Vikram Dayal · Anantha Duraiappah
Nandan Nawn *Editors*

Ecology, Economy and Society

Essays in Honour of Kanchan Chopra

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Vikram Dayal
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Editors and Contributors

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Introduction

Vikram Dayal, Anantha Duraiappah and Nandan Nawn

Kanchan Chopra, the honouree of this volume, is one of the early contributors in shaping the environment and development discourse in India besides being a forerunner of research in ecology–economy–society interface.[1] She has been influential in mentoring numerous young researchers, building and nurturing institutions besides opening new research frontiers through her works. Generations of researchers in India have been taught and trained by her in environmental and ecological economics.

This book deals with some of the complex linkages, interactions, exchanges, influences and impacts between the ecosystem, economic activities and human society. The contributions capture the dialectical relationship between (economic and social) development as perceived by the human society and the environment within which such development takes place in line with the dominant threads of the works of the honouree (see, Bibliography below).

This book covers the following themes: sustainability of development, institutions and environmental governance, environment and well-being. Contributions within each theme engage with policy issues and practice, as well as with both

[1]While being aware of the difference between ecology, ecosystem and environment, we use these terms interchangeably.

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macro- and micro-aspects. The book also includes two reflective essays on the honouree's institutional contributions.

The contributors are mainly economists and ecologists. The approach is interdisciplinary, both in spirit and content, in line with the honouree's works that went not just beyond the mainstream ideology of economics but also with the way she listened to ideas from disciplines like ecology and sociology. Some of the papers are in the nature of conceptual and reflective essays, and some report on research.

All the contributors were (and some are still) connected to either or more of the five institutions with which the honouree was most closely associated with: Institute of Economic Growth (IEG), Delhi, an internationally known think-tank, with which she was associated for almost three decades and been its Director; Indian Society for Ecological Economics (INSEE), a 500+ member body of professionals with an aim to further the cause of sustainable development, which she had co-founded in 1998 and been its two-time President besides being the Founder–President; International Society for Ecological Economics (ISEE), dedicated to advancing understanding of the relationships among ecological, social and economic systems for the mutual well-being of nature and people, where she had been a Board member; Millennium Ecosystem Assessment (MA), a body supported by UN, World Bank and others to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being, where she had been a co-chair of the Responses Working Group; and South Asian Network for Development and Environmental Economics (SANDEE), a network to bring together researchers and decision-makers from South Asia to address development–environment challenges that she had inspired and supported from its early days.

Contributors and editors of this volume have been associated with the honouree through these institutions: Shamik Chowdhury, Saudamini Das, Purnamita Dasgupta, Vikram Dayal, Amrita Goldar, Biswanath Goldar, Indrani Gupta, Gopal K. Kadekodi, Preeti Kapuria, M. N. Murty (all IEG); Nandan Nawn (INSEE); Joan Martinez-Alier, Richard B. Norgaard, Charles Perrings (all ISEE); Anantha Duraiappah, Harold A. Mooney, Walter V. Reid (all MA); Ram Chandra Bhattarai, Partha Dasgupta, Pranab Mukhopadhyay, Mani Nepal, Priya Shyamsundar, E. Somanathan (all SANDEE). While the extent of association varied across authors, nevertheless they remained sustained over the years.

1 Academic and Professional Life of Kanchan Chopra

This journey of many milestones began in a hospital in pre-independent India in Rawalpindi (now in Pakistan) on 14 May 1944. She started her formal education in Belgaum in 1950. The highlight of her school years was not the number of schools in places at Belgaum, Shimla, Srinagar, Ambala, Jabalpur, due to her father's transfers, but the amazing fact that she completed class ten when she was but 13 years of age. Her academic brilliance found her moving to a higher level at each shift to another city.[2]

Graduation from a college in Ferozepur followed with a postgraduation from Punjab University, Chandigarh saw her reaching Delhi University at the age of 19. Too young for the Ph.D. Fellowship, she kept herself independent and occupied with a couple of courses in Delhi University, till she attained the required minimum age of 21. A mentor and guide in the form of the Amartya Sen at Delhi School of Economics was inspiration enough to complete her thesis by 1968. Kanchan Chopra, then Kanchan Ratna, began her teaching career at Miranda House, University of Delhi in 1967.

She submitted her Ph.D. thesis titled 'Dualism and Investment patterns—an analysis of regional contrasts' in May 1968 and received the degree in 1969. She had taught graduate and postgraduate students for 13 years in Miranda House, before joining Institute of Economic Growth as Associate Professor in 1980—a kind of awakening to greener pastures. She remained associated with IEG for nearly three subsequent decades till May 2009 and been its Director. She has also been a member of faculty at the University of Dar-es-salaam and was a Visiting Professor at TERI University (now TERI School of Advanced Studies), New Delhi.

Her associations traversed a rather large canvas in academic, institutional and policy spaces.

In 2006, the Supreme Court of India had set up an Expert Committee chaired by her on the calculation of Net Present Value (NPV) lost by diverting forestland for non-forest use towards calculation of the associated compensation. Later, she will become member of numerous committees set up by the government including 'Green National Accounts in India: A Framework' [Chair: Partha Dasgupta, 2013; Ministry of Statistics and Programme Implementation], 'High Level Working Group on Western Ghats' [Chair: K. Kasturirangan, 2013; Ministry of Environment and Forests] and core committee for 'Monitoring of potential hazards of industrial development in Singrauli area' [Chair: Tapan Chakrabarti, 2014; National Green Tribunal]. Previously, Committee on Climate Change [Chair: R. Chidambaram, 2007; Ministry of Environment and Forests] besides of the Working Group on 'Gender Issues, Panchayati Raj Institutions, Public Private Partnership, Innovative Finance and Micro Finance in Agriculture' [Chair: Indira Hirway, 2007; Planning Commission of India], and chairing the sub-committee on 'Public Private Partnership, Panchayati Raj Institutions and Non Governmental Organisations' for the Eleventh Five-Year Plan. She was also the Chairperson of the Task Force for 'Social and Economic Aspects of Conservation and Restoration for the Environment and Forests Sector' [2006; Planning Commission of India] for the Eleventh Five-Year Plan as well. She was a Member of the Advisory Committee of 'Strategic Analysis [social benefits and costs] of India's River Linking Project' [Chair: M. S Swaminathan, 2009; International Water Management Institute (IWMI)].

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[2]The Editors are grateful to her family members for sharing this information.

She has been in editorial and policy/advisory boards of several national and international journals including *Environment and Development Economics* and *Ecological Economics* (ISEE), *Journal of Resources, Energy and Development* (TERI), Artha Vijnana (Gokhale Institute of Politics and Economics) and *MARGIN* (National Council of Applied Economic Research). She is one of the Founder–Editors of *Ecology, Economy and Society*–the INSEE journal and was its coordinating Editor (2017–18).

She has been a Member, Assessment Panel and Co-chair of Working Group on 'Responses Assessment' (2005; with Rik Leemans) in MA and a Member of Advisory and Management Committee of SANDEE. Presently, she is a Fellow of SANDEE and Beijer Institute. She was a Member of Review Board of *Inclusive Wealth Report 2014: Measuring progress toward sustainability*, of Science Advisory Committee (2007–2013) of International Institute for Applied Systems Analysis (IIASA) of Laxenburg, Austria, of Science Committee on bioSUSTAINABILITY, Ecoservices of Future Earth and of Scientific Steering Committee of International Human Dimensions Programme on Global Environmental Change.

The honouree was the Chairperson of the training committee for practicing economists and non-economists in the World Bank 'Capacity Building Programme in Environmental Economics' in India that has produced many of the practicing environmental and ecological economists of today, besides being a member of its Expert Committee with an overseeing role. She was a senior Associate Researcher, Programme in Ecological and Environmental Economics, International Centre for Theoretical Physics, Trieste (Italy). She has been a member of Advisory Board(s) of several institutions including but not limited to Ashoka Trust for Research in Ecology and the Environment (ATREE), Centre for Interdisciplinary Studies in Environment and Development (later merged into ATREE), Governing Board(s) of Revitalising Rainfed Agriculture (RRA Network), TERI University, Institute of Economic Growth, Winrock International India and G. B. Pant Institute of Himalayan Environment and Development. She was a Chair of Research Committee of ISEE.

Her field works at the 'grassroots' enabled her to connect with several civil society organisations including Society for Hill Resources (Bihar), Obeshwar Vikas Mandal and Seva Mandir (Udaipur) besides being associated with National Institute of Ecology (Jaipur).

She was elected Fellow of the Academy of Sciences for the Developing World (TWAS) in 2011. In 2016, she has been awarded the coveted Kenneth Boulding Award (with Arild Vatn) by the International Society for Ecological Economics; she is the first Asian to receive it.

2 Works of Kanchan Chopra

Her work has been on different aspects of water management, agricultural economics and project evaluation till the early 1980s before entering into the field of environmental and resource economics. Specifically, her work focused on forest and water participatory planning process, evaluation of environmental resources and the linkages between environment and development.

After her first publication almost half a century ago (*Indian Economic Review*; 1968) on multiplier analysis and regional income distribution, for the next decade and a half, her works have largely addressed various dimensions of the 'agrarian question' with a particular emphasis on the asset inequalities, both as a cause and an effect. A paper on evaluation of social forestry projects (*Resources Policy*; 1987) marks her entry into the field of ecology–economy–society interface. Just two years later, institutions will find a more prominent place through an oft-quoted paper (Chopra, Kadekodi and Murty 1987). During the next half a decade, her works will traverse a rather large canvas—from causes of natural resource degradation and sustainability of resource use in agriculture and agricultural growth to cost–benefit analysis of large dams to resource management and participatory development. The then hitherto unrecognised connection between environment and agriculture (at least among the economists) will start appearing in her works since a paper in 1992 (*Indian Economic Review*). In the next year, she was to publish both a 'core' environmental economics paper on valuation of non-timber forest products (*Economic Botany*) and also a 'core' ecological economics paper (in a volume from Centre for Science and Environment, New Delhi in its infancy then). Over time, institutional frameworks governing use and users of various natural resources in particular the common pool ones will feature more frequently in her works. With a celebrated work (Chopra and Kadekodi 1999), she will enter the 'real' world of practicing sustainability in Palamau, aided by ecological-economic modelling; this approach will be extended later to a national park, a wetland and Sundarbans.

