firm i is positive outside the curve and negative inside. The zero-marginal profit of firm j is the dotted curve close to the vertical axis. The marginal profit of firm j is also positive outside and negative inside. One of the disadvantages of the ambient charge is a moral hazard problem associated with the asymmetric information. In a situation in which each discharger's emission is not observable, it can increase its profit by choosing a lower level of abatement. When the ambient charge tax increases, firm i increases emissions and profit in the yellow region above the dotted curve in which the abatement technology of firm i is more efficient than that of firm j (i.e., $\phi_i < \phi_j$). On the other hand, firm j increases emissions and profit in the green region right to the dotted curve in which firm j has more efficient abatement technology.

Proposition 1 *When the ambient charge tax varies, moral hazard arises in cases with firms having strongly asymmetric abatement technologies.*

16.2.2 Second Stage

Given the ambient tax rate θ and the optimal output decisions q_i^* and q_j^* in (16.5), each firm determines the optimal abatement technology at the second stage. Substituting the optimal outputs into the profit function (16.2) and subtracting the implementation cost of the abatement technology present the reduced form of the profit function of firm i as

$$\pi_i^*(\phi_i) = (1 - q_i^* - q_j^*)q_i^* - \theta\left(\phi_i q_i^* + \phi_j q_j^* - E\right) - (1 - \phi_i)^2 \tag{16.11}$$

where θ is considered fixed. The arguments of q_i^* and q_j^* are omitted for notational simplicity. Differentiating (16.11) with respect to ϕ_i yields the first-order condition,

$$\frac{\partial \pi_i^*}{\partial \phi_i} = \frac{\partial \pi_i^*}{\partial q_i}\frac{\partial q_i^*}{\partial \phi_i} + \frac{\partial \pi_i^*}{\partial q_j}\frac{\partial q_j^*}{\partial \phi_i} + \frac{\partial \pi_i^*}{\partial \phi_i}_{|q_i^*, q_j^*:const} = 0, \tag{16.12}$$

where

$$\begin{aligned}
\frac{\partial \pi_i^*}{\partial q_i} &= 1 - 2q_i^* - q_j^* - \theta\phi_i = 0, \\
\frac{\partial \pi_i^*}{\partial q_j} &= -\, q_i^* - \theta\phi_j, \\
\frac{\partial q_j^*}{\partial \phi_i} &= \frac{\theta}{3}, \\
\frac{\partial \pi_i^*}{\partial \phi_i}_{|q_i^*, q_j^*:const} &= 2(1 - \phi_i) - \theta q_i^*.
\end{aligned} \tag{16.13}$$

The second-order conditions for firms i and j are

$$\frac{\partial^2 \pi_i^*}{\partial \phi_i^2} = \frac{\partial^2 \pi_j^*}{\partial \phi_j^2} = \frac{8}{9}\left(\theta^2 - \frac{9}{4}\right) \le 0 \tag{16.14}$$

that is satisfied if

$$0 \le \theta \le \frac{3}{2}. \tag{16.15}$$

Rearranging the terms in (16.12) simplifies the form of the first-order condition for firm i as

$$2(4\theta^2 - 9)\phi_i - 7\theta^2\phi_j = 4\theta - 18. \tag{16.16}$$

In the same way, the first-order condition for firm j is

$$-7\theta^2\phi_i + 2(4\theta^2 - 9)\phi_j = 4\theta - 18. \tag{16.17}$$

Solving (16.16) and (16.17) simultaneously yields the optimal choice of the abatement technology,

$$\phi_i^* = \phi_j^* = \phi^*(\theta) = \frac{18 - 4\theta}{18 - \theta^2}. \tag{16.18}$$

Since the firms are symmetric, their optimal choices should be identical. The choice of the optimal technology against θ is illustrated in Fig. 16.2. Notice that the dashed vertical line stands at $\theta_0 = 3\sqrt{2} \simeq 4.243$ and divides the horizontal axis into two parts, $18 - \theta^2 > 0$ for $\theta < \theta_0$ and $18 - \theta^2 < 0$ for $\theta > \theta_0$. To avoid congestion, θ_0 is labelled on the upper horizontal line. Accordingly, as is seen in Fig. 16.2, the optimal abatement technology is determined as

$$\frac{2}{3} \le \phi^*(\theta) \le 1 \text{ if } 0 \le \theta \le 4 \text{ and } 0 \le \phi^*(\theta) \le 1/3 \text{ if } \theta \ge \frac{9}{2},$$

where the first condition for θ is weaker than the SOC in (16.15) and the second condition violates it. The optimal choices for $\theta \ge 9/2$ are eliminated for further considerations.

Differentiating the optimal technology (16.18) with respect to θ presents

$$\frac{d\phi^*}{d\theta} = -\frac{4(\theta - 3)(\theta - 6)}{(18 - \theta^2)^2}. \tag{16.19}$$

The denominator is always positive unless $\theta \neq \theta_0$. On the other hand, the numerator is negative if $3 < \theta < 6$ and non-negative otherwise. Hence the derivative is definitely negative in the shaded region of Fig. 16.2 in which the SOC holds.

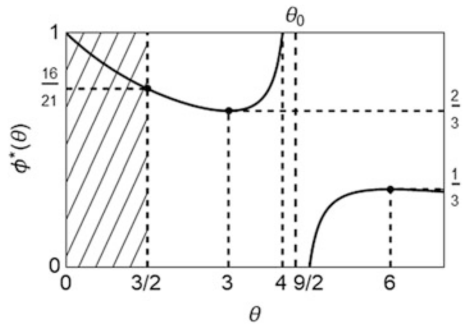


Fig. 16.2 Optimal abatement technology, $\phi^*(\theta)$

This is a natural result, implying that the rational firm chooses more effective abatement technology if the regulator imposes heavier ambient charges. Concerning the properties of the optimal abatement technology, we summarize the results obtained so far.

Proposition 2 *The optimal abatement technology is positive and less than unity and decreases as the ambient charges increase, since*

$$\frac{16}{21} < \phi^*(\theta) \leq 1 \text{ and } \frac{\partial \phi^*}{\partial \theta} < 0 \text{ for } 0 \leq \theta \leq \frac{3}{2}.$$

Optimal outputs with the optimal technology are obtained by inserting (16.18) into (16.5),

$$q_i^*(\theta, \phi_i^*, \phi_j^*) = q_j^*(\theta, \phi_i^*, \phi_j^*) = \frac{\theta^2 - 6\theta + 6}{18 - \theta^2}. \tag{16.20}$$

Since $\theta \leq 3/2$ is assumed, the denominator is positive. The numerator is nonnegative if either $0 \leq \theta \leq 3 - \sqrt{3}$ or $\theta \geq 3 + \sqrt{3}$, where the second case has no economic meaning. The optimal output under the optimal abatement technology denoted as $q^*(\theta)$ has two phases,

$$q^*(\theta) = \frac{\theta^2 - 6\theta + 6}{18 - \theta^2} > 0 \text{ if } 0 \leq \theta \leq 3 - \sqrt{3} \tag{16.21}$$

or

$$q^*(\theta) = 0 \text{ if } 3 - \sqrt{3} < \theta \leq 3/2. \tag{16.22}$$

Zero production means that the firms exit the market if a stronger environmental policy is enforced in the sense that $\theta \geq 3 - \sqrt{3} \simeq 1.268$.

Differentiating the optimal output (16.21) presents

$$\frac{dq^*}{d\theta} = -\frac{6\left[(\theta-4)^2+2\right]}{\left(18-\theta^2\right)^2} < 0 \text{ for } \theta \geq 0. \tag{16.23}$$

The negative derivative implies that increasing the tax rate decreases the output, leading to decreased emission of pollution.

Proposition 3 *The optimal output under the optimal abatement technology is positive and negatively sensitive to a change in the tax rate if the environmenat policy is not so strong,*

$$q^*(\theta) > 0 \text{ and } \frac{dq^*}{d\theta} < 0 \text{ for } 0 \leq \theta \leq 3-\sqrt{3}$$

and the firms exit the market if the policy is strong.

The total amount of pollutions emitted by the two firms at the second stage is the double of individually emitted pollutions since the firms are symmetric,

$$E^{**}(\theta) = 2\phi^*(\theta)\, q^*(\theta) \tag{16.24}$$

that is non-negative for $\theta \leq 3-\sqrt{3}$. We are now concerned with how the total amount changes in response to changes in the environmental policy. To this end, we first differentiate $E^{**}(\theta)$ in (16.24) with respect to θ to have,

$$\frac{1}{2}\frac{dE^{**}(\theta)}{d\theta} = \frac{d\phi^*}{d\theta}q^* + \phi^*\frac{dq^*}{d\theta} < 0, \tag{16.25}$$

where the inequality is due to (16.19) and (16.23). If the regulator decides to increase the ambient charges, then there are two effects on the total concentrations. First, the firms decrease output and get decreased amount of pollutions described by the second term in (16.25). Second, the firms improve their abatement technology more effective and get decreased amount of pollutions. This is described by the first term. The total effect on the concentration is the sum of these decreases and thus definitely negative. When the ambient charges rise, the total amount of pollutions will fall, implying that the policy is effective for controlling the pollutions. We summarize this as our second main result:

Theorem 2 *Assuming optimal abatement technologies and outputs, the increased tax rate θ decreases the total quantity of NPS pollutions,*

$$\frac{dE^{**}(\theta)}{d\theta} < 0 \text{ for } 0 \leq \theta \leq 3-\sqrt{3}.$$

Another way to see this result is to rewrite the right-hand side of (16.24) in terms of θ. By inserting (16.18) and (16.21) into (16.24), an alternative form of the total

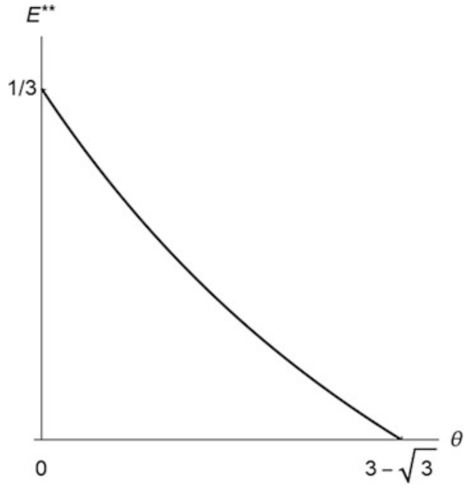


Fig. 16.3 Graph of the total concentrations, $E^{**}(\theta)$

pollutions is obtained,

$$E^{**}(\theta) = \frac{2(18 - 4\theta)(\theta^2 - 6\theta + 6)}{(18 - \theta)^2} \tag{16.26}$$

which is illustrated in Fig. 16.3.

Apparently $E^{**}(\theta)$ has a negative slope and in particular, differentiating (16.26) with respect to θ gives the following form:

$$\frac{dE^{**}(\theta)}{d\theta} = -\frac{4(\theta^4 - 21\theta^3 + 153\theta^2 - 486\theta + 596)}{(18 - \theta^2)^3} < 0 \text{ for } 0 \le \theta < 3 - \sqrt{3}. \tag{16.27}$$

Yet, in a third way we see Theorem 2 from a different point of view and start with the optimal production (16.5) with $\phi_i = \phi_j = \phi$,

$$\tilde{q}(\theta, \phi) = \frac{1}{3}(1 - \theta\phi). \tag{16.28}$$

Partial differentiation yields two derivatives,

$$\frac{\partial \tilde{q}}{\partial \theta} = -\frac{1}{3}\phi < 0 \text{ and } \frac{\partial \tilde{q}}{\partial \phi} = -\frac{1}{3}\theta < 0. \tag{16.29}$$

The first equation is the *ambient charge effect* that negatively induces changes in outputs. The firms decrease their outputs if a stronger environmental policy is advocated. The second is the *abatement technology effect* that the firms increase outputs if a better abatement technology is set up. These effects are independent as far as $\tilde{q}(\theta, \phi)$ is concerned, however, combined through a change in θ at the optimal point at which the optimal technology depends on θ, $\phi = \phi^*(\theta)$ and the optimal output depends on only θ, $q^*(\theta) = \tilde{q}(\theta, \phi^*(\theta))$. It is differentiated with respect to θ,

$$\frac{dq^*(\theta)}{d\theta} = \frac{\partial \tilde{q}}{\partial \theta} + \frac{\partial \tilde{q}}{\partial \phi}\frac{\partial \phi^*}{\partial \theta}. \tag{16.30}$$

The first term on the right-hand side is the ambient charge effect, itself and the second term describes how much the abatement technology effect is amplified by responsiveness of the abatement technology to a policy change. These terms are substituted into the right-hand side of (16.25) that is reduced to the following form, after arranging the terms:

$$\begin{aligned}\frac{\partial\left[\phi^*(\theta)\,\tilde{q}(\theta, \phi^*(\theta))\right]}{\partial \theta} &= \left[q^*(\theta) + \phi^*(\theta)\frac{\partial \tilde{q}}{\partial \phi}\right]\frac{\partial \phi^*}{\partial \theta} + \phi^*(\theta)\frac{\partial \tilde{q}}{\partial \theta} \\ &= q^*(\theta)(1-\varepsilon_q)\frac{\partial \phi^*}{\partial \theta} + \left[-\frac{1}{3}(\phi^*(\theta))^2\right],\end{aligned} \tag{16.31}$$

where ε_q denotes the elasticity of output with respect to the abatement technology at the optimal point,

$$\varepsilon_q = -\frac{\phi^*}{q^*}\frac{\partial \tilde{q}}{\partial \phi} = \frac{\theta\phi^*}{1-\theta\phi^*}. \tag{16.32}$$

Before going to equation (16.31), we turn a little attention to (16.32) from which we have

$$\varepsilon_q \gtreqless 1 \text{ according to } \phi^*(\theta) \gtreqless \frac{1}{2\theta}.$$

Solving $2\theta\phi^*(\theta) = 1$ gives the critical value of θ,

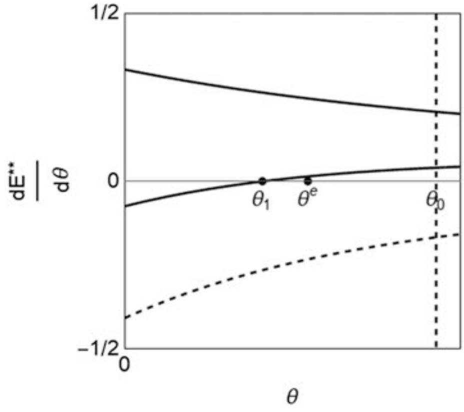
$$\theta_1 = \frac{3}{7}\left(6 - \sqrt{22}\right) \simeq 0.561.$$

Hence we have

$$\varepsilon_q \gtreqless 1 \text{ according to } \theta \gtreqless \theta_1.$$

The actual quantity of emitted pollutions is the fully-discharged pollutions times the abatement level of the technology. If the ambient charge is altered, then the emitted quantity is affected in two ways, how much pollutions are affected and how much technology is affected. Since it is already assumed that one unit of pollution is equal to one unit of production, to check the change in pollutions is equivalent to check the change in output. The change in output is given in (16.26) that is the

Fig. 16.4 Effects on the total concentrations



sum of changes caused by the ambient effect and the technology effect. However, as seen in the right-hand side of the first line in (16.31), the total effect is rearranged and is divided into the second term (i.e., the pollution effect) and the first term (i.e., the extended technology effect). The second term describes how much of changes in pollutions (i.e., output) is remained after abating. The first term is roughly equal to the improvement of technology times changes in pollution induced by changing the technology. The form in the second line of (16.31) simplifies these effects. If the regulator changes the policy, then the pollution effect is negative whereas the extended technology effect is negative if pollution is inelastic (i.e., $\varepsilon_q < 1$) and positive if elastic (i.e., $\varepsilon_q > 1$). However, we have already confirmed in Theorem 2 that even if pollution is elastic, the pollution effect dominates the technology effect.

In Fig. 16.4 (ignore the θ^e for now), the extended technology effect is illustrated by the upward-sloping solid curve, the pollution effect by the downward-sloping solid curve and the sum of these effects by the upward-sloping dotted curve. It can be seen first that the upward-sloping curve crosses the horizontal axis at $\theta = \theta_1$ where $\varepsilon = 1$[5] and thus the technology effect is positive for $\theta_1 < \theta < \theta_0$. Second, the dotted curve is located below the horizontal axis as the pollution effect dominates the technology effect.

16.2.3 First Stage

The regulator determines the optimal rate of ambient charges to maximize the social welfare function that is defined as

$$W = CS + PS + T + D, \tag{16.33}$$

[5]It also crosses at $\theta = 3$, where $\varepsilon_q > 1$.

where CS, PS, T, and D stand for consumer surplus, producers surplus (i.e., profit), tax collected associated with pollution emission, and the damage caused by NPS pollutions, respectively. Each of which is defined as follows:

$$\begin{aligned} CS(\theta) &= \int_0^{Q^*(\theta)} (1-Q)\,dQ - P^*(\theta)\,Q^*(\theta), \\ PS(\theta) &= P^*(\theta)\,Q^*(\theta) - 2\theta E^*(\theta) - 2(1-\phi^*)^2, \\ T(\theta) &= 2\theta E^*(\theta), \\ D(\theta) &= E^*(\theta), \end{aligned} \tag{16.34}$$

where

$$Q^*(\theta) = 2q^*(\theta). \tag{16.35}$$

Notice that the damage function has the simplest form to simplify the analysis. Hence the form of the welfare function is reduced to

$$W(\theta) = 2q^*(\theta) - 2\left[q^*(\theta)\right]^2 - 2(1-\phi^*(\theta))^2 - 2\phi^*(\theta)q^*(\theta). \tag{16.36}$$

Differentiating (16.36) with respect to θ yields

$$\frac{dW}{d\theta} = 2\left(1 - 2q^*(\theta) - \phi^*(\theta)\right)\frac{dq^*(\theta)}{d\theta} + 2\left(2(1-\phi^*(\theta)) - q^*(\theta)\right)\frac{d\phi^*(\theta)}{d\theta}.$$

Using (16.18), (16.19), (16.21), and (16.23), this derivative can be reduced to

$$\frac{dW}{d\theta} = \frac{4[(5\theta - 24)(3\theta^3 - 26\theta^2 + 66\theta - 36)]}{(18-\theta^2)^3}. \tag{16.37}$$

Solving the first order-condition for the welfare maximization, $dW/d\theta = 0$, yields two real solutions, $\theta_1 \simeq 0.746$ and $\theta_2 = 24/5$ which satisfy $\theta_1 < 3 - \sqrt{3} < \theta_2$. Hence the result is summarized as follows.