2.1 Some Key Features of Chopra's Works

Kanchan Chopra's core research work was characterised by studying people in specific places—for example, shrimp cultivators in the Sundarbans and tourists in Bharatpur. Typically, a survey was conducted relevant to the question being asked. This would be followed by econometric analysis. There would be a life cycle—submitting a research proposal, producing a research report and then producing a few papers, finally, at times, writing a book. Being at the IEG helped her to keep this work style going. She always worked hard, but avoided the temptation to take too much on board. Thus, she was able to devote a couple of years to work on a research question and followed up each project with the process of refinement that the academic publishing process brought.

Chopra also was happy to use both standard economics and also to incorporate other influences. Her study of Bharatpur saw her combine a standard valuation exercise with dynamic systems modelling based on time series data. It was a clever and ingenious combination that got to a key point—the value to tourists captured by the travel cost could simply have been calculated, but here she went further, showing the effect of the ecological forces in the park. She also incorporated a report showing that in this context, limited grazing actually helped the bird life of the park. And the role of water and the demands of irrigation for farming were clearly brought out.

Chopra was in some sense fortunate to be in the right place at the right time. At IEG, she along with Gopal K. Kadekodi and M. N. Murty worked in earnest on environment and development long before the subject got fashionable in India. In fact, it was an early example of the study of ecosystem services in Sukhomajri, long before Indian scholars would start thinking about payments for ecosystem services. Partha Dasgupta and Karl-Göran Mäler, two pioneering environmental economists would over a long extended period have scholarly exchanges with her. The Millenium Ecosystem Assessment process would see her work closely with a large international team of ecologists, economists and other scholars. She would participate in the exercise of developing the conceptual framework. Somewhat like Elinor Ostrom, she too relished the move between theorising and empirical work. Over time, she would collaborate with a wide circle of scholars, some of whom are contributors in this book.

A core theme in her work, apart from her work in agriculture, was the commons. But different facets of this theme would be studied—migration by those depending on the commons, the degradation of the commons affecting water supply, the role of international trade in conversion of the commons, the use of the capabilities approach in assessing the effects of the conversion of the commons. A brief review of her works in some key and selected areas follows.

Chopra's core research after the initial years in agricultural economics was in the area of the commons. She joined other scholars working on this area in the late 1980s. The work on the commons was multi-disciplinary and rooted in empirical enquiry. Jodha had in the context of India set out the importance of the commons for rural people. Partha Dasgupta had been developing the theory of the commons both technically and in terms of interpretation. In the USA, Elinor Ostrom was working on synthesising multiple contributions with the aid of the Institutional Analysis and Development (IAD) framework. Although Chopra did not use the IAD framework in her work, it provides a convenient way of putting together her many diverse contributions to the empirically grounded study of the commons. Figure 1 shows the IAD framework, which is familiar to scholars working on commons.

In her work on the commons, the exogenous variables, biophysical attributes and community features played a key role. Also, her work led her to investigate attempts to re-invigorate the commons, i.e. studying processes of institutional change leading to improved outcomes. She also brought a variety of lenses to the evaluation of outcomes—including both short-run and long-run considerations, incorporating both standard indicators of economic performance and also using the capabilities lens of Sen.

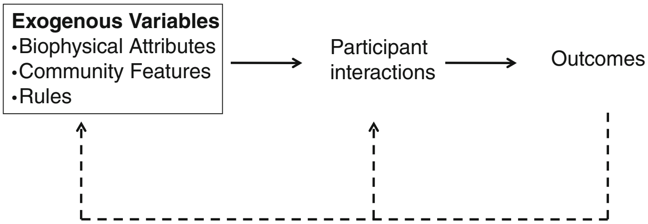

Fig. 1 Institutional analysis and development (IAD) framework, based on Edwards and Steins (1998)

Chopra, Kadekodi and Murty (1989) studied the case of participatory development in Sukhomajri. Soil erosion in the catchment of the Sukhna River led to siltation in the Sukhna Lake in the city of Chandigarh. Initial attempts at checking the soil erosion by government departments were met with indifference until 1978, when villagers participated and changed things around. This work examined the link between private property resources and common property resources. Thus, the central idea was about the role of attributes of the community influencing the grazing commons and the related outcomes for city dwellers (see Fig. 2).

In Chopra, Kadekodi and Murty (1989), the initial situation was that of a tragedy of the commons. The biophysical context was that there was severe soil erosion from the village of Sukhomajri that ended up getting washed down into the Sukhna Lake in the city of Chandigarh. Initially, there was indifference by the villagers to initiatives by government agencies, but a turning point came in 1978. The villagers now became participants—engaging, for example, in contour digging. This made a big difference in outcomes—the soil erosion went down from about 40 hectare metres (ha m) before 1960 to about 1.6 ha m by 1986. The authors saw this as a conversion from a prisoner's dilemma game to a cooperative game. The key factor in this evolution that they focused on was a community attribute—the distribution of private property resources and its complementarity with common pool resources.

Chopra and her two colleagues at IEG, Kadekodi and Murty, would go on to publish extensively in environment and development economics. But their book, published by Sage (Chopra, Kadekodi and Murty 1989), would be highly cited. One of the notable scholars citing their book was Partha Dasgupta as he went about illuminating the economics of the commons in the rural areas of developing countries [for example, Dasgupta (1995; *Journal of Economic Literature*, vol. 33, pp. 1879–1902)].

Chopra and Kadekodi followed up the work with an examination of participation, this time enhanced by including the case of Bhusadia, a village in Bihar where private property resources had been pooled and converted to common property resources. The presentation of the key features of the two empirical case studies is followed up by a theoretical model that strives to examine the evolution of participation. They suggest that key factors influencing participation are: (1) the

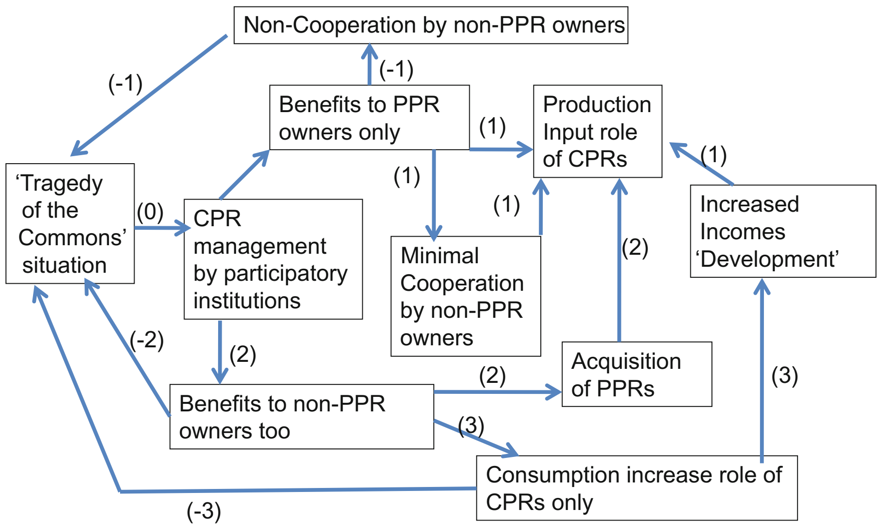

Fig. 2 Diagram 1 in Chopra, Kadekodi and Murty (1989)

relationships between private and common property resources, (attributes of the community) (2) using economies of scale if possible (biophysical attributes) and (3) the rules regarding distribution (see Fig. 1).

Chopra and Gulati (1998) studied a key theme in development economics, migration, in relation to the commons using data from six villages in Rajasthan. They found that if property rights were clarified, migration was reduced. Moreover, the decision to migrate was linked to the decision to participate in the management of the commons. Here, changes in the rules in use affect the action arena, and the outcomes, including lower migration, feedback to the rules (Fig. 1). Chopra's methodological pluralism is evident in a similar paper by Chopra and Gulati (1997) where econometric analysis of secondary data was combined with case studies of initiatives to remedy the open-access situation of some common pool resources. Chopra's attention to the connection between variables that exist in our theories and the variables that we end up with when we gather data is evident here. This is a key challenge in institutional analysis. In Chopra and Gulati (1997), the authors reflected on institutional change that was a result of NGOs working in the area. In order to capture the process of institutional change, they distinguished between villages by the number of years NGOs had been working there. They found that the institutional build-up in villages significantly improved participation. In Chopra and Gulati (1998), there is an acknowledgment that qualitative case studies in contrast to econometric data analysis generally give us more fine-grained views of the rules and nature of property regimes governing common pool resources.

A further evolution of Chopra's work occurred when she used systems modelling to incorporate ecology–economy links, studying the Keoladeo National Park. The biophysical attributes interact with the rules regarding grazing (see Fig. 1) that generate outcomes that can be valued by the analyst. Chopra and Adhikari (2004) simulated ecology–economy interactions in the park. They argued that wetlands give rise to a variety of values. To value an ecosystem service, we need to identify (1) the physical or environmental linkages which result in the supply of the service and (2) the economic links which help the ecosystem service contribute of human welfare.

In traditional recreational valuation models used for national parks, the number of trips is a function of travel cost incurred and household characteristics; in Chopra and Adhikari (2004), the number of trips is a function also of ecological health of the park. The ecological health of the park can be parametrized only by using medium or long-run time series data and by modelling the wetland system.

Chopra and Adhikari (2004) made projections for key variables for 23 years on a monthly basis. They found that (from the travel cost model) the visits by tourists were not responsive to private costs. The direct and indirect income from the park depended on ecological health indices. Further, the response or elasticity of income was more at high values of the ecological health indices. In other words, not only was the ecological health a significant determinant of income from the park, the relationship was marked by a nonlinearity as the ecological health indices varied over time.

The Sundarbans are one of the most intriguing landscapes in the world, and Chopra studied the emergence of shrimp cultivation in that setting, building on the idea of 'sustainable freedoms' of Amartya Sen. Sustainable freedoms combine the idea of enhancing peoples capabilities, which Sen had developed extensively, with the idea of sustainability, to which environmental economists have devoted attention. Chopra studied different stakeholders associated with shrimp cultivation. Here again, Chopra shows her pluralism to engage with different evaluative criteria to judge outcomes resulting from the use of commons (see Fig. 1), those of Amartya Sen, in terms of different stakeholders. Based on a primary survey, Chopra compares indicators for several stakeholders. One comparison she makes is between agricultural farmers and shrimp farmers. Although shrimp farmers have higher incomes per capita, they have lower income security and are also more prone to social conflict.

3 About the Contributions in the Book

The first section in the book is devoted to one of the key themes of the book and a key theme in Chopra's research: the sustainability of development. She had worked on natural resource accounts for forests in India, besides being a member of the Partha Dasgupta committee on Green National Accounts in India. Fittingly, this section begins with a paper by Partha Dasgupta, the renowned environmental economist on global dilemmas. A related piece by Anantha Duraiappah is on the inclusive wealth index. This is followed by a paper from Walter V. Reid and Harold A. Mooney on multidisciplinary science and Purnamita Dasgupta's piece on climate change and food grain production in India.

The next section is on institutions. Chopra had early in her career co-authored a paper with Gopal K. Kadekodi and M. N. Murty on private and common property interactions in Sukhomajri, and here Murty writes about collective and government action. A general methodology of institutions in a paper by Vikram Dayal, Chopra's doctoral student, opens the section. Charles Perrings the renowned expert on biodiversity writes about conservation beyond protected areas, and Chopra's long-time colleague B. N. Goldar and his co-author write about informal regulation and water quality in Indian rivers. Chopra's early research was on agriculture and the paper by Ram Chandra Bhattarai, Pranab Mukhopadyay and E. Somanathan is an empirical study of transaction costs in agriculture in Nepal.

The next section gets into well-being. Chopra had often adopted a multi-stakeholder approach in her papers, and examined the different values that were important to different stakeholders, and also in a later paper examined the well-being of stakeholders in the Sunderbans using Sen's capability approach. In this section, Joan Martinez-Alier writes about justice and conflicts. Priya Shyamsundar, Saudamini Das (another doctoral student) and Mani Nepal compare forest dependence in specific locations in India and Nepal. Indrani Gupta, one other Chopra's colleague and her co-author use data from a large survey to study infectious disease effects on households in India. Preeti Kapuria, one other Chopra's doctoral student, studies quality of life in an urban context.

In the last section, Richard B. Norgaard and Gopal K. Kadekodi give us a personal account of how Chopra contributed to the International Society of Ecological Economics (ISEE) and the Indian Society of Ecological Economics (INSEE) respectively. A brief summary of the papers follow.

Partha Dasgupta in 'Global Dilemmas' employs the historical data on GDP per capita, the common measuring rod for average standard of living in a society since 1 AD to show that average person to be rather poor and also the absence of sustained growth of income in any country/region of the world throughout history. It argues for a non-declining wealth, and hence, the productive capacity as a way out, for the omissions of social costs and nature's services in the GDP. For the former increasing and the latter declining, it raises a question mark over sustaining any rate of income growth. Without safeguarding natural capital through institutions and addressing the vast inequality in consumption inter- and intra-country, the Sustainable Development Goals (SDGs) or any such proclamation may not be achievable, the paper concludes.

'The Inclusive Wealth Index: Measuring the Sustainability of the Sustainable Development Goals' by Anantha Duraiappah takes this conclusion as its starting point and delves into operationalisation aspects—after all meeting SDGs will require a non-declining income flow. For measuring and assessing the nature and direction of change in the stock (and hence social value of the productive base of society), it proposes construction of an Inclusive Wealth Index (IWI), applies it for 140 countries and compares with the nature and direction of change in the GDP (absolute and per capita). Following the results, it was concluded that towards achieving sustainability the key is investment in education and knowledge generation followed by investment in natural capital. The paper concludes with identifying the key steps towards improving the computation of IWI for a more informed decision-making by the policymakers.

'The Millennium Ecosystem Assessment: Testing the Limits of Interdisciplinary and Multi-scale Science' by Walter V. Reid and Harold A. Mooney explores the role of Millennium Ecosystem Assessment (MA) towards understanding how the changes in biodiversity and ecosystems (resulting from human actions) were affecting ecosystem services and the connected human well-being apart from suggesting actions that could be taken in this regard. They argue that the recognition and influence of MA in the subsequent policy discourse and similar assessment were due to five factors: (a) the focus on how ecosystem changes affect people, (b) interdisciplinary framework for analysis involving natural and social scientists, (c) a politically legitimate process, (d) scientific credibility for the process being independent and (e) multi-scale research. One of its contributions has been the creation of the Wealth Accounting program at the World Bank, of which IWI (focus of the previous paper) is a natural successor.

In the backdrop of the concerns over breaching of planetary boundaries and meeting of the SDGs in such an environment, Purnamita Dasgupta in 'Climatic Change Impacts on Food Grain Production in India' asks the following question: if climate change increases vulnerability through its impacts on food security, which of the socio-economic factors are the key drivers for food production and its response to climate change impacts. Such identification can be helpful for policy-makers in judging the potential adaptation costs. The analysis is undertaken through a simulation model, with construction of alternative future food production scenarios (continuation of existing trend and improved/enhanced parameter values) against variations in climatic factors vis-a-vis ten major food grain-producing states in India and for four major categories. It predicts a range of shortfalls (say, 15–38 million tonne when it is 273 MT in 2016–17, for reference) and the concerns that follow from those across scenarios, one being over per capita food availability.

Vikram Dayal in 'Analyzing Institutions in Resource and Development Econometrics: Recognizing Institutions, Exploring Levels, and Querying Causes' provides an overarching framework for recognising and analysing institutions in the studies on development that use econometrics as a tool. It problematises the use of multi-level modelling for not just predictive but also causal purposes. Besides arguing for employing causal graphs, it calls for using instrumental variables in order to capture institutions. For both, the author points to the necessity of engaging with historical or socio-ecological studies by the development and resource economists. It uses three case studies—on biomass extraction, air pollution and carbon and forest livelihoods—for illustrative purposes.

In 'Environmental Management: Choice between Collective Action and Government Action', M. N. Murty compares the theory and practice of 'government action' and 'collective action' to control environmental externalities. For the former, the paper uses the institutional framework emanating from the works of Coase, Becker and Ostrom. Illustrations from India on controlling water pollution by the industry are used for the latter. For the public good type of externalities based on evidence from the ground, it locates possibilities for competition between two groups of stakeholders put together through effective cooperation between their respective constituents that may result into optimal control of the externality.

Charles Perrings in ‘Conservation beyond Protected Areas: The Challenge of Land Races and Crop Wild Relatives’ problematises the practices of ex situ conservation in comparison to in situ ones resulting from changes in the institutional framework governing this matter. Favouring ex situ conservation along with upholding of national sovereignty principle instead of common heritage had significant and adverse consequences for meeting the goals of conservation per se in general and maintained the value of the genetic basis for agriculture more specifically the paper argues. Theoretically grounded with Hotelling’s arbitrage condition, it puts forward a set of economically sound institutional mechanisms involving participation across all farmers, national governments and global community.

‘Water Quality in Indian Rivers: Influence of Economic Development, Informal Regulation and Income Inequality’ by Bishwanath Goldar and Amrita Goldar locates the significance of urbanisation, industrialisation, literacy (as a proxy for informal regulation) and income (expenditure) inequality in causing river water pollution in India, which has serious consequences on human health, ecology and agricultural production. An econometric study was carried out at the district level with dissolved oxygen, biochemical oxygen demand and faecal coliform count as the dependent variables. While informal regulation was found to improve water quality, income inequality was having the opposite effects.

In ‘Transaction Costs and Agricultural Productivity in Kathmandu Valley, Nepal’, Ram Chandra Bhattarai, Pranab Mukhopadhyay and E. Somanathan estimated components of transaction costs for 60 Farmer-Managed Irrigation Systems in Kathmandu, Lalitpur and Bhaktapur districts of Nepal that cover one or more Village Development Committees, the smallest administrative unit. Direct costs in the form of payments to hired labour and imputed components in terms of opportunity costs for time in managing the institution were computed at both system and household levels. While transaction cost was found to be only a small percentage of the total value of output per hectare, the authors argued—on the basis of field surveys—without the ‘waiting, watching and negotiating’ components, loss in productivity could be very large.

Joan Martinez-Alier drawn from the experience of global environmental justice movement in ‘Ecological Distribution Conflicts and the Vocabulary of Environmental Justice’. It looks at the roles that have been played and the contributions made by the Environmental Justice Organisations in not just in raising awareness or organising movements on the sufferings inflicted on and sacrifices made by those at the receiving end of increasing social metabolism, but also coining new terms in the process that are adopted by the academia later. The latter allows organisations across the globe to connect their struggle, resulting in a global environmental justice movement, the paper argues.

In ‘Forest Dependence and Poverty in the Himalayas—differences between India and Nepal’, Priya Shyamsundar, Saudamini Das and Mani Nepal explored the contribution of ecosystem services offered by the forests in the income of selected forest-dependent households in India and Nepal on either side of the Mahakali River. Curiously, it has been found that while Indians use and collect more than twice as much fuelwood as do their Nepalese counterparts in per capita terms and India also having a much better road network, Nepalese are much better off than the Indians. Examining several correlates of poverty did not offer any conclusive results, it has reported.