Theorem 3 *The optimal rate of ambient charges is determined as*

$$\theta^e \simeq 0.746 < \theta_0 (= 3 - \sqrt{3})$$

and in consequence, the optimal abatement technology and the optimal output are

$$\phi^e = \phi^*(\theta^e) \simeq 0.861 \text{ and } q^e = q^*\left(\theta^e\right) \simeq 0.119.$$

All solutions are confirmed to be feasible. Figure 16.1 is illustrated with $\theta = \theta^e$ and the black dot there corresponds to the point (θ^e, θ^e) that is in the red region, implying that $q^*(\theta^e, \phi^e, \phi^e)$ is positive. In Fig. 16.2, it can be checked that $\phi^e > 16/21 \simeq 0.762$. In Fig. 16.4, it is seen that $\theta^e > \theta_1$ implying $\varepsilon_q > 1$.

16.3 Concluding Remarks

In this paper, we consider whether the ambient charge controls NPS pollution. Solving a three-stage game, we determine the optimal level of the ambient charge, the optimal levels of abatement technology and the optimal levels of output. We also show that the ambient charge is effective for controlling NPS pollution.

An ambient tax could be effective to control NPS pollution. However, it has some disadvantages with monitoring. Ambient concentrations should be monitored at an acceptable level of accuracy from a fairness point of view and at a lower cost from a practical point of view. Conversely, monitoring is highly expensive and is very difficult to improve the accuracy level. Further, ambient concentrations have natural violability associated with weather condition and abatement technological uncertainty. It uniformly charges all pollutants, some of who are acting in good faith to reduce pollution levels and some others who do not operate the abatement technology at a non-desired level leading to more emissions. Apparently this could lead to a unfairness problem. These are future tasks to be urgently done.

Concerning the technical aspect of the model analysis, we impose strong assumptions to simplify the analysis. Needless to say, relaxing some of them will be done in a next paper. It is also an interesting task to generalize this duopoly model to n-firm Cournot and Bertrand oligopolies.

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Chapter 17
Unexpected Natural Disasters and Regional Economies: CGE Analysis Based on Inter-regional Input–Output Tables in Japan

Hiroshi Sakamoto

Abstract Japan is a country that faces many natural disasters. These disasters adversely affect the economy and are difficult to predict. This study aims to analyze the impact of such disasters on the local economy by using the Monte Carlo experiment.

In this study, we use an inter-regional input–output table consisting of two regions: Fukuoka prefecture and other prefectures. Fukuoka prefecture (Fukuoka-ken) is located on Kyushu Island where a large earthquake occurred in 2005 (Fukuoka Prefecture Western Offshore Earthquake). This region also faces frequent heavy rains and typhoons that cause severe damage.

Based on the table mentioned above, we constructed a CGE (Computable General Equilibrium) model. We then conducted simulations of natural disasters under the assumption that they will act to destroy productive inputs and efficiency. In order to establish a set of shocks representative of the sudden decrease in capital stocks and labor accompanying a natural disaster, we undertook Monte Carlo experiments. CGE simulations were then conducted using the outputs of the Monte Carlo experiments under four alternative scenarios. Results for macroeconomic and industry variables are presented, showing maximum, minimum and average effects, together with their standard deviation.

Keywords CGE Model · Inter-regional input–output table · Natural disasters · Fukuoka prefecture · Monte Carlo Experiment

JEL Classification C15, C68, D58, O53, R13

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17.1 Introduction

Japan is a country that faces multiple natural disasters and resulting economic effects. It is difficult to predict the occurrence of natural disasters and evaluate their impact. It is still hard to say when and where earthquakes will occur despite ongoing research on earthquake prediction. Events such as typhoons and heavy rains cause damage even though predicted routes are announced in advance. Moreover, there is further damage in the aftermath of these disasters. For instance, the accident at the Fukushima Daiichi Nuclear Power Plant, damage to the connecting bridge at Kansai International Airport, and the Hokkaido earthquake led to a power outage. The Great East Japan Earthquake in 2011 was particularly large, and the government created the Reconstruction Agency for the purpose of restoration and reconstruction. This propagated research on the recovery process from natural disasters (Tokunaga and Resosudarmo 2017). This study focuses on analyzing the regional economic impacts of unexpected natural disasters by undertaking CGE simulations of the damage to productive capacity as predicted through Monte Carlo experiments.

In this study, we use an inter-regional input–output table consisting of two regions: Fukuoka prefecture and other prefectures. Fukuoka prefecture (Fukuoka-ken) is located on Kyushu Island near the Korean peninsula. It faces the sea on three sides, bordering Saga, Oita, and Kumamoto prefectures and facing Yamaguchi prefecture across the Kanmon Straits. Fukuoka prefecture, similar to other areas, faced a big earthquake, in 2005 (Fukuoka Prefecture West Offshore Earthquake).

We proceeded by first developing a CGE (Computable General Equilibrium) model based on the inter-regional input–output table. Natural disasters are expected to affect production factors (sudden decrease in capital and labor) and logistics networks (purchase and use of intermediate goods). We analyze the impact on the regional economy when such capital, labor, and intermediate goods decrease by using Monte Carlo experiments to determine the size of the shock to be applied to the CGE model.[1]

17.2 The Model

The model in this study is based on the CGE models of economics used in various literature, mainly in Hosoe et al. (2004), the Global Trade Analysis Project (GTAP)

[1]The previous version is from Sakamoto (2019) where the method of simulation was slightly revised.

Table 17.1 Structure of inter-regional input–output table in Fukuoka prefecture

	Fukuoka	Others	Fukuoka	Others	Export	Import	Output
Fukuoka	*XM(fp,fp)*	*XM(op,fp)*	*FD(fp,fp)*	*FD(op,fp)*	*E(fp)*	*M(fp)*	*Y(fp)*
Others	*XM(fp,op)*	*XM(op,op)*	*FD(fp,op)*	*FD(op,op)*	*E(op)*	*M(op)*	*Y(op)*
Labor	*L(fp)*	*L(op)*					
Capital	*K(fp)*	*K(op)*					
Output	*Y(fp)*	*Y(op)*					

model (Hertel 1997), and an intermediate model (Rutherford 2010).[2] This study incorporated the features of the said three models to create a unique one.

Table 17.1 shows the inter-regional input–output table in Fukuoka prefecture as a variable for model development. Here, intermediate goods are written as *XM* and final demand is written as *FD*. With labor *L* and capital *K*, value-added goods *V* are produced. Intermediate goods, on the other hand, consist of those from both Fukuoka prefecture and other prefectures. These assume imperfect substitution using the CES (Constant Elasticity of Substitution) function.[3] Intermediate goods and value-added inputs are combined in constant proportions to produce domestic goods *Z*. Furthermore, the domestic goods *Z* and the import goods *M* are combined, and the final production goods (output) *Y* are produced. Domestic goods and import goods are imperfect substitutes (Fig. 17.1). Finally, production goods are divided into various final demand *FD*, intermediate goods *XM*, and export *E*.[4]

We now describe the mathematical equations. First, it is assumed that labor and capital stocks are fixed and the price fluctuates in the supply–demand relationship

[2]The model of Hosoe et al. (2004) solves an optimization problem from the production function including TFP (Total Factor of Productivity) and constructs a nonlinear model. The GTAP model also derives a cost function from the optimization problem and constructs a linear model through logarithmic conversion. The linear model is then solved using software which computes a nonlinear solution using the Euler method or similar (Harrison and Pearson 1996). Rutherford (2010) treats GTAP models as nonlinear models. This is because many researchers of CGE models use GAMS (General Algebraic Modeling System) as a computational tool. However, as shown in Fig. 17.1, while different solution methods are used for the each of the three models, the basic structure of the three models are similar. For instance, all have the same production technology and output transformation functions as depicted in Fig. 17.1.

[3]The substitution relationship is focused on whether capital and labor can be replaced in production. Needless to say, labor can replace capital equipment such as machines. Furthermore, even the same intermediate goods can be replaced if they are produced in different regions (Armington 1969). However, it is assumed that intermediate goods and value-added goods are not substitutable. The general form of the substitution relationships is a CES function. In the special case where the substitution elasticity is 1 the CES function reduces to a Cobb-Douglas function, while for a zero elasticity it reduces to a Leontief function which prevents substitution. In the case of perfect or infinite substitution, the form is $A+B$.

[4]In this study, no detailed assumptions are made for final demand, intermediate goods, and exports. A static model is assumed, and investment does not take a form that affects production in the next period. The General Equilibrium Model is constructed from the point of view that the production value should be balanced.

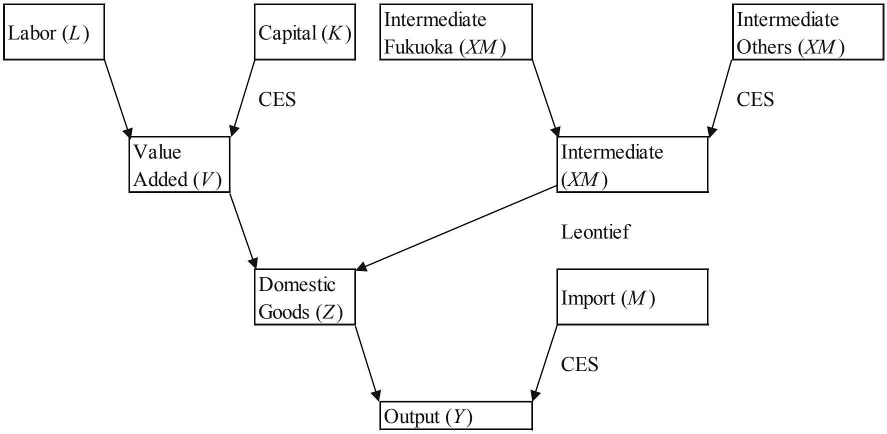

Fig. 17.1 Structure of CGE model's production technology

between labor and capital. The stock will decrease if it is damaged by a natural disaster.[5]

$$l_{r,j} = L_{r,j} \tag{17.1}$$

$$k_{r,j} = K_{r,j} \tag{17.2}$$

where l and k are endogenous variables of labor and capital stock and L and K are exogenous variables, respectively. The subscript r (s) indicates the region and j (i) indicates the industry. Since regions and industries are indicated, there will be no movement of labor and capital between regions and between industries.

Value-added goods are compounded by combining labor and capital. By constructing the optimization problem using the CES function, the cost function is expressed as follows:

$$pv_{r,j} = \left(\alpha_{r,j}^{VL} \cdot pl_{r,j}^{\left(1-\sigma_j^V\right)} + \alpha_{r,j}^{VK} \cdot pk_{r,j}^{\left(1-\sigma_j^V\right)} \right)^{\left(1 \big/ \left(1 - \sigma_j^V\right) \right)} \tag{17.3}$$

[5]In reality, both the price and quantity (stock) of labor and capital fluctuate, but in the model, it is easier to construct by fixing one of them. By fixing the stock, it is impossible to indicate excess labor (employment), but in the model, excess labor is absorbed implicitly by changing prices.

Here, *pv* is the price of value-added goods, *pl* is the labor price, and *pk* is the capital price. α is a share parameter and σ is an elasticity parameter. The price of the intermediate goods combined is also shown as follows:[6]

$$pxm_{r,i,j} = \left(\sum_{s} \alpha^{XM}_{r,s,i,j} \cdot py_{s,i}^{\left(1-\sigma^{X}_{j}\right)} \right)^{\left(1 \big/ \left(1 - \sigma^{X}_{j}\right) \right)} \tag{17.4}$$

Using the Leontief function to combine value-added goods and intermediate goods, the equation is as follows:

$$pz_{r,j} = \sum_{i} \alpha^{ZM}_{r,i,j} \cdot pxm_{r,i,j} + \alpha^{ZV}_{r,j} \cdot pv_{r,j} \tag{17.5}$$

The CES function is used to combine imported goods and domestic goods. The relative price is set to 1 in the absence of a special assumption for the prices of imported goods.

$$pm_{r,j} = 1 \tag{17.6}$$

$$py_{r,j} = \left(\alpha^{YZ}_{r,j} \cdot pz_{r,j}^{\left(1-\sigma^{Y}_{j}\right)} + \alpha^{YM}_{r,j} \cdot pm_{r,j}^{\left(1-\sigma^{Y}_{j}\right)} \right)^{\left(1 \big/ \left(1 - \sigma^{Y}_{j}\right) \right)} \tag{17.7}$$

The price *p* of the consumer goods is determined by adding the indirect tax *GTAX*, the subsidy *GSUB*, and the margin *MARG* to the production goods price *py*.

$$p_{r,i} = py_{r,i} \cdot \left(1 + GTAX_{r,i} + GSUB_{r,i} + MARG_{r,i}\right) \tag{17.8}$$

We now introduce the demand function of goods. The difference between this and the previous model is that the nested demand function is summarized, which

[6] *p* is added before the variables for price variables.

makes it possible to reduce the equations to be determined on the computer. For example, the demand function for labor and capital is as follows:

$$l_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \cdot \left(\frac{pz_{r,j}}{pv_{r,j}}\right)^{\sigma_j^Z} \cdot \left(\frac{pv_{r,j}}{pl_{r,j}}\right)^{\sigma_j^V} \cdot \left(\frac{pl_{r,j}}{1}\right)^{\sigma_j^L} \tag{17.9}$$

$$k_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \cdot \left(\frac{pz_{r,j}}{pv_{r,j}}\right)^{\sigma_j^Z} \cdot \left(\frac{pv_{r,j}}{pk_{r,j}}\right)^{\sigma_j^V} \tag{17.10}$$

Here, the nested structure of capital demand is as follows:

$$k_{r,j} = v_{r,j} \cdot \left(\frac{pv_{r,j}}{pk_{r,j}}\right)^{\sigma_j^V}, \quad v_{r,j} = z_{r,j} \cdot \left(\frac{pz_{r,j}}{pv_{r,j}}\right)^{\sigma_j^Z}, \quad z_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \tag{17.10'}$$

Also, there is further nesting within labor demand. Thus, the labor stock of each industry is composed of multiple types of labor, with imperfect substitution among labor types. However, the price of each labor (wage index) is assumed to be 1.[7]

Labor price (average labor price index in each industry) *pl* and capital price *pk* are determined using this demand structure and Eqs. (17.1) and (17.2).

Based on this, the demand for intermediate goods and imported goods is shown as follows:

$$xm_{r,s,i,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pz_{r,j}}\right)^{\sigma_j^Y} \cdot \left(\frac{pz_{r,j}}{pxm_{r,i,j}}\right)^{\sigma_j^Z} \cdot \left(\frac{pxm_{r,i,j}}{py_{s,j}}\right)^{\sigma_j^X} \tag{17.11}$$

$$m_{r,j} = y_{r,j} \cdot \left(\frac{py_{r,j}}{pm_{r,j}}\right)^{\sigma_j^Y} \tag{17.12}$$

[7] Such forms have been applied to various fields starting from Dixit and Stiglitz (1977). For example, Fujita et al. (1999) in spatial economics and Barro and Sala-i-Martin (2004) in economic growth theory.

The supply–demand relationship of goods is shown as follows:

$$y_{r,i} = \sum_{s} fd_{s,r,i} + \sum_{s,j} xm_{s,r,i,j} + e_{r,i} + ADJ_{r,i} \tag{17.13}$$

The income (GDP) of each region is shown as the sum of labor, capital, and other added value as follows:

$$inco_r = \sum_j pl_{r,j} \cdot l_{r,j} + \sum_j pk_{r,j} \cdot k_{r,j} + \sum_j py_{r,j} \cdot y_{r,j} \cdot \left(GTAX_{r,j} + GSUB_{r,j} + MARG_{r,j}\right) \tag{17.14}$$

Finally, the final demand and the demand for export goods are indicated by the following Cobb–Douglas function (*P* is the initial value of *p*).

$$fd_{r,s,i} = P_{s.i} \cdot inco_r / p_{s,i} \tag{17.15}$$

$$e_{r,i} = P_{r.i} \cdot inco_r / p_{r,i} \tag{17.16}$$

17.3 Data and Simulation

The data uses the 2011 table of the inter-regional input–output table consisting of two regions—Fukuoka prefecture (*fp*) and other prefectures (*op*). The sector (number of industries) is 42 (Table 17.2). In this study, a model is constructed using all the information in the table. The sum of consumer spending outside a household economy (row), wages and salary, social insurance premiums (employers' costs), other salaries and allowances, was used as labor stock. For capital stock, we used capital depreciation.[8] *GTAX* is the ratio of indirect tax except customs duty, *GSUB* is the ratio of subsidy, and *MARG* is the ratio of operating surplus. On the other hand, the final demand used the sum of consumer spending outside a household economy (column), private consumption, government consumption, government investment, private investment, and inventory. Although it is assumed that the supply and demand of data are well-balanced, there is an apparent error in editing the table which is offset by an adjustment term (*ADJ* of Eq (17.13)).

Table 17.3 summarizes the actual transaction amounts shown in the Fukuoka prefecture inter-regional input–output table (2011 version). The economic scale of Fukuoka prefecture is 3.78% of the value-added in other prefectures (remaining 46

[8]Capital depreciation is not a stock value. However, assuming that the relative price of capital is 1, it can be assumed that it is capital stock. Labor stock is the same procedure.