Indrani Gupta and Samik Chowdhury in 'Household Micro-environment and its Impact on Infectious Diseases in India—Evidence from the National Sample Surveys' attempt to show whether and how different intra-household micro-environmental characteristics, such as quality of drinking water, access to latrine, influence prevalence of infectious diseases using two large sample rounds of data collected by National Sample Survey Office in India. In the face of high out-of-pocket expenditures to address such factors, especially on poor households, it finds hope in Fourteenth Finance Commission's recommendation to more than double the grant for local bodies, both urban and panchayats.

In 'Understanding Quality of life in an Urban Context: Measurement of Poverty and Vulnerability using Fuzzy Logic', a paper connected with the previous, Preeti Kapuria used data from two most recent rounds of Indian Census district-level data, to examine the quality of life of people residing in city state of Delhi for the purposes of comparing and connecting 'income' and 'human' poverty, both constructed by her. Concept of vulnerability, defined against multiple dimensions, such as intra-household availability and quality of toilet facilities, extent of green cover in the district, was used to find quite distinct district rankings based on 'human' and 'income' poverty estimates to argue in the favour of targeting not just the *definitely poor* but also the *extremely vulnerable* population to achieve sustained long-run results.

Richard B. Norgaard in 'A Few Words on Kanchan Chopra's Role in the early years of the International Society for Ecological Economics' and Gopal K. Kadekodi in 'Birth of INSEE and my association with Kanchan Chopra' offer a review of honouree's contribution in two institutions and a brief reflection of her works.

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Part I
Sustainability of Development

Global Dilemmas

Partha Dasgupta

1 Social Evaluation of the Past

The economist Angus Maddison spent much of his professional life uncovering past living standards in various regions of the world. To do that, he chose gross domestic product (GDP) per capita as a measure of the average standard of living in a society. He chose that because GDP is the index in most common use today for assessing the performance of economies and for evaluating macroeconomic policy.[1] GDP is the market value of the flow of all finished goods and services produced within a country in a given year. It includes the monetary value of aggregate private consumption (consumer spending, as it is often called), gross investment (including the capital expenditures of business firms), the sum of government expenditures and the difference between exports and imports. GDP is a measure of an economy's aggregate output.[2]

By studying village people's engagements with their local commons, Kanchan Chopra has illuminated the conditions of life of rural India in the latter decades of the twentieth century. In this paper I pay tribute to her remarkable work by unearthing a dilemma humanity now faces as we go about our lives in the global commons.

[1]Any issue of the weekly newspaper, *The Economist*, would confirm the claim.
[2]GDP is to be contrasted from GNP (gross national product). The latter is GDP plus incomes earned by residents from overseas earnings, minus incomes earned within the economy by overseas residents. The difference between the two measures is of little significance for our purposes here.

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Table 1 Deep history, 1. GDP per capita (1990 international dollars)

Year	1 CE	1000	1500	1700	1820	1900	1950	2000
Western Europe	575	425	775	1,025	1,230	2,885	4,570	19,175
Western offshoots	400	400	400	475	1,200	4,015	9,270	27,395
Latin America	400	400	415	530	690	1,115	2,510	5,890
Asia	455	470	570	570	580	640	715	3,800
Africa	470	425	415	420	420	600	890	1,450
World	470	455	565	615	665	1,260	2,110	6,040

Data Source Maddison (2010)
Key "Western Offshoots" include what are today USA, Canada, New Zealand and Australia

Although it is routine today to study the performance of economies in terms of GDP, Maddison's work is especially interesting and important because it is on deep history. Peering into the past two thousand years with a measuring rod, which is what Maddison did, takes courage, some would say gumption; but Maddison used whatever record he could find that gave clues to wages, food consumption, clothing, housing, land rents and so on. Table 1 reproduces figures constructed in ongoing work by others in what is now known as the "Maddison Project" (Maddison 2010). The project is designed to improve upon the estimates Maddison offered in his now-classic work (Maddison 2001). The table presents GDP per capita in five regions of the world. The figures are expressed in 1990 international dollars.[3]

The first thing to note about the numbers is how very poor people were all over the world right up to the beginning of the early-modern period (1500 in our Common Era (CE)). In late antiquity and the middle ages, average income everywhere was barely above a dollar a day, the figure that was taken by the World Bank in the 1990s to be the line below which spells *extreme* poverty. It was only at the beginning of the modern era, 1700 CE, that the average person in western Europe enjoyed an income of 1,025 dollars. Even that was below the average income (1,120 dollars) in countries that were in the 1990s regarded as poor by the World Bank. The rest of the world was, however, still languishing in poverty, at just over a dollar a day. As tourists we are dazzled by the art, architecture and technology of past eras. We refer to them as great civilizations and imagine that those must have been prosperous times as well. Table 1 says we should imagine otherwise. The Taj Mahal, for example, which is today the most renowned construction of the early-modern era, was built in the mid-seventeenth century on the orders of a despot in memory of his favourite wife, on the backs of extremely poor subjects.

[3]In constructing international dollars, the official exchange rates of various currencies with respect to the US dollar are converted so as to bring the purchasing power in the regions on par with one another. In what follows I assume that by "dollars" is meant "international dollars".

Great art, great architecture, great literature, even great scientific and technological discoveries, can coexist with general squalor and widespread deprivation of the means available for a reasonable existence. And they have coexisted for nearly all of history. Average world income in 1820 CE, just after the start of the Industrial Revolution in what is now the West, was only 50% higher than in 1 CE. That means the rate of growth of world income per capita over the 1,820-year period averaged at 0.0002 (or 0.02%) per year, a figure that is indistinguishable from zero. Table 1 says that it was not until the beginning of the nineteenth century that income levels in the West rose above that of today's poor countries. But only just. Significant increases in the standard of living have taken place only in the twentieth century, mostly in the West (and Japan; see Maddison 2010). In five decades (1950–2000), GDP per capita increased nearly fourfold in western Europe (and nearly tenfold in Japan; see Maddison 2010). It is true that in 1945, those nations were in a devastated condition, meaning that the potentials for growth were large. But as Table 1 tells us, we should not imagine that the poorer a nation, the greater is its potential for advancement. Western Europe (and Japan) had institutions in place, an educated population and a social coherence that enabled them to take advantage of their potentials. In contrast, Africa, which at the end of the Second World War was a lot poorer than the West and Japan, continues to languish. Average income in Africa at the end of the twentieth century was about one-fifteenth of that in western Europe.

No doubt Table 1 hides social improvements that took place in various places from time to time during the 1,500 years following year 0. Even an interval of 1,000 years (0–1000 CE) hides fluctuations of fortunes. Temin (2013), for example, suggests that GDP per capita in the Roman Empire in second century CE was about the same as in India in 1990. But in time the Empire fell and incomes dropped. We also know of the Black Death and Europe's revival following it, both of which are hidden from view in the thick, 500-year spell 1000–1500 CE. Fouquet and Broadberry (2015), for example, have peered closer into Europe for the period 1200–1870 and have found that there were periods when some regions enjoyed considerable growth in GDP per capita, while others declined. But none would appear to have enjoyed sustained growth in incomes. I have reproduced the estimates of GDP per capita in deep history because they are pioneering, and because they are a stark reminder that for nearly all of history the average person was very, very poor.[4]

[4]Broadberry et al. (2015) have constructed figures for GDP per capita in Britain over a 600-year period, 1270–1870.

2 Living Standards

Maddison's aim was to study the evolution of living standards through history. He did that by regarding GDP per capita as a measure of the standard of living. The distribution of GDP matters, but excepting for the Modern Period (roughly, 1700 onwards), Maddison was unable to offer estimates of the distribution of GDP within regions because historical data are sparse.[5]

GDP is a different notion from an economy's productive capacity. The former reflects something like the quality of material life at a point in time, whereas the latter points to an economy's stock of assets (wealth). The difference between GDP and the economy's productive capacity is exacerbated by the fact that in estimating GDP, the investment ledger contains only *gross* investment. The qualifier "gross" means that the depreciation of an economy's assets over the year (natural wear and tear of buildings and machines, depletion of natural resources) is ignored. That alone tells us why GDP is not useful in sustainability and policy analysis.

Nevertheless, GDP has assumed such prominence in public discourse today that if someone mentions "economic growth", we know they mean growth in GDP. It is no exaggeration to say that governments today, whether in the rich world or in the poor world, regard GDP growth to be above all else on their list of objectives. The mainstream media extol it and the public succumb to it.[6] One reason stands out; when GDP increases, employment and investment opportunities expand. So, as incomes grow in a country where GDP was once low, households, communities and government are able increasingly to set aside resources for the production of things that make for a good life.

That could be why it has become customary to regard an economy whose GDP is large as wealthy. But that's to make a mistake. GDP is a *flow* (so many dollars worth of the flow of goods and services in a year), whereas wealth is a *stock* (so many dollars worth of assets, period). It could be that a country produces lots of goods and services by running down its assets, in which case GDP and wealth would be pointing in opposite directions. But they could not do so forever. With a dwindling stock of assets, such as environmental resources, even GDP would eventually have to take a beating. Economic growth would not be sustainable.

That GDP does not include the depreciation of capital explains why the phrase "Green GDP" is a misnomer and why to call for indefinite GDP growth and to demand sustainable development at the same time is to seek two incompatible objectives. But pointing to the absence of depreciation figures in GDP suggests that perhaps GDP minus depreciation, that is, net domestic product (NDP), could serve

[5]However, we can infer from the fact that GDP per capita was not much above subsistence level through most of history, that most people were very poor, and that only a few enjoyed a high standard of living.

[6]Bhutan, with its government's rejection of GDP in favour of a Gross National Happiness Index, is a very rare exception.

the social evaluator's purpose. Unfortunately, NDP also is inadequate: it is possible for an economy to eat into its productive base even while NDP increases for a while.[7]

3 Economic Growth and Sustainable Development

Writing at the very end of the eighteenth century, the Rev. Thomas Malthus postulated that population size and the standard of living had kept each other in check throughout history in what we would today call a low-level equilibrium. Whenever living standards rose above the equilibrium level, population grew and brought it down; whenever living standards fell below it, people died (wars and pestilence) and the system equilibrated. Both population and living standards in Malthus' theory, like any good theory, were determined by factors operating at a deeper level. So he identified various possible causes that had perturbed economies throughout history (wars and crop failure were two proximate drivers), from which they returned to equilibrium.[8]

Table 2, read from Maddison (2001), provides estimates of population size and expectancy of life at birth over the past two thousand years. Taken together, the two tables suggest that human experience until 1700 CE were pretty much in line with Malthus' theory. GDP per capita remained well under 2 dollars a day, world population was kept in check considerably below 1 billion, and a new-born was expected to live for at best 26 years. But Malthus published his book at the wrong moment. Almost immediately afterwards, his theory began to unravel in the West. The Industrial Revolution was the proximate cause, but by the beginning of the twentieth century, Malthus' theory began to unravel elsewhere too, barring Asia

[7]Official publications have been known to identify income with wealth. In giving expression to their moral disapproval of the enormous inequality in the contemporary world, authors of UNDP (1998: 30) wrote: "New estimates show that the world's 225 richest people have a combined wealth of over 1 trillion US dollars, equal to the annual income of the poorest 47 percent of the world's people (2.5 billion)".

But as wealth and income differ in dimension, they cannot be compared. Wealth has to be converted into an equivalent flow of income (or vice versa) before comparisons can be made. (UNDP 1999 repeated the mistake.) If we were to pursue UNDP's reasoning, we could follow the standard practice of converting wealth into a figure for permanent income by using, say, a 5% annual interest rate (i.e. divide wealth by 20). When the conversion is made on the data offered in UNDP (1998), my calculations, albeit they are very crude, tell me that towards the end of the twentieth century, the world's richest 225 people, having a combined annual income of over 50 billion US dollars, earned more than the combined annual incomes of people in the world's twelve poorest countries, or about 7% of the world's population (385 million). That is still a sobering statistic. Global inequalities in income have grown a lot further since we entered the new millennium.

[8]For a mathematical formulation of Malthus' theory, see Day (1983), who also drew attention to possible fluctuations away from equilibrium, depending on the parameters characterizing agrarian economies.

Table 2 Global health and numbers

Year	0	1000	1820	1900	1950	1999	2014
Life expectancy at birth (years)	24	24	26	31	49	66	68
Population size (million)	230	270	1,000	1,500	2,500	6,000	7,200

Data Source Maddison (2001), Tables 1-5b and B-10, for columns 1–6; World Bank (2013), for column 7

(Japan excluded; see Maddison 2001) and Africa. By then world population had risen to 1.5 billion, life expectancy at birth had advanced to 31 years, and average income had grown to nearly 1,500 dollars a year.

During the twentieth century, several key dimensions of life improved greatly (in the second half, they improved spectacularly). Output per head quadrupled, life expectancy of a new-born rose from 31 to 66 years (relatedly, people enjoyed ever greater protection against water- and air-borne diseases, greater use of potable water and sanitation and, since the end of the Second World War, antibiotics), even while world population grew by a multiple of four (to 6 billion). By 2015, global output per head reached approximately 10,000 international dollars (in 1990 prices), life expectancy at birth rose to 71 years, and population grew to nearly 7.4 billion.

In a famous 1930 essay "Economic Possibilities for our Grandchildren", John Maynard Keynes described a past that was consonant with the deep history of Tables 1 and 2. And he concluded that humanity in his time had never remotely had it so good (Keynes 1963). The world's living standard today is a lot higher than what it was even when Keynes made his observation. The average person not only enjoys far higher income and lives longer, the proportion of the world's population in absolute poverty (now regarded by the World Bank to be 1.9 international dollars a day) has fallen so dramatically (it is now just over 10% of the world's population, down from about 50% in 1980) that enthusiasts predict that within a generation the blight will have been eliminated for the foreseeable future (Jamison et al. 2013).

Talking in terms of percentage changes when identifying poverty or national carbon emissions or population growth, as development experts often do, can mislead. Earth's life-support system does not calculate percentage changes, and it responds to the absolute demands we make of it.[9] Nevertheless, if you worry about environmental degradation, you will be told that nature does not represent much more than 5% of global wealth (estimated from the share of agricultural income in global output) and that natural resources can be so shifted round in the contemporary world, that dwindling supplies in one place can be met by imports from another. Intellectuals and commentators use the term "globalization" to imply that location does not matter. The view emphasizes the prospects offered by trade and investment and says if they are not enough, technological progress can be relied upon to solve the problems arising from resource depletion and environmental

[9]Ehrlich and Holdren (1971) is the classic on this.

degradation. Today Malthus, the “pessimistic parson”, is seen as a “false prophet” remaining as wrong as ever (*The Economist* 15 May 2008); and books celebrating humanity’s achievements read as breathless expressions of triumphalism.[10]

But there is a problem. Humanity’s undoubted success over the past 250 years has been accompanied by significant losses that go unrecorded in official statistics. What economists and demographers have interpreted as economic success may thus have been a down payment for future failure. Even while industrial output increased by a multiple of 40 during the twentieth century, the use of energy increased by a multiple of 16, methane-producing cattle population grew in pace with human population, fish catch increased by a multiple of 35 and carbon and sulphur dioxide emissions rose by more than 10. As the figures are all flows (or fluxes) and rates of changes of flows, it could be countered that they do not reveal anything about the state of the biosphere. But the Millennium Ecosystem Assessment (MEA 2005a, b, c and d) reported that 15 of the 24 ecosystems the authors had investigated worldwide are either degraded or being exploited at unsustainable rates, due in large measure to excessive harvesting of renewable natural resources and to land-use changes that lead to habitat destruction. Studies have found that innumerable local ecosystems (wetlands, forests, mangroves, freshwater lakes, coastal fisheries) have degraded over the decades, in quality or extent, or both (MEA 2005a, b, c and d). Today some 25–30% of the 130 billion metric ton of carbon that is harnessed annually by terrestrial photosynthesis is appropriated for human use (Vitousek et al. 1986, 1997; Haberl et al. 2007; Krausmann et al. 2013). That is a stupendous amount for a single species. These figures put the scale of humanity’s presence on the planet in perspective and record that we are now Earth’s dominant species (Ehrlich and Ehrlich 2008). The figures also explain why our era is now called the Anthropocene.

In a report on population trends over the past 50 years of 3,148 species of wildlife in the UK, RSPB et al. (2013) have documented that 60% have declined in numbers and 30% have declined precipitously. Extinction rates of species have been far above background rates since 1500 and have increased further since the nineteenth century. The background rates—that is, extinction rates over millions of years until the emergence of humans some 200,000 years ago—are about 0.1–1 species per 1 million per year. The extinction rate today is estimated to be as many as 100 species per million per year (Wilson 2016). As that is 100–1000 times faster

[10]See, for example, Micklethwait and Wooldridge (2000), Ridley (2010), Deaton (2013), Lomborg (2014) and Norberg (2016). Theoretical models of technological change and capital accumulation have provided support for the belief that GDP can grow indefinitely (see, for example, Grossman and Helpman 1991; Helpman 2004). This they are able to do because creators of the models imagine that those two drivers of growth can always overcome the constraints our finite Earth imposes on us.

than previously, environmental scientists fear we are now witness to the Sixth Great Extinction. That the Sixth Great Extinction is taking place in the Anthropocene should not be a cause of surprise.[11]

4 The Anthropocene and Its Economic Correlates[12]

Studying biogeochemical signatures over the past 11,000 years, Waters et al. (2016) provided a sketch of the human-induced evolution of soil nitrogen and phosphorus inventories (more generally of polyaromatic hydrocarbons, polychlorinated *biphenyls* and pesticide residues) in sediments and ice. The authors reported a sharp increase in the middle of the twentieth century in the inventories. Their work shows that the now-famous figure of the "hockey stick" that characterizes time series of atmospheric carbon emission also characterizes a broad class of geochemical signatures, and signals a sharp increase in the rate of deterioration of Earth's life-support system. The authors proposed that mid-twentieth century should be regarded as the time we entered the Anthropocene.[13]

Their reading is consistent with macroeconomic statistics. World population in 1950 was 2.5 billion. Global GDP was a bit over 7.5 trillion international dollars. The average person in the world was therefore poor, with an annual income of a bit over 3,000 international dollars.[14] Since then the world has prospered materially beyond recognition. Population has increased to 7.4 billion, and world output of final goods and services today is about 110 trillion international dollars, meaning that world income per capita now is about 15,000 international dollars. A 15-fold

[11]Ehrlich and Ehrlich (1981), Wilson (1992), Kolbert (2014), Perrings (2014), Pimm et al. (2014), and Ceballos, Ehrlich and Ehrlich (2015) constitute as definitive an account as is possible today of the role biodiversity plays in our lives and of the threats humanity faces from its disappearance. For an illuminating construction of economic history in terms of natural resource exploitation since ancient times, see Barbier (2011). For a review of what we know today of environmental degradation as a driver of past societal collapses, see Diamond (2005), Butzer (2012), Endfield (2012) and Kintisch (2016). Dasgupta and Raven eds. (2017) is a collection of articles presented at the workshop on Biological Extinction that was held at the Pontifical Academies of Science and the Social Sciences, respectively, in 27 February–1 March 2017.

[12]This section is taken from Dasgupta and Dasgupta (2017).

[13]The Anthropocene Working Group has recently proposed that the immediate post-war years should be regarded as the start of the Anthropocene. See, Vosen (2016).