Table 17.2 Industrial classification

	Industry		Industry
a001	Agriculture	i022	Others
a002	Forestry	i023	Construction
a003	Fishing	s024	Electricity and gas supply
i004	Mining	s025	Water supply
i005	Food products and beverages	s026	Waste treatment
i006	Textiles	s027	Wholesale and retail trade
i007	Pulp, paper, and paper products	s028	Finance and insurance
i008	Chemicals	s029	Real estate
i009	Petroleum and coal products	s030	Transport
i010	Plastic and Rubber	s031	Communications
i011	Nonmetallic mineral products	s032	Public administration
i012	Iron and steel	s033	Education and research
i013	Nonferrous metals	s034	Medical treatment, health, social security, and care
i014	Fabricated metal products	s035	Other public services
i015	License machine	s036	Business services
i016	Production machine	s037	Hotel
i017	Business machine	s038	Restaurant
i018	Electronic components	s039	Entertainment
i019	Electrical machinery, equipment, and supplies	s040	Other services
i020	Information and communication facility	s041	Stationery for an individual
i021	Transport equipment	s042	Others

Table 17.3 Actual transaction amount in the inter-regional input–output table in Fukuoka Prefecture (trillion yen)

	Fukuoka	Others	Fukuoka	Others	Export	Import	Output
Fukuoka	9.62	6.27	12.38	4.95	1.94	−1.85	33.31
Others	6.31	440.57	4.40	467.39	69.01	−81.31	906.37
Value added	17.38	459.53					
Output	33.31	906.37					

prefectures) and 3.68% of other prefectures in production. Although these figures are higher than the average size of a prefecture (2.13%), the structure is such that national economic effects are unlikely to be large unless Fukuoka prefecture achieves quite significant results in its economic policy.

Table 17.4 shows elasticity parameters. The elasticity of substitution between labor types is the logarithm of the half-power of labor stock, which could result

Table 17.4 Elasticity parameter

	σ^L (*fp*)	σ^L (*op*)	σ^V	σ^X	σ^Z	σ^Y
a001	5.177	6.856	0.26	5.00	0.00	2.50
a002	3.774	6.027	0.20	5.00	0.00	2.50
a003	4.249	6.333	0.20	2.50	0.00	1.25
i004	4.413	6.031	0.20	10.80	0.00	5.40
i005	6.146	7.701	1.12	5.04	0.00	2.52
i006	4.919	6.954	1.26	7.56	0.00	3.78
i007	5.585	7.282	1.26	6.20	0.00	3.10
i008	5.615	7.403	1.26	5.72	0.00	2.86
i009	4.171	6.239	1.26	5.72	0.00	2.86
i010	5.814	7.425	1.26	5.72	0.00	2.86
i011	5.687	7.078	1.26	7.06	0.00	3.53
i012	5.774	7.151	1.26	7.06	0.00	3.53
i013	4.728	6.895	1.26	7.06	0.00	3.53
i014	5.791	7.469	1.26	7.06	0.00	3.53
i015	5.473	7.307	1.26	8.02	0.00	4.01
i016	5.657	7.562	1.26	8.02	0.00	4.01
i017	4.465	7.075	1.26	8.02	0.00	4.01
i018	5.494	7.455	1.26	8.80	0.00	4.40
i019	5.699	7.477	1.26	8.80	0.00	4.40
i020	4.012	7.084	1.26	8.80	0.00	4.40
i021	6.128	7.849	1.26	6.40	0.00	3.20
i022	5.793	7.421	1.26	8.02	0.00	4.01
i023	6.664	8.374	1.40	3.80	0.00	1.90
s024	5.578	7.276	1.26	5.60	0.00	2.80
s025	5.207	6.660	1.26	5.60	0.00	2.80
s026	5.597	7.212	1.26	3.80	0.00	1.90
s027	7.232	8.716	1.68	3.80	0.00	1.90
s028	6.295	8.083	1.26	3.80	0.00	1.90
s029	5.930	7.611	1.26	3.80	0.00	1.90
s030	6.684	8.237	1.68	3.80	0.00	1.90
s031	6.335	8.115	1.26	3.80	0.00	1.90
s032	6.572	8.241	1.26	3.80	0.00	1.90
s033	6.881	8.438	1.26	3.80	0.00	1.90
s034	7.028	8.570	1.26	3.80	0.00	1.90
s035	5.782	7.396	1.26	3.80	0.00	1.90
s036	6.795	8.478	1.26	3.80	0.00	1.90
s037	5.178	7.051	1.26	3.80	0.00	1.90
s038	6.285	7.921	1.26	3.80	0.00	1.90
s039	5.608	7.305	1.26	3.80	0.00	1.90
s040	5.924	7.650	1.26	3.80	0.00	1.90
s041	–	–	–	3.80	0.00	1.90
s042	4.384	6.074	1.26	3.80	0.00	1.90

Note: $\sigma^L = \text{Ln}(L\hat{}(1/2))$, σ^Z is a parameter of Leontief function without substitution
As no value-added data is recorded in s041 (stationery for an individual), no parameters are displayed
Source: Calculated by the author from the GTAP 8 database and the inter-regional input–output table in Fukuoka prefecture

in relatively large numbers.[9] For other elasticity parameters, for labor and capital substitution and for domestic goods and imported goods substitution, the elasticity parameters present in the GTAP 8 database are used. The degree of interregional substitution for intermediate goods is assumed to be twice that for substitution between domestic goods and imported goods. The substitution between value-added goods and intermediate goods is 0. This is assuming the use of the Leontief function.

We undertook four types of simulations in this study (Table 17.5). First, we assumed that natural disasters cause damage to specific sectors in Fukuoka prefecture. When the damage occurred, we gave a width to the size of the damage based on the premise that no damage will occur throughout Fukuoka prefecture unless it is a significant disaster. As a result, two types of probability distributions were used in the Monte Carlo experiment. Use random numbers based on the binomial distribution to set the damage that occurs for a specific sector. Here, we determined whether the damage would occur with a probability of 50%; and the magnitude is determined with uniform distribution. The width of the uniform distribution is different for production factors and intermediate goods. Among the production factors, labor stock is to be damaged up to 8% and damage to capital stock up to 40%. Regarding intermediate goods, damage to intermediate goods transactions in Fukuoka prefecture is up to 80%, and 40% for those outside. Damage to labor stock means that laborers will not be able to work due to the disaster. Since saving lives is a priority, heavy casualties are not expected. However, a substantial proportion of the capital stock is expected to become unproductive due to the destruction of properties. Although we set a relatively high number for the degree of damage, we thought that complete destruction was not a realistic possibility. Regarding intermediate goods transactions, we thought that the numbers should reflect a near extinction of these transactions because the infrastructure for logistics is expected to collapse. Therefore, the damage was set at 80%. In addition, because the disaster is assumed to be in the Fukuoka prefecture, the logistics infrastructure in other prefectures would not collapse. Therefore, we considered that the damage to intermediate goods flows within the Others region would be smaller than these flows with a Fukuoka prefecture origin or destination (Simulation 1).[10]

In the second simulation, we analyze the economic impact of damage to all sectors, not to specific sectors. Simulation 2 sets the uniform distribution which becomes the same as the damage of Simulation 1 on average.[11] For the next two simulations, the magnitude of the damage was generated in a nonuniform distribution as it is more likely that damage will be minimal. Here, a half-normal

[9]This is very rough calculation, but at least it was estimated to be higher than the substitution between labor and capital.

[10]Improving the accuracy of setting the probability of occurrence and the scale of damage will be the issue for the future. In the author's earlier study (Sakamoto 2019), we assumed a slightly higher damage than this.

[11]Given that a maximum of 40% of the damage occurs with a 50% probability and a maximum of 20% of the damage occurs with a 100% probability, the idea is that multiplying the two probabilities is equivalent.

Table 17.5 Monte Carlo experiment

	$L(fp)$	$K(fp)$	$XM(fp, fp)$	$XM(fp, op)$ and $XM(op, fp)$
Simulation 1	$L_*(1 - B(1,0.50)_* U(0,0.08))$	$K_*(1 - B(1,0.50)_* U(0,0.40))$	$XM_*(1 - B(1,0.50)_* U(0,0.80))$	$XM_*(1 - B(1,0.50)_* U(0,0.40))$
Simulation 2	$L_*(1 - U(0,0.04))$	$K_*(1 - U(0,0.20))$	$XM_*(1 - U(0,0.40))$	$XM_*(1 - U(0,0.20))$
Simulation 3	$L_*(1 - HN(0,0.04_* s))$	$K_*(1 - HN(0,0.20_* s))$	$XM_*(1 - HN(0,0.40_* s))$	$XM_*(1 - HN(0,0.20_* s))$
Simulation 4	$L_*(1 - T(0,0,0.04_* c))$	$K_*(1 - T(0,0,0.20_* c))$	$XM_*(1 - T(0,0,0.40_* c))$	$XM_*(1 - T(0,0,0.20_* c))$

Note: $B(1, 0.50)$ is a binomial distribution showing 1 at a probability of 0.50
$U(0, 0.08)$ is a uniform distribution in the range of 0–0.08
$HN(0,0.04_* s)$ is a half-normal distribution and represents the absolute value of a normal distribution with an average of 0 and a standard deviation of $0.04_* s$, $s = (\pi/8)\hat{}(1/2)$
$T(0,0,0.04_* c)$ is a triangular distribution with a minimum value of 0, a mode value of 0, and a maximum value of $0.04_* c$, $c = 3/2$

distribution showing the positive part of the normal distribution (Simulation 3) and a triangular distribution with a minimum value and a mode value of 0 (Simulation 4) is adopted. The standard deviation and the maximum value are set so that the average of the damage is the same as in Simulation 1.[12]

When damage occurs as shown in Table 17.5, the labor stock L, the capital stock K and the intermediate goods XM of Fukuoka prefecture decrease according to the probability.[13] The model is then recalculated under the changed variable. According to the equation of the model, the reduction of labor and capital stock firstly affects Eq. (17.14). The reduction in the intermediate goods transaction firstly affects Eq. (17.13). It also affects other equations and a new equilibrium solution is calculated.

17.4 Result

17.4.1 Simulation Based on Database

Table 17.6 shows the CGE results of Monte Carlo experiments for all simulations. The maximum, minimum, average, and standard deviation of output, price, nominal income (nominal GDP), and real income (real GDP) are shown. These experiments were repeated 500 times each.

In terms of output, the average damage result in Fukuoka prefecture is 0.889283 (i.e., a decrease of approximately 11% from a no-change output level of 1.000000) in Simulation 1, 0.889276 in Simulation 2, 0.889073 in Simulation 3, and 0.889244 in Simulation 4. On the other hand, in other prefectures and Japan (*jp*), the damage is less than 1% in all simulations. Along with this, the price has decreased slightly, but the average is around 1.3% at maximum. The average of nominal income in Fukuoka prefecture was 0.934199 in Simulation 1, 0.933750 in Simulation 2, 0.933932 in Simulation 3, and 0.933665 in Simulation 4. Real income is slightly higher than nominal income because prices are decreasing. As far as the average is seen, it is almost the same, consistent with the intention at the onset of the simulation.

However, the standard deviation is very different. The standard deviation of the output of Fukuoka prefecture is 0.010588 in Simulation 1, 0.004978 in Simulation 2, 0.006098 in Simulation 3, and 0.005797 in Simulation 4. The combination of the binomial distribution and the uniform distribution seems to distort the distribution of experimental results. This is because increase in the standard deviation is that for the non-damaged industry and while the various stocks do not change here, they do so for the damaged industry. The half normal and triangular distributions could also

[12]From Sakamoto (2019), Simulation 3 and Simulation 4 were added. The notes in Table 17.5 show the calculation method.

[13]The number of variables that change in a single Monte Carlo experiment is 3538 ($42_L + 42_K + 42 \times 42 \times 3_{XM} = 5376$ minus zero data 1838), and a corresponding number of random numbers are generated.

Table 17.6 Result of Monte Carlo–CGE experiments (simulation 1–4)

			Max.	Min.	Average	S.D.
Output	Simulation 1	*fp*	0.918632	0.862536	0.889283	0.010588
		op	0.996866	0.993037	0.995258	0.000695
		jp	0.993841	0.988727	0.991688	0.000933
	Simulation 2	*fp*	0.904296	0.875753	0.889276	0.004978
		op	0.996384	0.994420	0.995248	0.000344
		jp	0.993282	0.990497	0.991678	0.000459
	Simulation 3	*fp*	0.905359	0.868033	0.889073	0.006098
		op	0.996278	0.993496	0.995227	0.000428
		jp	0.993150	0.989678	0.991651	0.000561
	Simulation 4	*fp*	0.907693	0.871906	0.889244	0.005797
		op	0.996384	0.994064	0.995242	0.000401
		jp	0.993254	0.990033	0.991672	0.000536
Price	Simulation 1	*fp*	0.991876	0.981417	0.987362	0.001916
		op	0.999499	0.998792	0.999210	0.000128
		jp	0.999252	0.998290	0.998845	0.000166
	Simulation 2	*fp*	0.990140	0.985011	0.987375	0.000910
		op	0.999396	0.999058	0.999211	0.000062
		jp	0.999098	0.998646	0.998846	0.000081
	Simulation 3	*fp*	0.990536	0.983583	0.987428	0.001109
		op	0.999403	0.998959	0.999208	0.000077
		jp	0.999098	0.998548	0.998845	0.000101
	Simulation 4	*fp*	0.990310	0.984228	0.987419	0.001077
		op	0.999409	0.999007	0.999212	0.000074
		jp	0.999113	0.998606	0.998848	0.000097
Nominal Income	Simulation 1	*fp*	0.956633	0.906303	0.934199	0.008778
		op	0.998934	0.997926	0.998474	0.000188
		jp	0.997286	0.994704	0.996131	0.000430
	Simulation 2	*fp*	0.947335	0.923076	0.933750	0.004287
		op	0.998771	0.998241	0.998471	0.000093
		jp	0.996672	0.995545	0.996112	0.000213
	Simulation 3	*fp*	0.949394	0.912554	0.933932	0.005596
		op	0.998781	0.998067	0.998467	0.000115
		jp	0.996903	0.995144	0.996115	0.000274
	Simulation 4	*fp*	0.947867	0.919158	0.933665	0.005418
		op	0.998785	0.998163	0.998471	0.000111
		jp	0.996928	0.995411	0.996110	0.000265

(continued)

Table 17.6 Result of Monte Carlo–CGE experiments (simulation 1–4)

			Max.	Min.	Average	S.D.
Real income	Simulation 1	*fp*	0.967063	0.921593	0.946149	0.007847
		op	0.999442	0.999056	0.999263	0.000071
		jp	0.998200	0.996237	0.997284	0.000325
	Simulation 2	*fp*	0.959091	0.936264	0.945687	0.003828
		op	0.999375	0.999158	0.999259	0.000035
		jp	0.997753	0.996842	0.997263	0.000160
	Simulation 3	*fp*	0.959073	0.927224	0.945819	0.005070
		op	0.999378	0.999086	0.999259	0.000043
		jp	0.997839	0.996503	0.997268	0.000210
	Simulation 4	*fp*	0.958492	0.932223	0.945559	0.004892
		op	0.999375	0.999140	0.999259	0.000042
		jp	0.997812	0.996743	0.997259	0.000203

see larger standard deviations than the uniform distribution because the distribution is concentrated to the damage rate closer to zero. Generally, there are two points. First, even if a large natural disaster occurs in Fukuoka prefecture, the impact on the Japanese economy is not significant. Second, although the economy of Fukuoka prefecture suffers substantially, the situation of damage varies depending on how such damage occurs and its magnitude.

Table 17.7 shows the results of Monte Carlo experiments by industry, showing the output and prices in Fukuoka prefecture. The same trend was shown for each simulation except for the size of the result, so the result of Simulation 1 is displayed.[14]

Like Table 17.6, it can be seen from this table that the change in output is greater than the change in price. According to the table, in seven industries (i004, i007, i013, s026, s036, s041, and s042), the average output damage exceeds 30% and in 13 industries (i004, i011, i012, i013, i014, i020, i021, s026, s028, s031, s036, s041, and s042), the standard deviation of output exceeds 5%. Also, in five industries (a001, a003, i012, s029, and s042), the standard deviation of price exceeds 1%.

Figure 17.2 shows the distribution of experimental results of real income in each simulation. In creating the distribution, we used weighted frequency distribution to make it smooth.[15] Although the distribution of damage occurrence in each simulation is different, the result is close to normal distribution because the real income is the sum of each industry. Since the standard deviation is different, the

[14]Unlike Excel, random number generation in GAMS always generates random numbers with the same pattern (pseudorandom number), so it has high reproducibility due to recalculation.

[15]The frequency distribution was counted at an interval of 0.001, and a weight of 0.1 was applied to the frequency two before and two after it, a weight 0.2 was applied to the frequency one before and one after it, and a weight 0.4 was applied to the frequency.