[14]That is at 2015 prices. The corresponding figure in Table 1, of 2110 international dollars, is at 1990 prices. When comparing global incomes across time, as Maddison's studies enable us to do, we express figures in 1990 international dollars, because that was the unit in which he published his estimates. But when reporting the current state of affairs, I use current international dollars. That way we can relate to contemporary figures published by governments and international organizations.

increase in recorded economic activities over the past 65 years explains such evidence as we have that humanity's annual demand for the biosphere's products now exceeds sustainable levels.

The World Bank in its World Development Indicators 2016 reported that the 1.4 billion people living in its list of high-income countries enjoy a per capita income of 40,700 international dollars. Thus, the richest 19% of the world's population consume over 51% of world income (57 trillion/110 trillion). Assuming humanity's impact on the biosphere is proportional to income, 51% of that impact can be attributed to 19% of world population. If the UN's Sustainable Development Goals (SDGs) are to be met, consumption patterns in rich countries will have to alter substantially. The case for substantial taxation on the use of nature's services is overwhelming, but it remains absent from international discussions on the SDGs.

The UN's projection of world population in year 2100 is 11.2 billion. More than three-quarters of that increase is expected to be in sub-Saharan Africa, where population in 2100 is projected to rise from today's 1 to 4 billion. Per capita income in sub-Saharan Africa is currently 3,500 (international) dollars. At an aggregate output level of 3.5 trillion international dollars (just over 3% of world output), sub-Saharan Africa cannot remotely be held responsible for today's global environmental problems. But attempts to raise incomes there in the face of a 3-billion rise in numbers to even today's global average income will require an increase in the region's annual output from 3.5 to 60 trillion dollars. That rise will have severe consequences for the region's ecology, contributing to further societal conflicts and greater population movements within the region and to attempts at movements out of it. The counter position, expressed frequently by prominent African leaders, that the region could do with more people if it is to propel itself economically is at total variance with the demand our technologies make on nature's services.

That enormous increase in our use of Earth's services stores perhaps insuperable problems for our descendants. No doubt they will inherit a larger stock of manufactured capital than we did and hopefully will be better educated, but they will inherit a less productive biosphere. Moreover, a large body of work by ecologists and environmental scientists on "natural capital" (aquifers, the oceans, tropical forests, estuaries, wetlands, and the atmosphere's circulation patterns) has revealed that when subjected to extreme stress, natural systems change character dramatically for the worse, with little advance notice. That has been confirmed at the global scale in the processes involving climate change (Lenton et al. 2008); at local scales, they are routinely observed in the processes that lead to the eutrophication of fresh water bodies as small as the garden pond. Tipping phenomena are pervasive in the natural world.

The evidence we have reviewed says humanity's use of nature's services today exceed the rates at which nature is able to make them available. But by how much?

WWF (2012) reported that humanity's demand for ecological services currently exceeds by more than 50% the rate at which the biosphere is able to supply them. The figure is based on the idea of "global ecological footprint", which is the surface area of biologically productive land and sea needed to supply the resources a human population consumes (food, fibres, wood, water) and to assimilate the waste we produce (materials, gases). A footprint in excess of 1 means demand for ecological services exceeds their supply. That is plainly not sustainable. Migration (or rather, attempts at migration) by rural communities facing local ecological destruction is a spatially localized reflection of the phenomenon. Battle for resources results also in distress migration across borders.[15]

Humanity's demand for nature's services can exceed supply for a period, but not indefinitely. If economic development is to be sustainable, the footprint over time must, as a very minimum, equal 1 on average. To be sure, technological advances that are directed at reducing our impact on the Earth system, for example advances in biotechnology, can reduce the footprint and purchase improvements in the quality of life; but the advances would be successful only if they do not have large, unintended adverse consequences on the biosphere. Moreover, irreversible losses, arising say from biological extinctions, would act as constraints on the biosphere's ability to recover. The greatest contributors to the ecological-footprint overshoot are the OECD countries (a club of rich nations).

Among those who worry about humanity's future prospects on account of a diminished Earth, there is thus an intellectual tension, having to do with scale. There are those who focus on carbon emissions that affect the global climate with its attendant consequences; there are some who worry about degradation of biomes such as the Amazon forest and the African Savannah and the disappearance of pollinators, decomposers, scavengers, pest controllers, and carbon and nitrogen fixers that goes with it; and there are others who conduct field studies on the availability of firewood, freshwater, and coastal and forest products among rural communities in the poor world. Resource exhaustion and biodiversity loss may not have yet revealed themselves in a transparent form at the global level (governments do not collect the relevant data), but they are a terrible happening for villages where people stare at desiccated slopes, barren trees, receding forests, vanishing water-holes and unfertile coastal waters. Environmental problems appear in different

[15]For an early statement of the idea of ecological footprints, see Rees and Wackernagel (1994). WWF (2008), to which Mathis Wakernagel contributed, developed the idea and furnished data from which the quantitative estimates of ecological footprints were derived.

No doubt estimates of global ecological footprint are very, very crude. But the biases that ecologists have noted in estimates of national ecological footprints (trade in commodities makes national comparisons problematic) can be expected to be far less in global estimates because the national biases would be expected to cancel one another. In any event, in contrast to estimates of such development indicators as GDP, population size, life expectancy and literacy, which are made by a multitude of national and global institutions, we are obliged here to rely on the estimates of a solitary research group. That alone speaks to the paucity of interest in the population–consumption–environment nexus. Nevertheless, that there is an overshoot (ecological footprint in excess of 1) is entirely consistent with a wide range of evidence on the state of the biosphere, some of which we have just reviewed. As the figures are the only ones on offer, I make use of them.

guises to us. There is no single environmental problem, there are multitude of them, differing in geographical scale and temporal scale.[16]

What the phenomena have in common is this:

The decisions each of us makes on reproduction, consumption, production and our treatment of nature have unaccounted for consequences for others, including our descendants. Economists call the unaccounted for consequences for others of our actions, *externalities*.[17] It is not only that our decisions create externalities for our contemporaries and for future people, it is also that some people will be born owing to our decisions, while some who would have been born had we acted otherwise will not be born. Externalities manifest themselves along varying pathways, but there is one pathway common to all societies, which arises because humanity uses many ecological services free of charge. We do not cost those services before using them. So we eat into them at excessive rates, meaning that the externalities in question are detrimental to others. The wedge between the social cost of an activity and the cost borne by those who engage in is a subsidy that is shouldered by society at large. Innovators understandably create technologies that economize on the use of costly factors of production, not of factors that are free. That is how and why the price we pay in the market to bite into natural capital has declined over time. Bulldozers and chainsaws enable us to deforest land at rates that would have been unimaginable 250 years ago, and modern fishing technology devastates large swathes of seabeds in a manner unthinkable in the past. These are but two examples. The rate of population growth and technological innovations, both desired and desirable features of the Industrial Revolution and its aftermath, have left in their wake unforeseen negative side effects that official statistics do not record. Because of ineffective institutions governing our use of natural capital, the feedback loops in our relationships with ourselves and with nature get amplified continually. The resulting misallocation of resources is not self-correcting, meaning that Adam Smith's famous invisible hand cannot even in principle come to the rescue. Reasoned collective action is required—ranging from local to international level.

IMF (2015) has calculated that globally, subsidies on the use of oil alone amount currently to some 6.6% of global GDP. Authors of IMF (2015) calculated the subsidies on the basis of the damage to human health arising from excessive levels of energy-based pollution. That is an incomplete estimate; it does not, for example, include future losses owing to reductions in biodiversity and pressures on agriculture. But even that is an underestimate, as only those externalities associated

[16]Chopra et al. (1989) and Jodha (2001) are key empirical studies of the links between poverty and environmental degradation at the scale of villages in the semi-arid regions of India. MEA (2005a, b, c and d) is a four-volume report on the state of the world's ecosystems at round the beginning of this century. Gadgil and Guha (1992) is a classic study of the ecological history of India as seen in parallel with the history of Indian culture and statehood.

[17]See Dasgupta and Ehrlich (2013) for an analysis of how and why the externalities arise.

with the use of oil figures in the calculation; coal is absent. We should conclude that global subsidies on the use of the nature's goods and services, more generally, must be vastly greater.

5 Conflicting Perspectives

So we have two conflicting perspectives: confidence in a glorious future on the basis of something like a 250-year experience out of 14,000 years that have defined the Holocene (the Era since the most recent Ice Age), against the conviction that the population growth and the pattern of economic development we have been enjoying for the past hundred years or so are unsustainable. That we live with these opposing perspectives is reflected in the fact that the United Nations in 2015 launched its "Sustainable Development Goals", a full 15 years after it issued the "Millennium Development Goals". They should have been constructed at the same time and been under one heading. The gulf between the way the world is read by people who have been influenced by development and growth economics on the one hand, and those who have read the findings of environmental scientists and ecologists on the other, is now so great that if someone expresses concerns about the pressures on the Earth system that have been accumulating because of unprecedented growth in population, production and consumption over the past century, he is dubbed a Malthusian. That for the most part we put to bed our suspicion that all does not bode well for our descendants may explain why contemporary societies are obsessed with cultural identity and on the whole dismissive of any suggestion that we need to find ways to survive ecologically.[18]

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[18]I have myself been accused of Malthusian pessimism by the late Johnson (2001), in his comments on a paper of mine on population pressures on the Earth system (Dasgupta 2000). Malthus wrote over 200 years ago. That his formal model has proved to be wrong empirically to date is not at all the point. He was entirely right to direct our attention to the impact of human activities on the Earth system and the latter's response to those activities (see my reply to Johnson; Dasgupta 2001). Other classical political economists in contrast took natural capital (land) to be indestructible, albeit of different qualities (see Dasgupta 1985).

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The Inclusive Wealth Index: Measuring the Sustainability of the Sustainable Development Goals

Anantha Duraiappah

1 Introduction

2015 was a monumental year for the global community. For the first time, countries came together to agree on a set of universal goals and targets aimed at not only improving the well-being of the present generation but also improving future generations. The set of proposed 17 goals ranges from eliminating extreme poverty to ensuring peaceful societies across the world (UNDESA 2014). Departing from the previous development paradigm of focusing development primarily on low- and middle-income countries, the sustainable development goals (SDGs) were meant to be for all countries. The universality of these goals was indeed to be applauded.

The challenge of course lies in the design and implementation of policies to achieve these goals. There is no denying that financial, human, and natural resources will be needed to implement the projects required to achieve the SDGs. For example, governments will need to invest in schools, teacher training, and information technology to achieve the SDG on education. Similarly, governments will have to conserve or restore habitats to halt the loss of biodiversity if they are to meet the SDG on environmental sustainability. Three key points emerge. First, resources will be needed, and this will have to come from the assets a country owns. Second, there will be instances whereby trade-offs need to be managed but also the potential of synergies to be exploited when making decisions on the use of assets to achieve the set of SDGs. Third, the stock of assets in totality will need to be non-decreasing over time if improvements in well-being—now represented collectively by the SDGs—is to be achieved (Arrow et al. 2004).

The use of assets and the monitoring of assets have been the privy of economic institutions within countries. The System of National Accounts (SNA) developed in

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the late 1940s in response to the Great Depression keeps a close track of capital assets such as infrastructure, roads, bridges and schools. The accounts, however, pay little or no attention to natural assets such as forest, fisheries and water stocks, to name a few. The same can be said for human assets such as knowledge and health (Liu and Fraumeni 2014). Moreover, the SNA does not reflect the potential present value of the future flow of goods and services provided by the stock of each capital asset at any point of time. This oversight therefore does not allow policymakers to know if the present consumption levels, whatever that might, can be supported for future generations based on the stock of assets the country owns at the present (Arrow et al. 2004). This is critical information that should be used by policymakers when designing and implementing the policies to implement the SDGs.

2 The Conundrum: The Sustainable Development Goals and the Sustainability of the Sustainable Development Goals

There is a fundamental disconnect between the sustainable development goal discourse and the sustainability process (Barbier 2012). There has been little thinking on making the connection between resource use and the SDGs. There seems to be an underlying assumption that our present macroeconomic policy frameworks will provide the adequate structure to guide the investment strategies and project selection process required to make the SDGs a success.

The conundrum countries will face when trying to achieve the SDGs is the following. On the one hand, a non-declining asset base will be needed to achieve the SDGs. However, the primary indicator used by countries to evaluate if they are performing well and well-being is improving is the gross domestic product (GDP). The GDP measures flow of goods and services that are produced by the country's asset base. The connections with GDP per capita are well recognised. Its measurement does not pose much difficulty, while the method is theoretically well grounded besides being rigorous theory. Further, the data needed in these calculations do not pose much challenge. As a result, countries were quick to adopt this method, offered through the System of National Accounts.

However, it is erroneous to employ GDP per capita to measure well-being. Notwithstanding such attempts like Human Development Index made by the United Nations to redress this matter, there still remain some serious problems in accounting for sustainability. In fact, none of the existing indicators can offer any signal whether a country is on a sustainable path or not (Dasgupta 2009). As a result, natural environment continues to be degraded and low priority is extended to education and health. Perhaps we are using an inappropriate parameter to offer guidance to policymaking towards sustainable development.

What is therefore needed is an indicator that monitors and keeps track of the assets, stocks and their changes across time in a country. This indicator should serve two purposes. First, it should provide an overview of the stock of the assets a country owns, and second, it is an indicator that can illustrate potential trade-offs and synergies that might emerge when attempting to achieve the various SDGs.

3 Transitioning to Sustainability

We propose in this paper one such indicator. It is drawn from the theoretical framework proposed by Arrow et al. (2004), on inclusive wealth (IW). It is premised on social welfare theory and covers the multiple aspects that any notion of sustainable development may attempt to address. At the very beginning, this work defines the objective of sustainable development as a discounted flow of utility and moves away from rather arbitrary term of needs. Consumption, in turn, was considered as the utility. Such consumption, by construction, includes items of consumption which are non-material in origin, such as leisure.

It is the 'equivalence theorem' that extends the necessary elegance to the IW framework. Through the theorem, authors could demonstrate that well-being improves as long as the total asset base of a country does not decrease. The framework emphasizes on the importance of maintaining the total capital asset base and not just one particular asset base. The total capital asset base was considered as the productive base of the nation. This, the authors argued, forms the basis for sustainable development. More importantly, it offers the benefit of tractability, like GDP, which is useful for all the interested parties including governments.

The Inclusive Wealth Index (IWI) was developed to measure the total social value of a country's productive base. The assets comprise of produced capital (roads, buildings, machines, and equipment), human capital (skills, knowledge, health) and natural capital (subsoil resources, ecosystems, the atmosphere).

4 The Inclusive Wealth Index

In this paper, we shall employ a revised definition of sustainable development (Dasgupta and Duraiappah 2012). [1]

Definition 1 By sustainable development, we mean a pattern of societal development along which (intergenerational) well-being does not decline.

[1]Equations in this section are adapted from Arrow et al. (2012) and Dasgupta and Duraiappah (2012).

Intergenerational well-being V is defined as

$$V(t) = \int_{t}^{\infty} [U(C(s))e^{-\delta(s-t)}]ds, \quad \delta > 0 \tag{1}$$

where **C**(t) denotes a vector of consumption flows at time t and δ, the discount rate.

Hence, **U**[**C**(t)] denotes the utility flow at time t.

Let **K**(t) denote a set of vector stocks of capital assets at time t. For a given **K**(t), **C**(t), **U**(**C**(t)) and together with Eq. (1), we can write

$$V(t) = V[K(t), M] \tag{2}$$

where **V**(t) denotes intergenerational well-being at t, **K**(t) denotes a set of vector stocks of capital assets at time t, and **M** denotes an evolving political economy.

Differentiating **V**(t) with respect to t in Eq. (2), we obtain:

$$dV(t) = \frac{\Delta V}{\Delta t} + \sum_{i} \left[\frac{\Delta V(t)}{\Delta K_i(t)} \cdot \frac{dK_i(t)}{dt} \right] \geq 0 \tag{3}$$

Let $\Delta V(t)$ represents a small change in **V**(t) and $\Delta K_i(t)$ represent a small increase in capital asset i at time t. Using definition 1 together with Eq. (2), we obtain the shadow price of asset i at time t

$$P_i(t) = \frac{\Delta V(t)}{\Delta K_i(t)} \quad \text{for all } i \tag{4}$$

To measure inclusive wealth, we represent **Q**(t) as the shadow price of time that is reflected in

$$Q(t) = \frac{\Delta V(t)}{\Delta t} \tag{5}$$

Using Eq. (6), we can construct an aggregate index of a country's stock of capital assets by using the shadow prices as weights. This index is known as inclusive wealth. Formally, we define an economy's inclusive wealth as the shadow value of all its capital assets including time.

$$W = Q(t)t + \sum_{i} P_i(t)K_i(t) \tag{6}$$

where $P_i(t)$ refers to shadow price of capital asset $K_i(t)$. Institutions are reflected in $P_i(t)$.

An important relationship exists between changes in inclusive wealth when small perturbations are made at constant prices and changes in intergenerational well-being (Arrow et al. 2012).

To show this formally, let Δ denote small perturbations and see observed changes in intergenerational well-being. We take Eq. (2) and derive through small perturbations in time.

$$\Delta V(t) = \left[\frac{\Delta V(t)}{\Delta t}\right]\Delta t + \sum_i \left[\frac{\Delta V(t)}{K_i(t)}\right]\Delta K_i(t) \tag{7}$$

By using Eqs. (4) and (5), we can express Eq. (7) as

$$\Delta V(t) = Q(t)\Delta t + \sum_i P_i(t)\Delta K_i(t)$$

If we take Eqs. (6) and (7), we can see that they are equivalent with Eq. (7) stating that any positive (negative) change in well-being is equal to a positive (negative) change in wealth, i.e., a positive (negative) change in the capital asset base or productive base of a nation.

In this way, we show that changes in inclusive wealth mirror the changes in human well-being; i.e., positive changes in inclusive wealth suggests improvements in well-being, while negative changes in IWI imply a decrease in well-being (Arrow et al. 2004). Correspondingly, positive changes imply sustainability, whereby the stock of assets at any point of time is able to support the consumption of all goods and services of not only the present generations but future generations as well.

What does this mean for the implementation of projects targeted at achieving the SDGs? Let us say a country is intending to reduce poverty (SDG 1) by creating jobs through investment in roads and bridges. The construction of roads and bridges, however, might require the conversion of some forests and wetlands. A typical macroeconomic level analysis will suggest that building the roads and bridges would add to the infrastructure of a country, thus increasing the value of produced capital and subsequently an increase in GDP. However, the loss of the ecosystem services offered by the forests and wetlands such as water purification, biodiversity conservation and flood regulation is not accounted in the decision to build the roads and bridges.

However, using the IW framework, building roads and bridges will be accounted as before in the form of additional produced capital. However, the loss of the forests and wetlands would be now reflected in the loss of natural capital. The net gain or loss would of course depend on the social values of both capitals. It is important to make the distinction here between market prices and social prices. Economic valuation of ecosystem services points towards relatively high social values of ecosystems such as wetlands when the full suite of ecosystem services these ecosystems offer for human well-being is factored in decision making (Barbier 2014; MA 2005).