Table 17.7 Results of Monte Carlo–CGE experiments (output and price in Fukuoka Prefecture), simulation 1

	Output				Price			
	Max.	Min.	Average	S.D.	Max.	Min.	Average	S.D.
a001	0.979844	0.755711	0.914855	0.049514	0.990185	0.899595	0.961969	0.020817
a002	0.985176	0.900891	0.957101	0.016353	0.989335	0.939143	0.972052	0.009958
a003	0.994086	0.848027	0.956017	0.027033	0.993447	0.914000	0.967226	0.016612
i004	0.912117	0.312426	0.709371	0.118429	0.998883	0.993360	0.996236	0.001456
i005	0.996993	0.847280	0.939027	0.028714	0.998344	0.985377	0.993775	0.002823
i006	0.930090	0.811035	0.876429	0.021136	1.005763	1.001377	1.003260	0.000804
i007	0.893379	0.654065	0.787898	0.047788	1.013396	1.001442	1.006645	0.002324
i008	0.957551	0.754751	0.880357	0.040744	0.997136	0.990913	0.994751	0.001165
i009	0.964753	0.773314	0.884876	0.040574	0.996056	0.982211	0.990422	0.002784
i010	0.944104	0.800366	0.877455	0.028085	0.999236	0.993891	0.997306	0.000995
i011	0.959918	0.652901	0.854091	0.055226	1.004738	0.995901	0.999149	0.001423
i012	0.983714	0.743639	0.902797	0.056404	0.994593	0.931338	0.974364	0.014244
i013	0.905222	0.628057	0.784448	0.052363	1.005099	1.000079	1.002175	0.000912
i014	0.954485	0.573317	0.823423	0.069309	1.025927	0.990843	1.005247	0.005545
i015	0.979921	0.860391	0.931449	0.024661	1.005458	0.994782	0.999845	0.001925
i016	0.986643	0.895084	0.952901	0.020951	1.001986	0.993800	0.998416	0.001426
i017	0.943719	0.751724	0.877109	0.038196	1.009702	1.000902	1.003970	0.001742
i018	0.974287	0.750587	0.882597	0.046562	0.997986	0.994377	0.996605	0.000691
i019	0.967364	0.875117	0.924434	0.019677	1.003555	0.997554	1.000510	0.000995
i020	0.952744	0.756924	0.880372	0.051353	1.002424	0.999984	1.000872	0.000647
i021	0.986045	0.769481	0.919395	0.052699	0.998679	0.994353	0.997064	0.000843
i022	0.894084	0.746960	0.831121	0.027343	1.011840	1.002764	1.006615	0.001564
i023	0.935915	0.843635	0.896619	0.017288	1.003295	0.997587	1.000748	0.000978
s024	0.929545	0.712164	0.839825	0.035447	0.981160	0.923154	0.958631	0.009262
s025	0.929035	0.775686	0.858797	0.029651	0.981377	0.945148	0.965281	0.006847
s026	0.927459	0.596379	0.796305	0.058398	1.023985	1.000146	1.008646	0.004042
s027	0.970138	0.903900	0.940783	0.011621	0.998944	0.990882	0.995527	0.001145
s028	0.917025	0.659837	0.829129	0.050362	0.994100	0.979995	0.989075	0.002304
s029	0.970561	0.919212	0.951295	0.010181	0.953575	0.875960	0.924005	0.015236
s030	0.914022	0.716515	0.830189	0.037209	0.996610	0.991261	0.994428	0.000876
s031	0.933553	0.676559	0.821115	0.051246	0.991507	0.969016	0.981826	0.004136
s032	0.962143	0.911546	0.940261	0.008404	0.991082	0.980002	0.985566	0.002043
s033	0.932831	0.793296	0.878542	0.025798	1.003026	0.997923	1.000116	0.000923
s034	0.959216	0.896472	0.931247	0.011482	0.998974	0.996221	0.997570	0.000467
s035	0.926813	0.843135	0.888973	0.013518	1.006989	1.000830	1.003735	0.001008
s036	0.876921	0.555018	0.753479	0.055139	0.991455	0.964554	0.982795	0.004195
s037	0.993957	0.982773	0.988980	0.001709	0.996946	0.993355	0.995313	0.000678
s038	0.973274	0.925744	0.954274	0.008582	0.997730	0.993053	0.995616	0.000875
s039	0.984598	0.945374	0.969055	0.008019	0.995160	0.988819	0.992123	0.001132
s040	0.969955	0.906002	0.944268	0.013469	0.992556	0.984504	0.989155	0.001519
s041	0.877834	0.455265	0.714308	0.074986	1.001842	0.999300	1.000601	0.000467
s042	0.894292	0.444707	0.719006	0.095822	0.981052	0.921173	0.959614	0.012461

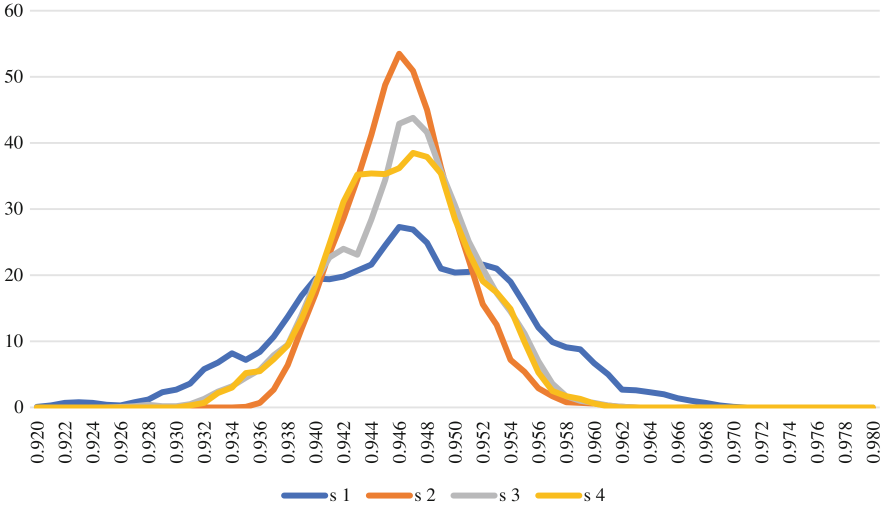

Fig. 17.2 Distribution of experimental results of real income in each simulation

shape of the distribution is also different hence showing that the distribution of Simulation 1 is the widest.

17.4.2 Comparison with Past Disasters

The Fukuoka Prefecture West Offshore Earthquake occurred in March 2005. Although this earthquake was relatively large, the damage was not so compared to the other one that introduced later. According to "Fukuoka Prefecture Main Natural Disaster Damage Statistics (after 1954)" in Fukuoka prefecture,[16] the damage amount was 31,497 billion yen. Other examples of large earthquakes include the Great Hanshin-Awaji Earthquake in January 1995, the Niigata Chuetsu Earthquake in October 2004, the Great East Japan Earthquake in March 2011, and the Kumamoto Earthquake in April 2016. According to the policy director of the Cabinet Office on "Assessing the impact of the 2016 Kumamoto earthquake",[17] the estimated damage of these large earthquakes are 9.6–9.9 trillion yen (Hanshin-Awaji Earthquake) and 1.7–3 trillion yen (Niigata Chuetsu Earthquake), 16.9 trillion yen (Cabinet Office for Disaster Prevention) and 16–25 trillion yen (Cabinet Office for Analysis) (East Japan Earthquake), 2.4–4.6 trillion yen (Kumamoto Earthquake).

[16] http://www.pref.fukuoka.lg.jp/uploaded/life/298282_53094633_misc.pdf

[17] https://www5.cao.go.jp/keizai3/kumamotoshisan/index.html

From here, we analyze the Kumamoto earthquake that occurred in Kumamoto and Oita prefectures, which are adjacent to the Fukuoka prefecture. According to "Assessing the impact of the 2016 Kumamoto earthquake," the damage amount of Kumamoto prefecture is about 1.8–3.8 trillion yen while that of Oita prefecture is about 0.5–0.8 trillion yen. The total for both prefectures is estimated to be 2.4–4.6 trillion yen. This is the amount of loss of capital, and with respect to the capital stock of both prefectures, the estimated loss was about 63 trillion yen (34 trillion yen for Kumamoto prefecture and 28 trillion yen for Oita prefecture). If the damage amount is divided by the capital stock, the damage rate of the Kumamoto earthquake will be 3.8–7.3% (5.3–10.0% for Kumamoto prefecture, 1.8–2.9% for Oita prefecture). In addition, the impact on GDP is estimated to be about 90–127 billion yen (Kumamoto prefecture is 81–113 billion yen, Oita prefecture is 10–14 billion yen), and against each prefecture's GDP (gross prefecture product) 55,645.6 billion yen and 43,782.32 billion yen,[18] the damage rate was 1.0–1.3% (1.5–2.0% for Kumamoto prefecture and 0.2–0.3% for Oita prefecture). In this way, when a large earthquake occurs, it can be seen that even if the stock has a relatively large impact, the flow has little impact.

Comparing this with the results in Table 17.6, the average real income was 0.946149 (about 5.4% loss) in Simulation 1. Although not introduced in the table, the average damage rate of capital was 10% in any simulation (one-half of the width of the uniform distribution is the average). This is realistic as the largest estimate of damage to capital stock in the Kumamoto earthquake is 10%. However, the average loss of real income in this study is over 5% versus 2% which is the largest estimate GDP loss in the Kumamoto earthquake. Even within the distribution of Fig. 17.2, damage within 2% (0.980) is negligible as it seems exaggerated. This study assumes that besides the loss of capital stock, there is a further loss on both labor stock and intermediate goods due to damage to logistics networks. As it is forecasting in advance, it seems better to make some pessimistic predictions.

17.5 Concluding Remarks

In this study, the adverse effects of natural disasters on the economy that cannot be easily measured are analyzed in advance through Monte Carlo experiments using CGE models aided by the inter-regional input–output table for Fukuoka prefecture and Other prefectures region. In the Monte Carlo experiment, random numbers from binomial distributions were generated as the possibility of damage occurrence, and degree of damage; random numbers with uniform distribution, half-normal distribution, and triangular distribution were generated.

[18] Cabinet Office of Japan, "Kenmin Keizai Keisan (Prefectural economic accounts)," (https://www.esri.cao.go.jp/jp/sna/sonota/kenmin/kenmin_top.html). The figures for 2016 have not been published so nominal values for 2015.

It goes without saying that the larger the scale of the damage, the greater the negative impact on the economy. However, if there are regional and industrial variations in the occurrence of damage, the standard deviation of the impact on the economy will be larger. In this study, the damage scale was set relatively large. The negative impact on the Fukuoka economy was significant, but the impact on the Japanese economy was minimal. Also, compared with the actual damage of the Kumamoto earthquake, it can be said that the assumption of the damage in this study is significant.

Since it is not easy to prevent natural disasters in advance, it is necessary to exert efforts to minimize the damage. However, since unexpected damage may still occur, the response, in this case, is in need of examination.

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Chapter 18
Survival Strategies of the Displaced People Due to Riverbank Erosion: A Study of Victims Living on the Bank of Padma River, Bangladesh

Md. Fakrul Islam and Md. Mosharof Hossain

Abstract Riverbank erosion is one of the natural disasters in the riverine Bangladesh. River erosion often destroys cultivable lands, dislocates human settlements, damages the growing crops, massively disrupts road linkages and communication infrastructure in the riparian track of the country. It is one of the most unpredictable and critical types of disasters that depend upon the quantity of rainfall, soil structure, river morphology and topography. The present study has been conducted to assess the losses and miseries caused by the riverbank erosion, find out the effects of erosion on livelihood and to explore the survival and coping strategies adopted by the displaced people of the study area. The study was conducted in two villages near River Padma at the **Shariatpur** district of Bangladesh. Data were collected from both primary and secondary sources to fulfil the objectives of the study. Findings of the study revealed that on an average, 280-acre land and 240 houses of the study area were eroded per year during the period during 2009–2013. It is also found that during this period the rate of damage in 2011 and 2012 was higher than previous years and it was highest in the year 2013. It was an indication of increased erosion rate. The main reason for such variation was climate change-induced intensifying rainfall pattern and unplanned interventions. The marginalised people not only lost property but also experienced socio-economic deprivation through displacement. Because of the dynamic character of the braided channelled river and the failure of structural measures, the sufferings of the people continued. Long-term policies and strategies should be taken to cope with bank erosion taking into account the social and institutional adjustment measures. Land reallocation assurance may be the appropriate strategy to cope up with such disaster. In addition,

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a flood plain zone is essential to lessen the vulnerability of riverbank erosion. Adequate intervention of the concerned government agencies is required to protect the lives and properties. More attention is to be given for rehabilitating the displaced families. This study has both academic and policy-related implications. Findings will be useful for policymakers, project managers and development workers as well as people of Bangladesh to protect erosion, rescue lives and resources and to rehabilitate the displaced people of riverbank erosion in Bangladesh. This study will help in understanding the livelihood strategies of the victims of riverbank erosion in general and the displacees of Shariatpur district in particular.

Keywords Padma River (Ganges in India) · Displaced people · Riverbank erosion · Survival strategy · Land reallocation · Environmental rehabilitation

18.1 Introduction

Nowadays global warming and environmental disaster issues have become a worldwide concern. From this point of view, Bangladesh has been considered as one of the vulnerable countries of the world. People of this country have to face various natural disasters every year like flood, tornado and river erosion. A large number of people are being environmental refugees every year due to environmental disasters. Riverbank erosion is one of the silent disasters in Bangladesh.

Every year about one million people become homeless due to the erosion of the country's two largest rivers—the Jamuna and the Padma (BBC 2000). International Federation of Red Cross and Red Crescent Society (IFRCS) have identified the river erosion as one of the biggest concerns of Bangladesh. According to them, river erosion causes much more destruction than any other natural disaster. However, very few people are concerned about it. The complexity of this issue is needed to be informed to the people through mass media communication. This is a slow but silent disaster (BBC 2000). In a recent study, the DFID has identified the river erosion as one of the topmost disasters from the point of losses. About one million people are affected by the river bank erosion and flood. Flood inundates 9000 hectares of land every year (World Disaster Report 2010).

Bangladesh being predominantly a riverine country, has 250 rivers, big and small, with a stretch of 2400 kilometres bank line. The country is a living delta formed of alluvial soil, which is very prone to erosion with any degree of river water movement. 283 locations, as well as 85 towns and growth centres, are being affected by riverbank erosion almost every year. Besides, another 1200 km of bank line has been identified as vulnerable to erosion.

About half of the victims of riverbank erosion cannot easily find out a new settlement due to poverty and resource constraints. They are to live a floating life. At this moment, there are more or less 4.0 million homeless people in the country. In most cases, such floating families live on public land such as khas lands, embankments, abandoned railway trucks, slopes of highways, etc. Through

Table 18.1 Loss of land due to river erosion between 1996 and 2000

Year	Affected areas	Affected population
1996	71,680 acres	10,103,635
1997	7756 acres	173,090
1998	41,519 acres	321,000
1999	227,755 acres	899,275
2000	219,310 acres	415,870

Source: Md. Salim & Others, Climate Change & River Erosion in Bangladesh. Cost Position Papers 5

migration, many of them increase the concentration of people in the urban slums (IRIN 2009). Geography and Environmental Science Department at Jahangirnagar University presented a chart of the losses of river erosion between 1996 and 2000, which is given in Table 18.1.

Table 18.1 shows the loss of land due to riverbank erosion between 1996 and 2000 by the mighty rivers in Bangladesh.

18.2 Objectives of the Study

The major objectives of the chapter are as follows:

1. To assess the losses and miseries caused by the riverbank erosion in Bangladesh in general and study area in particular.
2. To understand the present socio-economic conditions of the displaced people of the study area.
3. To explore the survival and coping strategies adopted by the displaced people of the study area.
4. To recommend in formulating necessary policies and programs for improving the condition of displaced people in the matter of their rehabilitation.

18.3 Rationale of the Study

The environmental disaster like riverbank erosion is not a new phenomenon in Bangladesh. It is estimated that about one million riparian people are being displaced by this disaster annually. The riverbank erosion displacees usually take curative rather than preventive strategies for adapting to their hazardous riverine environment in their own way. Their strategies for curative measures are embodied in low-level technological capacity. They usually tend to follow curative measures but none of those are adequate and effective for their permanent settlement.

In the absence of government policies and strategies, the displacees are forced to formulate various indigenous strategies in adapting to the unsafe riparian environment due to the lack of organisational support. It is disappointing to note that the land dislocation and population displacement due to riverbank erosion in Bangladesh have received no specific attention either by social scientists or by the government (Zaman and Wiest 1991).

Riverbank erosion is one of the major causes of rural–urban migration. Most of the floating people and slum dwellers of Dhaka city are environmental refugees—especially displaced by riverbank erosion. Riverbank erosion has been identified as a silent tsunami in Bangladesh by environmental specialists. So, there is a great demand for giving proper attention to the people who have lost their lands and shelters. For attaining expected social advancement, to gain economic development, to alleviate poverty and to achieve sustainable development government should give proper attention to those people who are displaced by riverbank erosion. This study will help in understanding the livelihood strategies of the victims of riverbank erosion in general and the displacees of Shariatpur district in particular.

Consequences and cumulative effects of the river erosion are presented in Fig. 18.1.

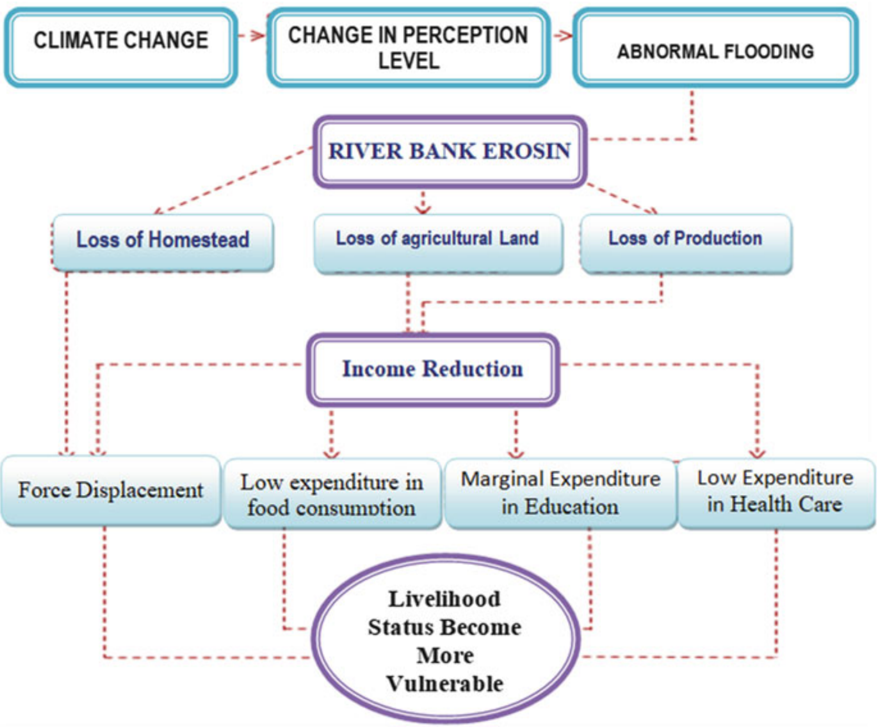

Fig. 18.1 Conceptual framework

18.4 Key Issues and Study Design

For achieving the study objectives descriptive technique has been followed. Secondary data have been collected from the government offices and from related publications. Social survey method was used for collecting data from the victims of the river erosion by the mighty river Padma. It aimed at knowing the problems faced by the victims and strategies adopted by the displaced people to survive. Appropriate statistical techniques have been used for the purpose. The research issues and research design have been presented in Fig. 18.2.

18.4.1 Sampling Procedure and Sample Size

Two villages of Naria Upazila named 'Charjujira' and 'Condipur' have been selected as a study area. There were 334 victim families in these two villages. Of them 148 families live in the village Chandpur and 164 families in the village Charjujira. All of them were the victim of river erosion. The total victim households of the selected villages were considered as universe. Out of those displaced households, 50 households from Condipur (33.78%) and 50 households from Charjujira (30.48%) were selected following simple random sampling technique keeping in the mind the proximity of all categories of victims being included.

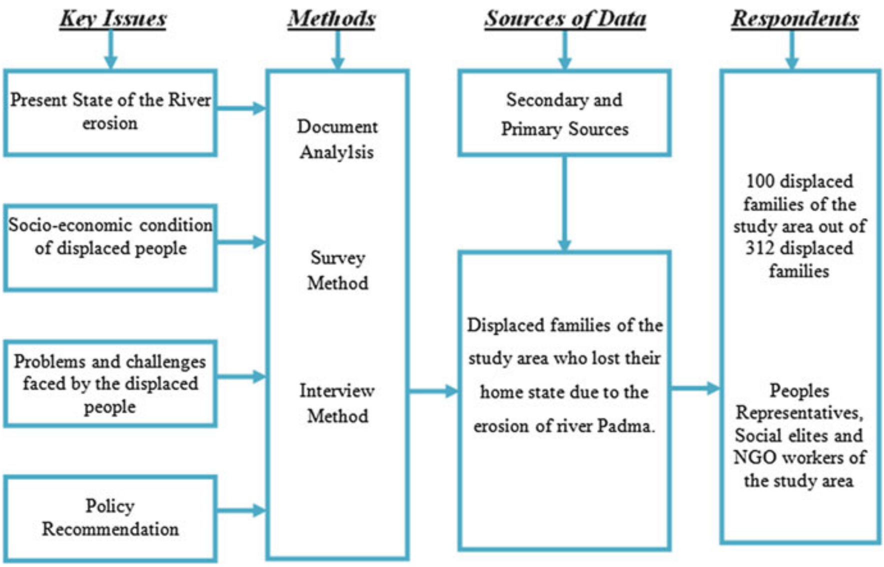

Fig. 18.2 Key issues of research and design to achieve the objectives

Table 18.2 Sample population

Name of village	Number of displaced families	Number of respondents	Percentage
Condipur	148	50	33.78
Charjujira	164	50	30.48
Total	**312**	**100**	**32.13**

Source: Field data

Table 18.2 shows the name of selected sample villages. It also shows the number of displaced victim families and the number of selected samples using simple random sampling.

18.4.2 Techniques of Data Collection

For collecting data sampled family headmen of the victims' families were interviewed through a structured questionnaire after having being pretested. Respective household headman considered as the sample unit. In addition to the survey method, data have been collected through conducting focus group discussions (FGDs), oral deliberations of the victims and through case studies. Formal interviews with the local elites and union council leaders were taken and incorporated. Observation method was also used.

18.5 Analysis of Data

Data have been presented through univariate, bivariate and multivariate tables and pictures (graphs and diagrams). Statistical techniques such as central tendency, correlation and test of significance have also been used to analyse the data. Data has been computerised and analysed using different software techniques.

18.5.1 Intensity of River Bank Erosion of Shariatpur District with Special Reference to the Study Area

Shariatpur is one of the most vulnerable districts in the country from the river erosion point of view as this district is surrounded by three big rivers of the country named Padma, Meghna and Arialkhan. An online newspaper highlights the devastating damage of erosion of this district during the last 40 years.

As per the report of the Executive Engineer, Water Development Board of Shariatpur, near about 10 km highway, 14 km local road, 6 bridges, 8 culverts, about 1900 houses, 4 educational institutions and about 200 acres of land have been

Table 18.3 Damage by erosion during the last 40 years

Sl	Particulars	Figure
1	Village (of 25 unions)	80
2	Land (acres)	70,000
3	Educational institution	100
4	Village Market	08

Source: http://www.al-ihsan.net/FullText.aspx?subid=2&textid=1761. Accessed on 18.4.14

Table 18.4 Damage by erosion at Naria Upazila during 2009–2014

Particulars	Unit	Totally damaged	Partially damaged	At stake
Highways	Kilometer	03	.80	06
Road	Kilometer	05	02	01
Bridge	Number	04	02	05
Culvert	Number	01	01	02
House	Number	1200	100	2200
Institution	Number	04	02	05
Land	Acre	1200	00	500
Embankment	Kilometer	2.5	04	05

Source: Office of the Executive Engineer, WDB, Shariatpur

completely destroyed (See Appendix Photos 18.2, 18.3, 18.4, and 18.5) during the last 5 years. At a glance reports of damages in the last 40 years are given in Table 18.3.

Report of damages that occurred at *Naria Upazila* (see Appendix Photos 18.2, 18.3, 18.4, and 18.5) during 2009–2014 are given in Table 18.4.

18.5.2 Consequences and Challenges Faced by the Study Population

18.5.2.1 Frequency of Displacement

The people of the study area are living within a continuous struggle and are facing many challenges. When they try to overcome their miseries with hardest efforts; devastation comes making them into deep shook. Table 18.5 represents the intensity of erosion and frequency of displacement experienced by the respondents' families.

Highest 39% of the responders have lost their homestead and were forced to shift their houses 3–4 times followed by 17% 7–8 times, 13% 11 times and above, 11% 5–6 times, 10% nine to ten times and 10% one to two times. Besides, they have to face various economic, social and mental problems. Lack of safe drinking water, lack of safe sanitation facilities and discontinuation of the education of their children were the burning issues of the displaced families. Moreover, physical and mental hazards and unhygienic environments become the cause of various diseases. Depending

Table 18.5 Frequency of displacement by the river erosion

Frequency	Number	Percentage
1–2 times	10	10
3–4 times	39	39
5–6 times	11	11
7–8 times	17	17
9–10 times	10	10
11–above	13	13
Total	100	100

on the field visit, observation and interview with victims, social leaders, public representatives, NGO workers and government officials the following problems and challenges are being faced by the victims.

18.5.3 Accommodation Strategy

It was observed that when the villagers feel that their life and homestead are at stake, they shift their family members, livestock, house structure and other tangible assets from their affected homestead to temporary shelters like the highway slope, embankment, relatives' house or nearby villages. Overcoming the first hazards they pay heed to resettle their homestead and start struggling to survive. The people adopted different indigenous strategies for accommodating their families. Only solvent families could resettle their homestead with their own resources. Others took loan from bank, NGO or debt from relatives. The accommodation status after the resettlement of the respondents is given in Table 18.6.

18.5.3.1 Ownership Status of the Homestead

Most of the respondents resettled their house in the land of their relatives, neighbours, government khas land or in the leased land. A highest of 36% of the respondents resettled on the leasing land followed by 19% on the relative's land, 17% on their own purchased land, 16% on paternal land and 12% on government khas lands.

18.5.3.2 Housing Conditions

Housing conditions of the people is one of the indicators of living standard. After destruction of their houses by river erosion none of the victims could build a pucca house. Out of 100 respondents, only 8% is living in a semi pucca house. The highest portion of respondents (59%) live in a tin shed house. The rest 15% of respondents live in a hut and 18% in shack house.

Table 18.6 Accommodation strategies of the respondents

	Number	Total	Percentage	Total (%)
1. Ownership of homestead				
Paternal land	18	100	18	100
Newly Purchased land	15		15	
Relatives' land	19		19	
Lease land	36		36	
Govt. khas land	12		12	
2. Housing condition				
Pucca	0	100	0	100
Semi pucca	8		8	
Tin shed	59		59	
Hut	15		15	
Shack	18		18	
3. Dwelling environment				
Congested	43	100	43	100
Fair	38		38	
Comfortable	19		19	
4. Drinking water				
Safe water	93	100	93	100
Unsafe water	7		7	
5. Sanitation				
Hygienic Latrine	49	100	49	100
Unhygienic Latrine	42		42	
No latrine	9		9	

Source: Field data

18.5.3.3 Dwelling Environment

After displacement, most of the resettled families (43%) are living in a congested house. Accommodation condition 38% is not fair and only 19% families are living in a modest dwelling environment.

18.5.3.4 Drinking Water

It is evident that 93% of respondent families have access to safe drinking water rest 7% of respondent families do not have access to safe drinking water. They use water of river, canal or pond for their domestic purposes.

18.5.3.5 Sanitation

Overall sanitation arrangement of the study population is not satisfactory. 51% of the respondent families are living with unhygienic sanitary condition out of which 42% use unhygienic latrine and 9% living without any latrine.

18.5.4 Adjustment and Coping Strategies of the Respondent in the New Environment

The displaced families took their adaptation strategies at the individual level. For coping with the changed environment they had to take different strategies. Their strategies were interesting in their features. The displacees generally used multiple strategies, as none of those was adequate for their purpose. Their strategies were moulded based on the situation to cope with the hazardous phenomenon. Socio-economic and environmental situations significantly influenced the displacees to adopt local strategies.

18.5.4.1 Shifting of Lives and Properties During Erosion

The shift of lives and properties from erosion-threatened homestead to a safer place was one of the significant coercive strategies undertaken by the victims. It was found that all the respondent families (100%) shifted their family members, tangible properties and livestock from their affected homestead to the highway slope, BWDB embankment, relatives' shed, neighbours' land, khas land and to other villages (see Appendix Photo 18.1). In local language such types of temporary shelter is called '**Patna**'.

18.5.4.2 Salvaging House Structure

The displacees formulated and undertook some local strategies to reduce the quantity of their economic loss induced by riverbank erosion attack. The loss reduction strategy of salvaging housing structure was widely used by the displacees. This strategy promptly helped them to build a hut on the embankment or on khas land or on the land owned by kin or neighbour after their displacement. Table 18.7 is showing the salvaged condition.

Most of the structural patterns of residence of the respondent's families were salvageable. A total of 61 percent of the respondent family shifted their houses to safer places and 31% of respondent families partially shifted their houses because those families used brick as wall martial and rod cement (RC) as floor material. Only 8% of *kacha* and mixed type houses could not be shifted due to quick erosion.

Table 18.7 Salvaging house structure

Nature of salvage	Number	Percentage
Fully salvaged	61	61
Partially salvaged	31	31
Could not salvaged	8	8
Total	100	100

Source: Field data

18.5.4.3 Cutting Standing Crops and Trees

It was found that 94% of the respondent families cut their standing trees and saved it from the attack of riverbank erosion. Among them, 51% sold those trees for procuring money to meet the needs of resettlement. Another 43% preserved them for use in their resettlement. The rest 6% of the respondents could not cut or sell their trees because it was engulfed by erosion quickly. Out of 100 respondents, 47% had standing crops on their land. Out of which 25% could cut their crops and 16% of corps were immature. Rest 6% of families could not salvage their standing crops due to sudden attack of erosion.

18.5.4.4 Sale of Properties

A considerable proportion of the displaced families sold their properties at the time of displacement for reducing their loss. They adopted this strategy to procure some cash in adapting to the changing environment.

It is evident that 26% of the respondents could sell their stored crops, livestock 18%, furniture 15%, ornaments 12%, remaining land 6%, irrigation equipment 4% and other valuable assets 11% and 8% of the displacees were forced to sell their land engulfed by riverbank erosion. Table 18.8 shows that they sold it to the wealthy landowners who could wait for the re-emergence of that dislocated land.

18.5.4.5 Change of Occupation

Most of the people of the study area were involved in agriculture and agro-based occupations like farming, dairy, animal husbandry, etc. After displacement, 58% of the respondents were forced to change their occupation out of which 19% took small business as their occupation, day labourer 12%, rickshaw puller 11%, engine boat driver 4%, carpenter 3%, tailor 3%, fisherman 2%, butcher 1% and 1% went abroad taking a job for overcoming their miseries.

Table 18.8 Sale of properties

Items	Number	Percentage
Stored crops	26	26
Livestock	18	18
Furniture	15	15
Ornaments	12	12
Eroded land's title	8	8
Remaining land	6	6
Irrigation equipment	4	4
Other valuable assets	11	11
Total	100	100

Source: Field data

Table 18.9 Strategies adopted by the respondents for fulfilling the basic needs

Strategies adopted by the respondents	Number	Percentage
Adapted new occupation	45	45
Selling livestock and properties	13	13
Help received from relatives'	11	11
Taking loans from the NGOs	10	10
Early employment of adolescent	8	8
Money spent from savings	7	7
Loan from the bank	5	5
Went abroad for earning	1	1
Total	100	100

Source: Field data

18.5.5 *Strategies Adopted by the Displaces for Fulfilling Their Basic Needs*

It is evident that the monthly income of the respondent was Tk.16832 before displacement, which reduced to Tk 12,158. Moreover, a large number of people become unemployed due to the loss of their traditional occupations. To overcome the loss of erosion and to maintain their livelihood they were striving hard. No single strategy or initiative was found sufficient to survive. The respondent household adapted various types of strategies simultaneously for fulfilling their basic needs.

In Table 18.9, it was found that 45% of the respondent adopted in new occupation for maintaining their livelihood. 13% of the respondents sold their various assets and livestock for fulfilling their basic needs, 11% of the respondent received help from relatives, 10% took a loan from NGO, 8% of the respondent families engaged their young members in work before completion of their education. 7% spent money from savings, 5% took loan from scheduled banks and 1% went abroad for bringing solvency in their family.

18.5.6 *Consequences and Challenges Faced by the Victims of River Erosion*

Riverbank erosion is a silent but very cruel natural disaster in riparian areas of the country. River erosion washed away land, crops and houses, which ultimately took away the happiness of the dwellers leaving aside various socio-economic problems.

18.5.6.1 Loss of Land and Homestead

The first and most significant effect of river erosion is the loss of homestead and land. Landholding by the respondent households before and after displacement is given in Table 18.10.

Table 18.10 Land holding by the respondents before and after displacement

Land (in acres)	Before		After	
	Number	Percentage	Number	Percentage
Land less	0	0	67	67
Below 1 acre	3	3	27	27
1–2	31	31	6	6
2–3	26	26	0	0
3–4	17	17	0	0
4–5	11	11	0	0
5–above	12	12	0	0
Total	***100***	***100***	***100***	***100***

Table 18.11 Economic conditions of the respondents before and after displacement

Level of solvency	Before displacement		After displacement	
	Number	Percentage	Number	Percentage
Solvent	61	61	21	21
Insolvent	35	35	61	61
Below poverty line	04	04	18	18
Total	100	100	100	100

It is evident from Table 18.10 that there were no landless families among the respondents before displacement, however, 67% of them became landless after displacement. Rest 18% held their remaining land and 15% of respondents purchased small piece of land after displacement for resettlement. Only 3% of respondents were the owners of the marginal land before displacement which increased to 27% after displacement. Landholding up to 2 acres was 31% before displacement which decreased to 6% only. 66% of the respondents were the owners of 3 and above acres of land, however, none of them found in that category after displacement.

18.5.6.2 Decreasing Economic Solvency

Economic solvency of the respondent families decreased after displacement that is given in Table 18.11.

Table 18.11 shows that 40% of the respondent families lost their solvency out of which 26% became insolvent and rest 14% went below poverty line after displacement.

18.5.6.3 Economic Obstacles Faced by the Victims

The degree of economic loss and vulnerability of the people due to riverbank erosion has severely increased in recent years. The impact of land loss involves primarily the loss of homestead, housing structures, crops, cattle, trees and household equipment. Loss of homesteads forces people to move to new places without any option. Almost one million people are directly affected each year by riverbank erosion throughout the whole country. The total monetary loss is estimated to be approximately US$500 million in a year. About 300,000 displaced persons usually took shelter on roads, embankments and government-requisitioned lands. Bank erosion affects people, irrespective of farm sizes. Riverbank erosion causes a setback for agriculture. Along with homestead settlements, it erodes farmland, infrastructure and the communication network. It affects the income of all people. The big farmers are also affected, followed by the medium and marginal farmers. The affected people lose their assets and are forced to depend on savings and often fall into further debt (Rahman 2010). Economic problems faced by the displacees are loss of homes; they are to sell the land, livestock and ornaments to meet the needs. They are to change previous occupation and some become unemployed.

It is found that 100% of the respondent families lost their homestead being affected by erosion and consequently become displaced. Due to the loss of cultivatable land, crops and all sorts of agro products of the displaced families were decreased significantly. They were also forced to sell their properties and livestock. 67% of the respondents became landless. Monthly income of the 64% households reduced significantly after displacement. 40% of the respondents lost their economic solvency after displacement out of which 26% became insolvent and rest 14% went under the poverty level. 26% families being indebted, 58% respondents were forced to change their occupation and 7% become unemployed (Source: Field data).

18.5.6.4 Social Problems Faced by the Victims

Beyond economic problems, displaced families were to face various social problems in maintaining their livelihood. Social problems faced by the victims are given in Fig. 18.3 based on the field data.

18.5.7 Internal–External Help and Assistance Received in Coping Up with the Problems

Victims' families received help and assistance from various sources at the different stages of rehabilitation like shifting house structure, resettlement and coping with the situation and survivability. In this study, saving of the respondent families, sale of properties, earning of the respondent family members and the help of close relatives such as brother, sister, maternal and paternal uncle, father-in-law and brother-in–law are the internal source and the help of public representatives, government agencies, non-government and other financial organisation and people like friends, well-wishers have been categorised as external resources.

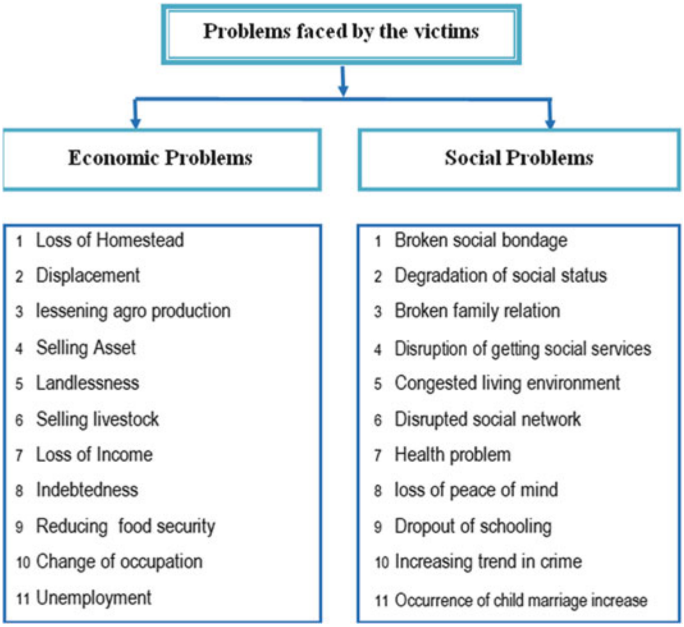

Fig. 18.3 Problems faced by the victims

Table 18.12 Internal–external help received for primary shelter

	Have taken shelter with the help of	Number	Percentage
Internal 68%	Own source	39	39
	Help of relatives	29	29
External 32%	Help other than relatives	23	23
	Help of government agencies	04	4
	Help of Union Parishad	05	5
		100	100

18.5.7.1 Internal–External Help and Assistance Received for Primary Shelter

When the villagers fell into the risk of erosion they tried to shift their assets to a safe place from the vulnerable place. The respondents received assistance from different sources that are given in Table 18.12.

18.5.7.2 Internal–External Help and Assistance Received for Resettlement

Overcoming the first hazard of salvaging lives and asset the victims concentrated their attention to resettlement. Table 18.13 shows that from the field survey it was

Table 18.13 Internal–external help received for resettlement

Source		Number	Percentage
Internal 57%	Previous saving	10	10
	Land sale	17	17
	Asset sale	14	14
	Borrowing money from relatives	16	16
External 43%	Loan from individual	05	05
	Loan from cooperative society	07	07
	Loan from NGO	19	19
	Loan from bank	08	08
	Government relief	04	04
Total		100	100

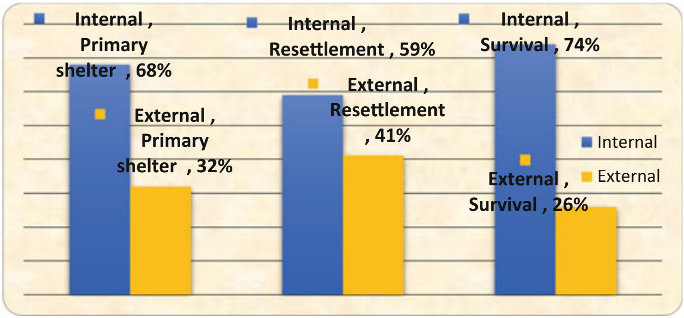

Fig. 18.4 Internal–external help received by the respondents

found that 57% of the respondent household resettled their house depending on their internal resources and rest 43% received help from external sources.

18.5.7.3 Internal–External Help and Assistance Received for Maintaining Their Livelihood

From the field data, it was found that respondent families received help from external sources for solving their problems and fulfilling their basic needs. The contribution of the internal and external sources is given in Fig. 18.4.

It is evident that 43% of respondents received assistance from external sources including 19% from NGOs, 8% from bank, 7% from cooperative society, 4% from government agencies and 5% loan from individual and 57% of the respondents did not get any support from external sources. They tried to survive on their own initiative.

18.6 Findings of the Study

It is estimated that about 100,000 people are being homeless every year due to the country's two largest rivers the Jamuna and the Padma (BBC News 2009). Mr. Bob Makenro, the regional chief of the International Federation of the Red Cross and Red Crescent Societies (IFRCS) in 2000 identified the river erosion as the largest concern of Bangladesh. But very few people are concerned about it. He mentioned that the complexity of the issue is critical enough to be focused in the mass media communication. According to him, this is a slow and silent disaster. Another report (DFID, in association with Disaster Forum) identified the river erosion as the country's topmost disaster from the point of view of losses. The World Disaster Report 2001 published by IFRCS, reveals that in Bangladesh annually 1 million people are having displaced and 9000 hectares of land inundated by river erosion (Equity bd. 2007).

Centre for Environment and Geographic Information Services—CEGIS showed in a study that during the last 34 years submerging of riverside lands were 219,286 acres in Jamuna, 69,135 acres in Ganges and 95,119 acres in Padma (COAST Trust n.d.). Geography and Environmental Science Department of the Jahangirnagar University presented a chart of the losses of river erosion between 1996 and 2000. In 1996 financial loss 5809 m, affected areas 71,680.4 acres and affected population 10,103,635 consequently in 1997 financial loss 33,012 m, affected areas 7756 acres, affected population 173,090. In 1998 financial loss 2201 m, affected areas 41,519 acres, affected population 321,000. In 1999 financial loss 10,535 m, affected areas 227,755 acres, affected population 899,275. In 2000 financial loss was US$3286 million, affected areas 219,310 acres, affected population 415,870. No loss of life happened due to erosion but it made people homeless and helpless.

The present study was conducted to assess the losses and miseries caused due to riverbank erosion, finding out the effects of erosion on livelihood and to explore the survival and coping strategies adopted by the displaced people of the study area.

Monthly average income of the respondent households BDT 12,158 of which BDT 10,500 from principal occupation BDT 1150 from subsidiary occupation and BDT 508 from incidental sources. Principal occupation is the only source of income for most of the people of the study area. However, some people have scope to earn from other sources like seasonal business, private tuition, auto driving, fishing and brokering only a few respondents have some resources such as land, auto rickshaw, trolar and fishing boat.

After displacement, monthly income of the respondent decreased by BDT 3000.00 from main occupation, BDT: 850.00 from subsidiary occupation and BDT: 828.00 form casual sources. Average monthly income of the displaced families has decreased by BDT 4,678.00.

It is evident that respondent families spend BDT 9650 for food and cloth, BDT 1200 for education of their wards, BDT 1175 for treatment and medicine and BDT 2077 for other purposes. However, before displacement, their expenditure for food and cloth and treatment was relatively low such as BDT 6500 and BDT 950. One the other hand expenditure for education, recreation and for other social involvement reduced significantly after being displaced.

Monthly average income of the respondent household is BDT 12,158.00 and monthly expenditure is BDT 14,102.00 that is higher than income by BDT 1741 that means monthly average deficit of the respondent is BDT 1944.00.

It is evident that there were no landless families among the respondents before displacement, however, 67% of them became landless after displacement (see Appendix Photo 18.1). Rest 18% holding their remaining land and 15% of respondents purchased small piece of land after displacement for resettlement. Only 3% of respondent was the owner of marginal land before displacement, which increased to 27% after displacement. Land ownership was up to one acre was 31% before displacement, which decreased to 6% only. 66% of the respondents were owner for 3 and above acres of land, however, none were found in that category after displacement. It is evident that 40% of the respondent families lost their solvency after displacement out of which 26% became insolvent and rest 14% went below poverty line.

The study findings revealed that on an average, 250 acres of land and 200 households of the study area were eroded per year during the period of 2009–2013. It was also found that during that period the rate of damage in 2011 and 2012 was higher than in previous years and it was highest in the year 2013, which was an indication of increased erosion rate.

Displaced families have undertaken different indigenous strategies for overcoming their misery and to survive. 45% of the respondents adapted to a new occupation for maintaining their livelihood. 13% sold their various assets and livestock to fulfil their basic needs. 11% of the respondent received help from relatives, 10% have taken loan from NGO. 8% of the respondent families involved their young members in work before completion of education. 7% spent money from saving, 5% have taken loan from scheduled banks and 1% went abroad for bringing solvency in their family.

According to the opinion of the respondent families and discussion with the social leaders, social workers, public representatives and local administration, it was found that most of the victims are not willing to receive relief, they want full recovery of their loss. They expect necessary support and cooperation from the government to cope with the adverse situation and to get rid threat of further damage.

It was evident that 100% of the respondents expected permanent dam and effective protection of the river bank. 67% of respondents demanded allocation of khas land among the displaces, 58% asked for a bank loan without interest, 53% desired free education of their children, 46% asked for trained rescue team for saving the lives and properties. 42% demanded well-planned and proper resettlement of the displacees, 32% claimed for employment opportunity at home and abroad and 23%, made their appeal to excuse their previous bank loan.

18.7 Policy Recommendations

It is common in Bangladesh that the victims of riverbank erosion do not get the same response like the victims of flood, tornado and cyclone—who get importance in the list of disasters. Because of its slow process and scattered incidences, displacees of riverbank erosion fail to draw attention of the respective authorities. Riverbank erosion does not get so much medium coverage as like victims of other disasters. As a result, almost a silent catastrophe is going on throughout the year to that unfortunate group of people. But there is no specific policy or program for the riverbank erosion displacees neither in government nor in non-government sectors. Riverbank erosion victims are not treated properly as the victims of other disasters. Government has issued general principles for the distribution of relief goods to the victims of all disasters. In May 2007, four important government circulars were issued by the Ministry of Food and Disaster Management directing guidelines for distribution of CI Sheets, General Relief (cash), allotment (cash) for house building and General Relief (Food) among the victims of cyclone/fire/flood/riverbank erosion/tidal bore /earthquake, etc.

Riverbank erosion displacees do not get the first two types of assistance because of absence of the required conditions. For getting CI Sheets, victims should have their own land. But, victims became 'displacees' losing their land due to riverbank erosion. So, they fail to get CI Sheets that is essential for building a temporary shelter. They do not get general relief (cash) also. If a person dies due to other disasters his/her family gets assistance as cash. But, death is rare in case of riverbank erosion. Twenty kilograms of rice is distributed to each family only once as general relief, with which a five-membered family can run only for 10 days. Three thousand Taka is given to each family to repair their damaged houses.

Problem also lies in selecting victim families. There are temporary shelters built by the government at cyclone-prone areas, where people take shelter during cyclone surge. Authorities can easily get reach to them. They also can reach to those who do not come to the shelter, because they live in their own land. It is also the same for the flood-affected people. But there is no temporary shelter for riverbank erosion victims or no early warning system or no early evacuation process to evacuate the inhabitants of erosion-prone areas. As a result, after losing homestead, displacees leave the area on their own initiatives to distant safer places as there is no chance of getting land. Field level experience shows that most of them move to different administrative Jones. So, the officials of their original area cannot assist them and the officials of resettled area have limited scope to help them as they are not the victims of that administrative area. The consequence is that these environmental refugees become more vulnerable and are compelled to live under extreme poverty (Islam and Rashid 2011).

One the basis of the above discussion the following recommendations can be put forward to reduce the vulnerability and improve the condition of the riverbank erosion induced people following the policy model shown in Fig. 18.5.

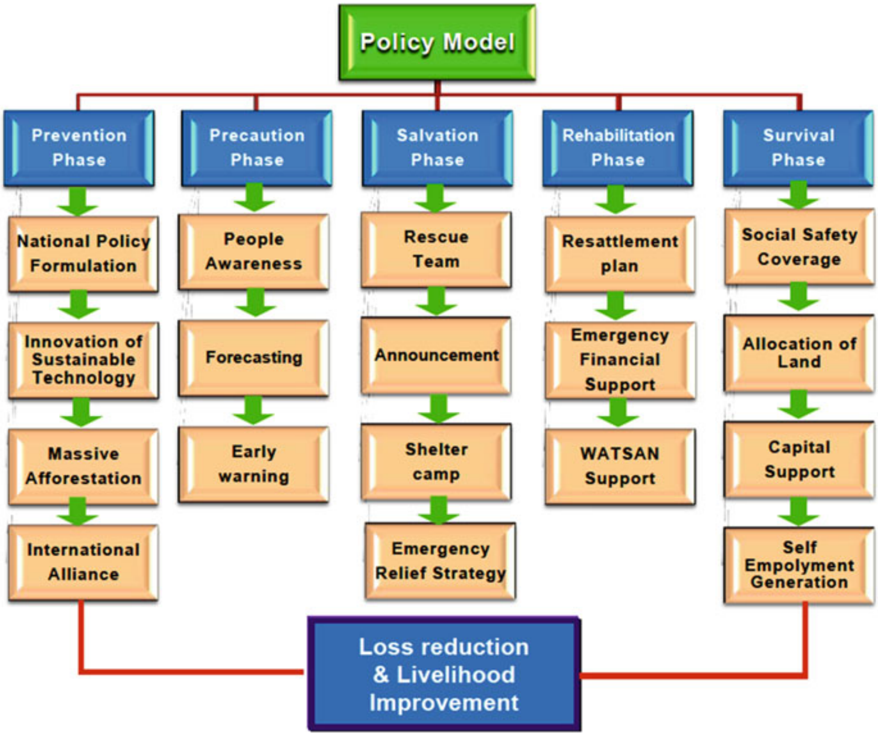

Fig. 18.5 Phases of loss reduction and livelihood improvement

18.7.1 Prevention Phase

18.7.1.1 National Policy Development

It is estimated that about 100,000 people are made homeless every year by river erosion. It is one of the topmost disasters in respect of losses. The National Disaster Mitigation Council (NDMC) should enact a comprehensive river bank erosion management policy for protecting the rights of the displacees and coordinate bank protection works and displacees' livelihood development program. Government should develop a long-term plan for helping the displacees due to riverbank erosion.

18.7.1.2 Innovation for Sustainable Technology

Technical assessment and innovation of sustainable technology for bank protection is needed for ensuring sustainable protection. The government should undertake large-scale engineering works and allocate funds for preventing the riverbank erosion and should ensure regular maintenance

18.7.1.3 Massive Afforestation

Massive afforestation program should be implemented with the involvement of GO, NGOs and the participation of local people and their maintenance can reduce the erosion. Stern action against deforestation should also be taken.

18.7.1.4 Form an International Alliance

Government should take initiatives to form an alliance among SAARC countries in order to ensure water distribution and advance warning about water follow, flood, etc. and share knowledge among them. International agencies also be contacted in respect of riverbank protection and rehabilitation of the displacees due to riverbank erosion.

18.7.2 Precaution Phase

18.7.2.1 People Awareness

More consultation and discussion on climate change and its consequences are required in order to create awareness among the people. Training on disaster preparedness involving local institutions/local government can help the victims to reduce the loss and to take preparation quickly to face the situation.

18.7.2.2 Early Warning System

Forecasting on riverbank erosion using advanced technology and satellite connection and development of an early warning system can help the people to take early preparation and reduce their losses. Regular monitoring of the situation at critical period and the use of local knowledge for providing early warning to the people in dangerous situations can be effective for salvaging people and property.

18.7.3 Salvation and Protection Phase

18.7.3.1 Rescue Team

Government should form a rapid response team with logistic support for salvaging lives and property at the critical moment for the most erosion-prone areas in the country.

18.7.3.2 Evacuation Announcement

Evacuation announcement and assistance be provided in advance in the dangerous situation can be helpful to the victims.

18.7.3.3 Designation of the Area for Resettlement

Some areas or sites are to be designated for resettlement where the victims may be allowed to rebuild their structure quickly. Government should provide them with adequate assistance for their shelter.

18.7.3.4 Emergency Food Ration

The displacees face food crisis immediately after erosion. So, emergency food provision may be given to the victims. They expect that the food rationing be provided by the government to the victims of riverbank erosion.

18.7.4 Rehabilitation Phase

18.7.4.1 Resettlement Plan

Displacees resettle themselves here and there as per their capacity. Comprehensive plan for resettlement should be made for the better settlement. Local administration and local government can take measures for resettlement with income-generating activities and skill development.

18.7.4.2 Support to the Severely Affected Families

The homestead plot, housing materials and financial support are needed for the victims. They expect that the government and non-government organisations should come forward to extend help and assistance to the needy families.

18.7.4.3 Support in Health and WATSAN

The displacees are subject to health hazard and its ultimate result is epidemic. The government should provide them with health care and low-cost house with sanitary latrine and arsenic-free drinking water facilities. This assistance will help them in adapting to their hazardous riverine environment.

18.7.5 Survival and Livelihood Management Phase

18.7.5.1 Social Safety Coverage

Expansion of social security program for the displaces like VGD, VGF, widow allowance, old-age pension, disability pension and stipend for disabled children should be extended to the displacees.

18.7.5.2 Distribution of Khas Land

Distribution of government khas land among the displacees of below poverty level can be helpful in rehabilitating the victims. Agricultural equipment should be distributed among the displacees either free of cost or at a subsidised rate.

18.7.5.3 Education for Children

The displacees lost not only their homestead and cultivable land but also the educational institution. Government should take initiative for ensuring the continuation of study of their children. Satellite schools may be established for the children of the victim families.

18.7.5.4 Employment Generation

The displacees wait for their employment by the government and non-government organisations for their survival. They should arrange skill development training which can enable them to get suitable employment. Effective plan for exporting manpower from among the erosion victims with short-term training and financial support by the government can be helpful program with respect to the rehabilitation.

For addressing the problem of erosion government, NGOs and public representatives should pay head and take interest in the problem. National policy and comprehensive action plan should be taken.

18.8 Conclusion

This study was conducted to focus on the socio-economic conditions of the riverbank erosion victims of Bangladesh and focus on the strategies taken by the erosion displacees for coping with the situation and to survive. The results of the present survey and contents of the past surveys have been presented to show the massiveness of river erosion in the study area. Using past and recent field survey data the researcher has clarified the devastating situation of the mighty *Padma* riverbank erosion and explored some coping strategies for better survival of the respondents. The study had focused on four specific objectives—to assess the losses and miseries caused by the riverbank erosion; to understand the present socio-economic conditions; to explore the survival and coping strategies and finally, to recommend in formulating necessary policies and programs for improving the condition of displaced people in a matter of their rehabilitations. The researchers had tried to incorporate all these matters in the findings.

In the absence of adequate institutional and structural support, the victims undertake their own strategies to confront their precarious condition. It is found that the influences of the ecological and the socio-economic conditions and the strategies taken by the victims are less effective to survive with the changing circumstances. By developing social relationships with their social counterparts the victims of riverbank erosion have adopted some indigenous strategies to cope with their insecure conditions. They share sorrows and pleasures with their counterparts.

It is found that the displaced people have adopted diversified strategies for their initial adaptation to the physiographic, economic and socio-cultural situation in the villages. The researchers have listed as many as 11 diversified strategies. It seems that the most important way of dealing with it is to allocate bank loans for them without interest. They also obtained help from relatives. However, a few of the villagers admitted receiving some kind of help from the government and local NGOs. But they rarely got any help from the local leaders and UP members. This study has both academic and policy-related implications. Under the circumstances the policymakers and development workers at the national level needed to be aware of the nature of socio-economic and environmental conditions of riverbank erosion in Bangladesh.

From the above discussion, it is clear that the erosion has a great impact on the livelihoods of riparian population, agriculture and environment. Different types of vulnerabilities are being generated as a consequence of erosion. Family relations and social bondage break down, and the social status is degraded. The social services and social networks are also disrupted. Therefore, structural measures and at the same time nonstructural measures should be adopted for reducing socio-economic problems of the displaced people due to the Padma riverbank erosion.

A.1 Appendix

Fig. A.1 Shifting of housing structure

Fig. A.2 Padma River erosion at UpaZila Health Complex Naria, Shariatpur. Source: www.thedailystar.net

Fig. A.3 Padma River erosion at Naria 2019, Bangladesh. Source: www.thedailystar.net

Fig. A.4 Padma River erosion at Naria, Bangladesh. Source: www.thedailystar.net

Fig. A.5 Padma River erosion at Naria, Bangladesh. Source: www.thedailystar.net

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Chapter 19
Gender and Age as Factors in Disaster Vulnerability: A Study of River Erosion Victims in Bogra District, Bangladesh

Wardatul Akmam, Shubhana Lina Hasin, and Md. Fakrul Islam

Abstract This study endeavors to measure the vulnerability of individuals to the erosion of Jamuna River in two unions (Kornibari and Kutubpur) within Sariakandi Upazila of Bogra district, Bangladesh and discover the factors that are associated with such vulnerability. The data were collected from 218 respondents using social survey methods, who were selected purposively in order to represent different age groups (e.g., 13–19 years, 20–40 years, 41–60 years, and more than 60 years) and the two genders (male and female). SPSS and Microsoft Excel software have been used for processing and analyzing data. Individual was the unit of analysis. Vulnerability level of each of the respondents has been calculated. Findings show that on the basis of the model and indicators used in this study to calculate vulnerability, 76.1% of the respondent riverbank erosion victims belonged to the "more vulnerable" group assuming a value between 0–1 and 23.9% to the "less vulnerable" group assuming a value between -1 and 0. Chi-square test results reveal a significant association between the level of vulnerability and age, being solvent, family income, having access to financial institutions, getting the help of neighbors, having completed at least 5 years of schooling, having sources of income other than agriculture and having experienced erosion more than once. However, gender was not found to be significantly associated with vulnerability.

Keywords Disaster · Vulnerability · Factors associated with vulnerability · Gender · Age · Riverbank erosion victim · Exposure · Adaptive capacity · Sensitivity

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19.1 Introduction

Bangladesh is a disaster-prone country. Various types of natural disasters like floods, cyclones, salinity in soil and river water, riverbank erosion, earthquakes, and adverse effects of climate change pose serious threats in the path of development of Bangladesh. According to WHO, ". . . disaster is an occurrence disrupting the normal conditions of existence and causing a level of suffering that exceeds the capacity of adjustment of the affected community" (WHO/EHA 2002). People who fall victim to disasters possess different characteristics and are not equally vulnerable to the consequences brought about by these disasters. Wisner et al. (2004) define vulnerability as "characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard" (p. 11). According to WHO, hazard is a "natural or human-made event that threatens to adversely affect human life, property or activity to the extent of causing a disaster" (WHO/EHA 2002). Vulnerability is a function of exposure, adaptive capacity, and sensitivity (Bhuiyan et al. 2017). Research investigations on vulnerability thus far have been carried out with an aim to assess the vulnerability of either group/community/system or individuals. These studies have adopted qualitative (e.g., in Massmann and Wehrhahn 2014; Fordham 1999; Laska and Morrow 2006; Few and Pham 2010) as well as quantitative means (e.g., Das et al. 2017) for assessment of vulnerability.

The present study endeavors to measure the vulnerability of individuals to the erosion of Jamuna River in two unions (Kornibari and Kutubpur) within Sariakandi Upazila of Bogra district, Bangladesh and discover the factors that are associated with such vulnerability. Moreover, the study aims to find out whether gender and age as factors play a significant role in determining vulnerability of the riverbank erosion hit people. It is to be noted that riverbank erosion is one of the "endemic and recurrent natural hazards" in Bangladesh, which occurs when rivers reach their mature stage and become sluggish and braided which cause massive erosion that destroys cultivable land, standing crops, homesteads, and buildings indiscriminately (Banglapedia 2019).

Chen et al. (2013) believe that vulnerability is a social construction and that level of vulnerability varies with differences in groups and places. They also emphasize the underlying socioeconomic and political contexts in addressing the factors that make differences in vulnerability. Population Reference Bureau (2018) contends that women and girls are more negatively affected by hazards than men and boys as women have less financial resources to cope with these hazards. In this connection, it is emphasized that single mothers having the responsibility of making living arrangements not only for themselves but also for their children with no or meager resources. According to Fothergill (2017), girls are more vulnerable than boys to sexual violence and exploitation after a disaster has taken place. Hamidzada and Cruz (2017) have found that in Afghanistan women were more vulnerable to disasters because of their low level of education, lack of income, and traditional role in society.

Population Reference Bureau (2018) also mentioned age and disability as factors that influence vulnerability. According to the findings of Lee and Vink (2015), the group aged 70 years or more were three times more likely to be vulnerable to floods than those aged less than 70 years. Disaster risk and Age Index developed by HelpAge International show that among 190 countries, Bangladesh is ranked 25th on the basis of vulnerability of the old aged people who were vulnerable (Harris and Mihnovits 2015). Fothergill has shown that although children and youth are portrayed as helpless and passive they may play an important role in preparing their community people for the hazards and for recovery (Fothergill 2017).

19.2 Objectives of the Study

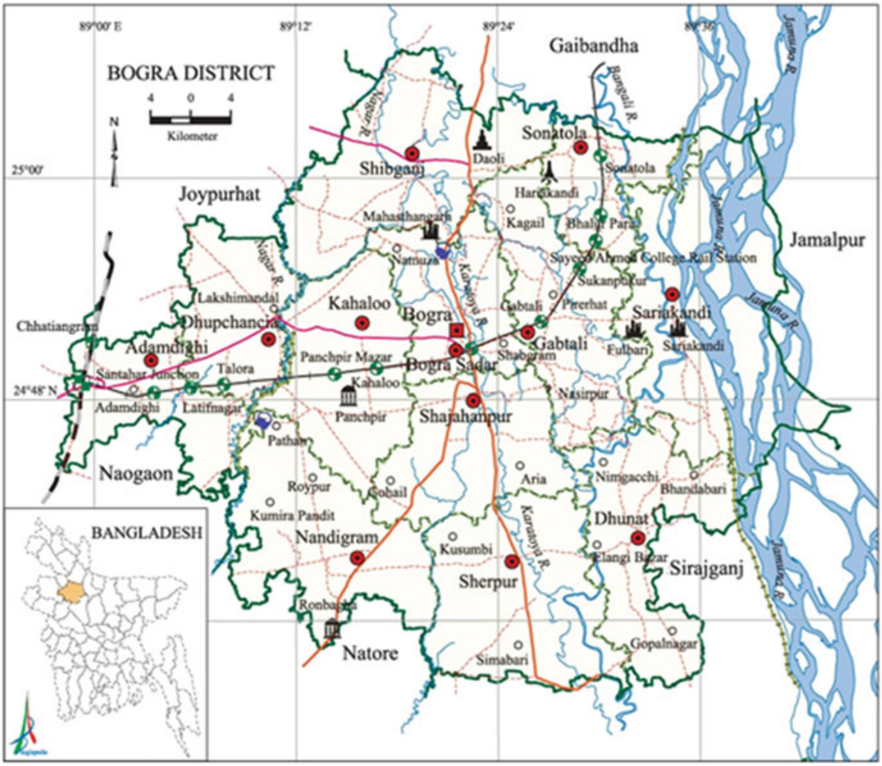
The overall objective of this study was to study gender and age as factors of disaster vulnerability. More specifically the objectives of this research were the following:

1. To calculate the vulnerability level of the respondents under study.
2. To find out the factors that are associated with the vulnerability level of the respondents.
3. To observe whether age and gender are significantly associated with the vulnerability of the respondents.

19.3 Methodology

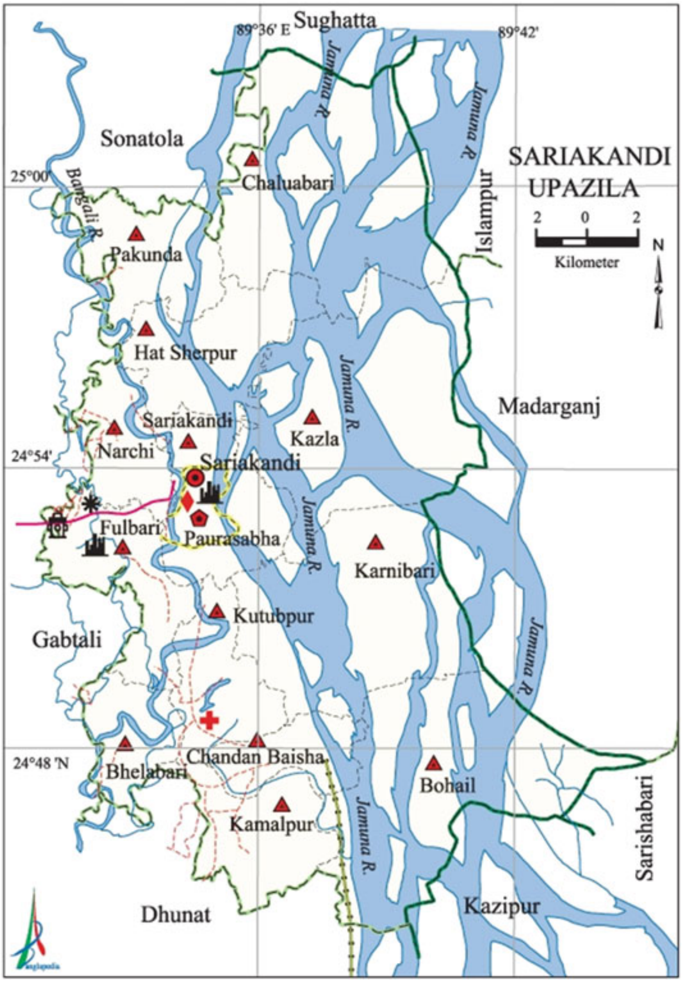
Social survey was the method used for this study. Data were collected from respondents by interview using a structured interview schedule. The locale of this study consists of two *unions* (local administrative units) of Sariakandi *Upazila* (relatively larger local administrative unit than a *union*) located within Bogra district. The names of these two unions are Karnibari and Kutubpur. The people of Karnibari have been affected by the erosion of the Jamuna River many times and have been relocated to different places, including Karnibari and Kutubpur. For the present study, 218 people relocated in Karnibari and Kutubpur after being hit by river erosion in Karnibari have been selected as respondents. They were selected purposively in order to represent different age groups (e.g., 12–19 years, 20–40 years, 41–60 years, and more than 60 years) and the two genders (male and female). SPSS and Microsoft Excel software have been used for processing and analyzing data. Individual was the unit of analysis. Vulnerability level of each of the respondents has been calculated. Chi-square tests have been used to find out the association between vulnerability level and various sociodemographic factors like age, gender, solvency, education, and occupation.

Before conducting the interview, informed consent was obtained from the respondents. They were informed about the objectives of the research and that



their data will be used for research only. They were assured that the data will be protected from any kind of abuse. Names of the respondents were not written down on the interview schedules to maintain anonymity. The respondents participated in the study voluntarily without any hesitation.

There are various perspectives of studying disaster vulnerability, e.g., the livelihood perspective, the political ecology perspective and the spatial perspective (Matyas and Pelling 2012). In this research, the first two perspectives have been considered. Disaster vulnerability can be measured using various means (see for reference Moret 2014; Nelson 2018; Villegas et al. 2017; Schneiderbauer et al. 2019, Ciurean et al. 2013). Along with studying vulnerability using qualitative means the trend of measuring vulnerability quantitatively continues (Cutter et al. 2003; Armas 2008; Myers et al. 2008; Mendes 2009; Wijaya and Hong 2018). Many studies have been carried out to study the impacts of riverbank erosion on the vulnerability of individuals, communities, and regions to such hazard (see, for example, Rahman 2010; Bhuiyan et al. 2017). In order to calculate vulnerability



level of the respondents in this study, the formula given by Bhuiyan et al. (2017), following Intergovernmental Panel on Climate Change (IPCC 2001) has been used:

$$\text{Vulnerability} = (\text{Exposure–Adaptive capacity}) \times \text{Sensitivity}$$

where exposure refers to the extent to which an individual faced river erosion, sensitivity means the degree to which an individual will respond to river erosion and adaptive capacity is defined as the ability of a person afflicted by river erosion to cope with the stresses resulting from that hazard.

Table 19.1 Indicators of the different factors

Factor of vulnerability	Indicators
Exposure	Whether the respondent faced more than one incidence of riverbank erosion or not
	Whether the respondent him/herself or any member(s) of household faced injury due to riverbank erosion
	Whether the respondent (or his/her family) lost any landed property or not
Sensitivity	Whether it takes more than 1 h to reach the nearest health center or not
	Whether the respondent faced insufficiency of food or not
	Whether the respondent and/or his/her family used a sanitary latrine or not
	Whether the respondent used a safe water source for drinking or not
	Whether the respondent's household was female headed or not
	Whether the respondent was cheated on taking advantage of his/her weakness
	Whether the respondent had a feeling of insecurity or not
	Whether the respondent observed any corruption in the distribution of relief goods among the riverbank erosion victims or not
	Whether the respondent (or his/her family members) suffered from long-term illnesses due to erosion or not
Adaptive capacity	Whether respondent's family has sources of income other than agriculture
	Whether respondent has access to financial services of any financial institution or not
	Whether respondent has a family member working outside the village at a relatively developed place or not
	Whether respondents received any kind of support from neighbor in the past 1 month
	Whether any family member is affiliated with any organization or not
	Whether the respondent's family has communicative devices (TV, radio, mobile, etc.) at home or not
	Whether respondent has completed at least 5 years of schooling or not
	Whether any of the respondent's family members had any formal or informal skill for income generation or not
	Whether family is solvent or not
	Whether the respondent has been vaccinated for the major six diseases (e.g., tuberculosis, polio, diphtheria, whooping cough, tetanus, and measles) **or not**

The indicators of exposure, sensitivity, and adaptive capacity (modified from the study by Bhuiyan) are presented in Table 19.1. In order to make the calculation easier, all these indicators were given equal weight. Each respondent's level of exposure was calculated by the number of positive answers to the questions on exposure divided by the number of questions used to measure exposure (3). The value of exposure remained in between 0 and 1, as the responses of respondents assumed the

Table 19.2 Gender and age distribution of the respondents

		Age (in years)				Total
		12–19	20–39	40–59	60 or above	
Gender	Male	33	20	13	39	105
	Female	40	19	19	35	113
Total		73	39	32	74	218

values—either 0 or 1. In a similar manner level of sensitivity and adaptive capacity were also calculated. Finally, the vulnerability level was calculated by subtracting the value of adaptive capacity from the value of exposure and then multiplying the value of sensitivity with the result of subtraction. The value of vulnerability remained between –1 and 1. Respondents who have assumed a value between –1 and 0 were regarded as "less vulnerable" and those who have assumed value in between 0 and 1 were considered "more vulnerable." None of the respondents' vulnerability score was 0.

The interview schedule was designed in such a way so that all the indicators mentioned in Table 19.1 were included in it. Moreover, there were some questions to assess the overall demographic and socioeconomic condition of the respondents (see Tables 19.2 and 19.3).

19.4 Hypotheses

The present study has been carried out with the following two principal hypotheses:

1. Gender is significantly associated with vulnerability of the respondents.
2. Age is significantly associated with vulnerability of the respondents.

19.5 Findings of the Study

Before proceeding to discussion on vulnerability of the respondents it is necessary to focus on their socioeconomic attributes that have been portrayed below using some tables.

Table 19.3 Socioeconomic profile of the respondents

Religion	Frequency	Percentage
Islam	215	98.6
Hindu	3	1.4
Total	**218**	**100.00**
Whether has a physical/mental disability	Frequency	Percentage
Yes	8	3.7
No	210	96.3
Total	**218**	**100**
Marital status	Frequency	Percentage
Married	143	65.6
Single	75	34.4
Total	**218**	**100.00**
Head of household	Frequency	Percentage
Self	67	30.7
Son	19	8.7
Father	80	36.7
Mother	5	2.3
Husband	45	20.6
Elder daughter	2	.9
Total	**218**	**100.0**
Education level	Frequency	Percentage
Below primary	97	44.50
Primary to secondary	117	53.67
Above secondary	4	1.83
Total	218	100
Occupation	Frequency	Percentage
Housewife	69	31.65
Service	9	4.13
Student	72	33.02
Business	5	2.30
Farmer	47	21.56
Teaching	1	.46
Day labor	10	4.58
Unemployed	5	2.30
Total	**218**	**100**
No. of family members	Frequency	Percentage
1–3	89	40.83
4–6	129	59.17
Total	218	100

(continued)

Table 19.3 (continued)

Monthly family income (Taka)	Frequency	Percentage
0–8000	97	44.5
8001–15,000	85	39.0
15,001–30,000	32	14.7
>30,000	4	1.8
Total	218	100.0
Solvency	Frequency	Percentage
Yes	108	49.5
No	110	50.5
Total	218	100.0
Type of toilet used	Frequency	Percentage
Sanitary	151	69.7
Non-sanitary	66	30.3

19.5.1 Demographic and Socioeconomic Features of the Respondents

As age and gender have been specially focused in this study, respondents were selected ensuring representation of males and females in all the age groups. Table 19.2 shows gender and age of the respondents. It portrays that the number of men and women in each age group was more or less similar. Among the respondents 113 (51.8%) were female and 105 (48.2%) were male. Of the different age groups, the dependent age groups (12–19 years and 60 years or above) had much higher representation than the working age group (20–59 years). The reason for this is that a large number of the working people (35.3%) have left the area to other developed areas in search of better employment.

Table 19.3 portrays socioeconomic profile of the respondents. Almost all of them (98.6%) were Muslims and only a few were Hindus (1.4%). Only 8 (3.7%) had physical/mental disability and 96.3% were free of such features. Most of the respondents were married (65.6%) and 34.4% were single. Most of the respondents ($n = 80$, 36.7%) had their fathers as head of household, 30.7% were themselves the head of household and 20.6% had their son as head of household. More than 44% of the respondents were educated up to “Below primary level,” 53.67% belonged to “Primary to secondary” level, and only 1.84% of the respondents were educated up to “Above secondary” level. Among the respondents 33.02% were students, 31.65% were housewives, and only 21.56% were farmers. About 41% of the respondent riverbank erosion victims had 1–3 members in their family and 59.17% had 4–6 members. Of the respondents’ families 44.5% earned less than 8000 Taka, 39% earned 8000–15,000 Taka, and 14.7% earned between 15,000 and 30,000 Taka per month. Almost half of the respondents (49.5%) said their families were “solvent.” About 70% of the respondents informed that they used a sanitary toilet. Almost 90% of the respondents’ (89.1%) homes were illuminated with electricity at night and

8.7% used kerosene for this purpose. Although 73.4% of the respondents' families were landless 41% of them depended solely on agriculture, meaning that they were agricultural laborers. To get information 3.2% of the respondents used radio, 58.3% used TV, 32.3% used cell phone and 0.9% used newspapers. Thus, TV appeared as the most popular means of getting information.

19.5.2 Issues Relating to Vulnerability of Respondents to Riverbank Erosion

Table 19.4 depicts vulnerability-related situation of the respondents. Among them, only about one-fifth experienced erosion of the Jamuna River only once. About 5% of the respondents experienced this hazard for more than ten times. Ninety-four (43.1%) of the respondents fell a victim to riverbank erosion 2–5 times and more than 30% of them were exposed to the hazard 6–10 times. Thus, most of the respondents were very much exposed to riverbank erosion.

Only about 64% of the respondents had their current homes built on land which their family owned and 36% of the respondents lived in rented houses or on houses built on government-owned land or on land owned by others. Among them 73.4% were landless (did not own any cultivable land). Only four (1.8%) respondents did not lose any land owing to riverbank erosion. All the others lost at least some land. Most of them (39%) lost 1–33 decimals of land, 23.5% experienced loss of 34–100 decimals of land, 16% lost 101–200 decimals, and more than 21% lost more than 200 decimals of land owing to riverbank erosion. A significant proportion of the respondents (37.6%) suffered from insufficiency of food, but only 4.1% had family members with long-term diseases and 2.3% had family members suffering from infectious diseases like tuberculosis (Table 19.4).

Some factors, e.g., access to financial institutions, involvement may help to strengthen adaptive capacity to reduce vulnerability of the respondents to riverbank erosion. More than four-fifths of the respondents (83.9%) were immunized for six common diseases in Bangladesh, e.g., tuberculosis, polio, diphtheria, whooping cough, tetanus, and measles, 36.2% had access to financial institutions as banks and cooperative associations and 18.3% were related to government or nongovernment organizations like GAK, BRAC, and ASA. Cooperation between neighbors often strengthens adaptive capacity and helps to reduce vulnerability. Among the respondents, 20.6% received cooperation from and 18.3% extended cooperation with their neighbors. A health center nearby helps in saving lives during a disaster. In the study area, 81.2% of the respondents could reach the nearest health center within 30 min; for 13.3% it took 30–60 min and only 6% of the respondents more than 1 h was required to reach the nearest health center from their houses. The respondents were asked if they were deceived by anyone, who took advantage of their unstable condition. About 7% (6.9%) answered in the affirmative to this question. More than 9% of the respondents felt insecure, mainly because they had their houses

Table 19.4 Vulnerability related situation

Number of experiences of riverbank erosion	Frequency	Percentage
1	47	21.6
2–5	94	43.1
6–10	67	30.7
>10	10	4.6
Total	218	100
Ownership of land of residence	Frequency	Percentage
Yes	139	63.8
No	79	36.2
Total	218	100.0
Ownership of cultivable land	Frequency	Percentage
Landless	160	73.4
Owns some land	58	26.6
Total	218	100
Whether agriculture is the only source of income	Frequency	Percentage
Yes	91	41.7
No	127	58.3
Total	91	41.7
Amount of land lost owing to riverbank erosion (decimals)	Frequency	Percentage
0-33	85	39.0
34-100	51	23.4
101-200	36	16.5
>200	46	21.1
Total	218	100.0
Whether faced insufficiency of food	Frequency	Percentage
Yes	82	37.6
No	136	62.4
Total	218	100.0
Access to financial institution	Frequency	Percentage
Yes	79	36.2
No	139	63.8
Total	218	100.0
Whether a family member works in a developed city	Frequency	Percentage
Yes	77	35.3
No	141	64.7
Total	218	100.0
Whether related with GO/NGO	Frequency	Percentage
Yes	40	18.3
No	178	81.7
Total	218	100.0

(continued)

Table 19.4 (continued)

Whether receives help from neighbors	Frequency	Percentage
Yes	45	20.6
No	173	79.4
Total	218	100.0
Whether respondents were immunized or not	Frequency	Percentage
Yes	35	16.1
No	183	83.9
Total	218	100.0
Distance to health center	Frequency	Percentage
0–30 min	177	81.2
31–60 min	29	13.3
>60	12	5.5
Total	218	100.0

built on land that was owned by others, possibility of robbery, and other types of social insecurity. Women/girls did not mention of insecurity related to their gender. After being hit by erosion, 22% of the respondents received relief items from the government (rice, dry food, cow, goat, sewing machine, clothes, and corrugated iron sheets), and 11.5% from nongovernment organizations (blanket, rice, food, etc.). The most alarming finding is that according to 60.6% of the respondents' corruption took place in the distribution of relief items. The victims had to pay money to the distributors to get relief goods, which they should have received for free.

19.5.3 Vulnerability of the Respondents to Riverbank Erosion

Following the formula stated above vulnerability of the respondents of this study was calculated using SPSS and Microsoft Excel. Most (76.15%) of the respondents belonged to the "more vulnerable" (with a score between 0 to 1) category, while 23.85% belonged to the "less vulnerable" (with a score between −1 to 0) category.

19.5.4 Factors That Affect Vulnerability Level

The present study focuses on the factors that affected the vulnerability of the respondents. Chi-square tests have been conducted to find out the factors that were significantly associated with respondents' vulnerability. Results of these tests are presented in Tables 19.5–19.18.

One of the specific objectives of this study was to see whether gender was significantly associated with vulnerability of the respondents or not. Table 19.5

Table 19.5 Association between gender and vulnerability

Gender	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
Male	21	40.38	84	50.60
Female	31	59.62	82	49.40
Total	52	100.00	166	100.00

$\chi^2 = 1.656$, d.f. $= 1$, $p = .198$

Table 19.6 Association between age and vulnerability

Age group	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
12–14 years	18	34.61	15	9.04
15–39 years	25	48.08	54	32.53
40–64 years	6	11.54	63	37.95
65 years or more	3	5.77	34	20.48
Total	52	100.00	166	100.00

$\chi^2 = 33.534$, d.f. $= 1$, $p = .000$

shows the relationship between gender and vulnerability. Chi-square test value indicates that there is no significant relationship between these two variables. Women's vulnerability in this study was found to be relatively lower than that of men, which can be attributed to the fact that the proportion of women with at least 5 years of schooling was significantly higher than that of men ($\chi^2 = 4.434$, d.f. $= 1$, $p = .035$). Table 19.10 shows that completion of at least 5 years of schooling was very significantly associated with vulnerability. Thus with education as the intervening variable, the association between gender and vulnerability was not found significant. This finding can be related to the finding of Hamidzada and Cruz (2017) that a low level of education was one of the reasons for the higher level of women's vulnerability. Thus, it may be surmised that the education level of women has significantly reduced their vulnerability in the study area. The findings portrayed in Table 19.5, prove that hypothesis no. 1, which states, "gender is significantly associated with vulnerability" is false.

Table 19.6 shows association between the respondents' age and the vulnerability, which was mentioned as a specific objective of this research. Chi-square value confirms a significant association between these two variables. It proves that hypothesis no. 2 which states, "there exists significant association between age and vulnerability of the respondents" is true. The table portrays that those aged between 12 and 14 years were the least vulnerable. Higher percentages of respondents were found in the "more vulnerable" category as age increased. Fothergill (2017) has suggested that children and youth can play a significant role in preparing for imminent hazards and in recovering from them. This statement seems to be true for the river erosion victims of Sariakandi. The young instead of being vulnerable, appear to be relatively strong.

Married people are socially and psychologically in a better position than single persons—this is the usual belief. However, the opposite seems to be true for the riverbank erosion hit people in Sariakandi. Table 19.7 shows that almost 76% of the more vulnerable respondents were married, while 67.31% of the "less vulnerable" respondents were single. Marital status and vulnerability were thus strongly associated according to the Chi-square test results.

Intensity of exposure increases vulnerability. Table 19.8 portrays that 95.18% of the "more vulnerable" respondents had experienced riverbank erosion more than once and 75% of those who experienced it only once belonged to the "less vulnerable" category, showing a very strong association between the number of experiences of riverbank erosion and the vulnerability ($\chi^2 = 113.431$, d.f. = 1, $p = .000$).

Higher number of family members put pressure on the limited resources of the family. However, Table 19.9 shows that higher number of family members makes an individual "less vulnerable." We find that 75% of the "less vulnerable" respondents had 4–6 members in their family, while 45.78% of the "more vulnerable" respondents had 1–3 members in their family, which shows that in combating hazards relatively higher number of family members may be more useful.

Education is a factor that is positively associated with resisting vulnerability. Five years of schooling makes a person much conscious and they do not easily fall prey to the deceit of other people. Table 19.10 shows that 76.92% of those who were "less vulnerable" had completed at least 5 years of schooling and 66.27% of those who were in the "more vulnerable" category did not complete 5 years of schooling.

Table 19.7 Association between vulnerability and marital status

	Level of vulnerability			
	−1–0		0–1	
Marital status	No. of respondents	Percent	No. of respondents	Percent
Married	17	32.69	126	75.90
Single	35	67.31	40	24.10
Total	52	100.00	166	100.00

$\chi^2 = 32.762$, d.f. = 1, $p = .000$

Table 19.8 Association between vulnerability and whether experienced erosion more than once

	Level of vulnerability			
	−1–0		0–1	
Whether experienced erosion for more than once	No. of respondents	Percent	No. of respondents	Percent
No	39	75.00	8	4.82
Yes	13	25.00	158	95.18
Total	52	100.00	166	100.00

$\chi^2 = 113.431$, d.f. = 1, $p = .000$

Table 19.9 Association between vulnerability and number of family members

Number of family members	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
1–3	13	25.00	76	45.78
4–6	39	75.00	90	54.22
Total	52	100.00	166	100.00

$\chi^2 = 7.080$, d.f. $= 1$, $p = .008$

Table 19.10 Association between vulnerability and whether completed at least 5 years of schooling

Whether completed at least 5 years of schooling	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
No	12	23.08	110	66.27
Yes	40	76.92	56	33.73
Total	52	100.00	166	100.00

$\chi^2 = 9.969$, d.f. $= 1$, $p = .000$

Table 19.11 Association between family income per month and vulnerability

Family income per month (Taka)	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
0–8000	10	19.23	87	52.41
8,000–15,000	30	57.69	55	33.13
15,001–30,000	11	21.16	21	12.65
>30,000	1	1.92	3	1.81
Total	52	100.00	166	100.00

$\chi^2 = 17.875$, d.f. $= 3$, $p = .000$

Table 19.11 portrays the association between family income and vulnerability of the respondents. It is observed that more than 52% of the respondents who were "less vulnerable" had a monthly family income of 0–8000 Taka only per month, while almost 81% of those who were less vulnerable earned more than 8000 Taka per month.

Respondents were asked whether they were solvent (able to pay for their daily necessities with their own income) or not. Table 19.12 shows that out of 90 respondents who were "not solvent" 73 (81.11%) belonged to the "more vulnerable" category, on the other hand, 35 (67.31%) of the respondents who were less vulnerable belonged to the "solvent" category. Thus, solvency is significantly associated with respondents' vulnerability.

Table 19.12 Association between solvency and vulnerability

Whether solvent or not	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
No	17	32.69	73	43.98
Yes	35	67.31	93	56.02
Total	52	100.00	166	100.00

$\chi^2 = 8.623$, d.f. $= 1$, $p = .003$

Table 19.13 Association between having special skills for earning and vulnerability

Whether possesses special skills for earning or not	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
Yes	15	28.85	9	5.42
No	37	71.15	157	94.58
Total	52	100.00	166	100.00

$\chi^2 = 22.177$, d.f. $= 1$, $p = .000$

Table 19.14 Association between having sources of income other than agriculture and vulnerability

Whether has sources of income other than agriculture	Level of vulnerability			
	–1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
Yes	42	80.77	85	51.20
No	10	19.23	81	48.80
Total	52	100.00	166	100.00

$\chi^2 = 14.432$, d.f. $= 1$, $p = .000$

Having a special income-generating skill often helps reduce vulnerability. Of the 24 respondents who had some special skills, 15 (62.5%) belonged to the "less vulnerable" category while 94.58% of those who were in the "more vulnerable" category did not possess such skills (Table 19.13).

Among the respondents 73% were landless. However, more than 41% of them solely depended on agriculture for their living. For those who did not own sufficient cultivable land, being engaged in an occupation other than agriculture was very important to reduce vulnerability. Table 19.14 points out that 80.77% of those who were less vulnerable had income sources other than agriculture.

Having good relationship with a neighbor is certainly a social capital that significantly helps to reduce vulnerability. Among the 218 respondents 173 (80.92%) did not receive help from their neighbors. Of them, 140 belonged to the "more vulnerable" group (Table 19.15).

Having relationship with government and nongovernment organization may help to cope with the vulnerable situation. Table 19.16 shows that 52% of the respondents

Table 19.15 Association between receiving help from neighbor and vulnerability

Whether received help from neighbor or not	Level of vulnerability			
	−1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
Yes	19	36.54	26	15.66
No	33	63.46	140	84.34
Total	52	100.00	166	100.00

$\chi^2 = 10.534$, d.f. $= 1$, $p = .001$

Table 19.16 Association between being involved with GO/NGOs and vulnerability

Whether involved with GO/NGOs or not	Level of vulnerability			
	−1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
Yes	21	40.38	19	11.45
No	31	59.62	147	88.55
Total	52	100.00	166	100.00

$\chi^2 = 10.534$, d.f. $= 1$, $p = .001$

Table 19.17 Association between suffering from insufficiency of food and vulnerability

Whether suffers from insufficiency of food or not	Level of vulnerability			
	−1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
Yes	27	51.92	55	33.13
No	25	48.08	111	66.87
Total	52	100.00	166	100.00

$\chi^2 = 5.958$, d.f. $= 1$, $p = .015$

who were related to such organizations belonged to the less vulnerable group. Moreover, 147 out of 178 respondents (82.58%) who did not have relationship with such organization belonged to "more vulnerable" category.

Eighty-two respondents faced insufficiency of food. Among them 55 (67.07%) belonged to the "more vulnerable" category (Table 19.17).

Having access to financial institutions are likely to enable people to borrow loans institutionally, instead of borrowing from local money lenders who lend money at very high interest. Of the 139 respondents who did not have access to financial organizations 114 (82.01%) were "more vulnerable." Again, 52 (65.82%) of the 79 respondents who did have access to such institutions belonged to the "more vulnerable" group (Table 19.18).

Table 19.18 Association between having access to financial institutions and vulnerability

Whether has access to financial institutions	Level of vulnerability			
	−1–0		0–1	
	No. of respondents	Percent	No. of respondents	Percent
No	25	51.92	114	68.67
Yes	27	48.08	52	31.33
Total	52	100.00	166	100.00

$\chi^2 = 7.271$, d.f. $= 1$, $p = .007$

19.6 Discussion and Conclusion

The objectives of this study were to calculate vulnerability level of the respondents, to identify the factors that were associated with it and to observe whether age and gender were significantly associated with the vulnerability level of the respondents or not. The findings of the study show that on the basis of the model and indicators used in this study to calculate vulnerability, 76.1% of the respondent riverbank erosion victims belonged to the "more vulnerable" group and 23.9% to the "less vulnerable" group. When the association between two specific variables were measured through Chi-square test significant association between the level of vulnerability and age, being solvent, family income, having access to financial institutions, getting help of neighbors, having completed at least 5 years of schooling, having sources of income other than agriculture, having experienced erosion more than once was found to be significantly associated. The hypotheses of the study stated that age and gender were significantly associated with vulnerability level of the respondents. Findings reveal that age was significantly related to vulnerability, but gender was not. The factor that might have intervened here was education of women. As vulnerability was significantly associated with education level and women in Sariakandi were better educated than men, not much difference was observed between the vulnerability of men and women. The finding that gender was not significantly associated with vulnerability contrasts with the findings of Population Reference Bureau (2018) and Fothergill (2017), which revealed a significant association between gender and vulnerability.

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