The IWI therefore allows a much richer representation of a nation's assets over time (see Fig. 1). Moreover, the IWI addresses three issues, for implementing the sustainable development agenda. While they are elaborated below, it is worth highlighting here. First, it addresses the concerns over the assumption of

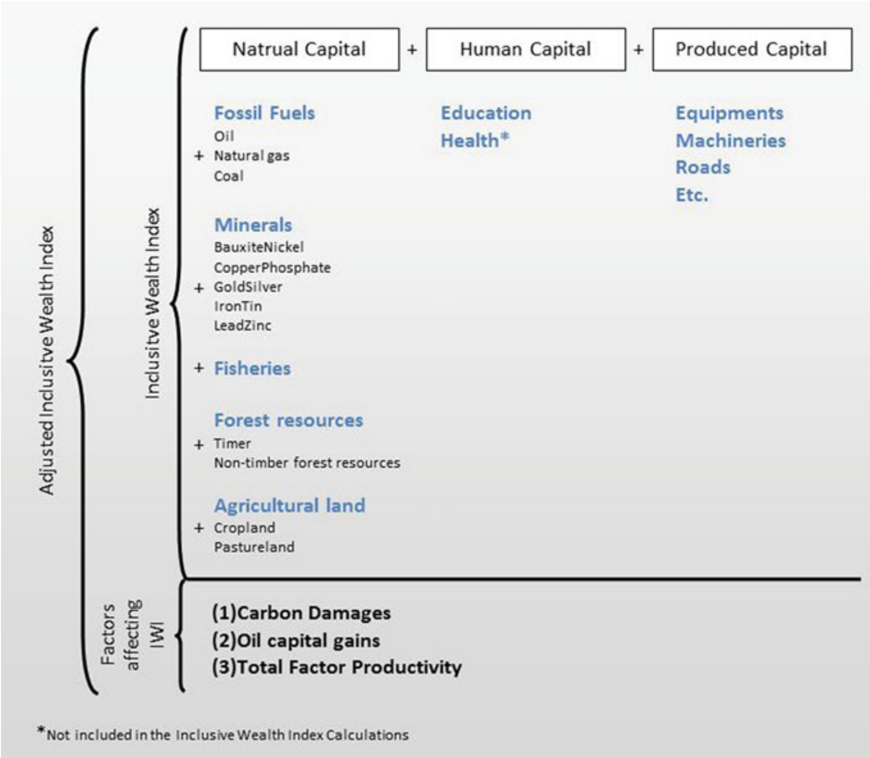

Fig. 1 Schematic overview of productive base of economy. *Source* IWR 2014 (IHDP 2014)

substitutability between nature's ecosystem services with other types of capital in a typical economic framework. Next, it captures the impact of population growth on sustainability. Further, it also considers how one country's progress might come at the expense of other countries. The notion of global responsibility for the sustainable development of nations follows from this third point.

Substitution Substitution possibilities across the different types of capital are integral to the inclusive wealth framework. Thus, it does not prioritise any specific interest of any particular constituency. It follows that, here, natural capital is preserved for its overall contribution to the productive base and not for its own sake. Consider a country endowed with extensive forest stocks. To increase the inclusive wealth, the country may convert some of these stocks to other types of capital. It is the ratio of the shadow prices of the capitals in question that determine the degree of substitutability across the capitals. It follows that these shadow prices hold the key to the degree or extent of transformation in a given country. For taking decisions on investment strategies, this can be a valuable source of information for the policymakers within a given country.

Population Change In this framework, population is treated explicitly. This makes growing population an important variable in determination of the sustainable track of a given country. Countries with a rapidly expanding population will have to by virtue of the IWI grow its capital assets base at a higher growth rate to ensure a productive base that is able to accommodate the needs of a growing population.

Interconnected Externalities This framework captures one of major global environmental problems, namely climate change. This arises from the growing frequency of such phenomena that include nitrogen deposition and biodiversity as well. Each impacts country's wealth prospects which in turn affect its ability to adopt and maintain a sustainable path. It follows that adoption of all the right measures by a given country can be only a necessary condition to follow a sustainable path. There are some external variables which are beyond its control that can influence its inclusive wealth.

Including the impacts of climate change as an explicit feedback within the IWI framework demonstrates how climate change can have an impact of a country's productive base and therefore its sustainability trajectory. This will have significant implications on the final inclusive wealth estimates for the countries and can be useful in guiding international climate change negotiations. Information on the externalities that spills across the borders can also be useful in determining international compensations, irrespective of the form—financial or technology transfers.

5 The IWI: Some Preliminary Results

In this section, some results from the first IWR report released in 2014 (IWR 2014 henceforth) will be presented. Figure 2 shows the percentage changes in inclusive wealth both in absolute and in per capita terms for 140 countries over the period of 1990–2010 (IHDP-UNU 2014). The results show population growth having a major impact on many countries moving them from positive to negative growth rates.

The IWR 2014 estimates show that 128 of the 140 countries (92%) experienced a positive annual average growth rate in inclusive wealth. However, this number dropped to 84 (60%) when population growth was included as shown in Fig. 3. This result offers two important policy directions. First, it tells that population growth rates are key for the achievement of the SDGs. This is a factor hardly ever discussed in any macroeconomic or sustainable development policy dialogues (Dasgupta and Ehrlich 2013). Second, if population growth policies are not considered, then focus must shift to moderating consumption to levels that can be supported by the inclusive wealth of the country.

Two questions most finance ministers will ask of the inclusive wealth accounts are as follows: (i) What has been the size of each capital's contribution towards the growth of the inclusive wealth of a country, and (ii) what has been the wealth composition of each capital? The former gives an idea of the overall investment a country has directed towards that particular capital, while the latter gives

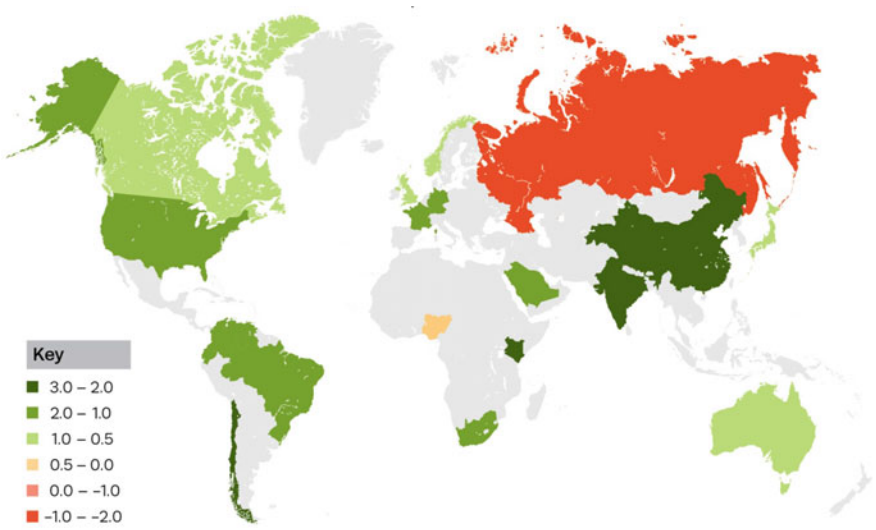

Fig. 2 IWI growth rates (1990–2010) across 140 countries. *Source* IWR 2014

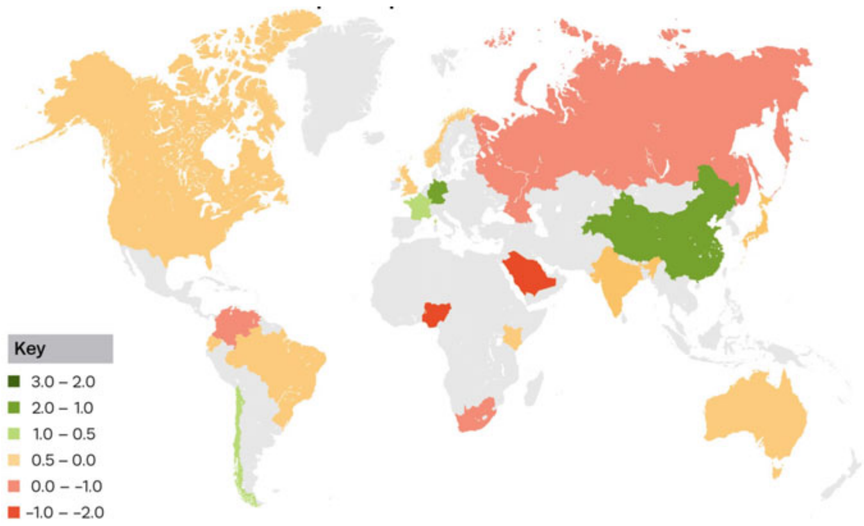

Fig. 3 IWI per capita growth rates (1990–2010) across 140 countries. *Source* IWR 2014

information on the weight of each capital in the inclusive wealth portfolio of a country. The IWR 2014 reports that on the average, human capital contributed approximately 55% towards the growth in inclusive wealth of countries followed by produced capital with 32% and natural capital forming the remaining 13%. In terms of composition, human capital comprised of 54% of inclusive wealth, followed by natural capital with 28% and produced capital 18%. The clear signal we get from these results suggest investment in education and knowledge generation is key to achieving sustainability. Next comes investment in natural capital.

The IWR 2014 also revealed that the System of National Accounts most countries use tracks only approximately 18% of a country's assets; the remaining 82% of inclusive wealth—of which human and natural capitals account for 54 and 38% respectively—is ignored or only partially covered. Unsurprisingly, a cause of concern has been the state of natural capital, which increased in only 24 countries and made the largest contributions to changes in wealth in only 12 countries around the world. The potential for investment in natural capital is large and an area worth exploring when countries design the implementation strategies for the SDGs and economic development simultaneously.

There is an important lesson in the results for natural capital. Although natural capital only contributed 13% towards the growth in inclusive wealth, it holds a 28% share of inclusive wealth. What does this mean for policymakers in macroeconomic terms? One clear recommendation coming out from this result is the switch from investment in produced capital to natural capital would yield a higher inclusive growth rate than continuing the present trend of focusing solely on produced capital as the engine of economic growth. This is a key game changer as far as present investment policies are concerned. At the present, investment in natural capital is seen only through the eyes of meeting environmental regulations and therefore takes a backseat in most country's economic policymaking and in particular during the budget setting process. The IWR 2014 results show that investment in natural capital can actually be an engine for economic growth.

When nations are grouped according to income level, as presently done using GDP per capita, high-income economies predominantly show a positive development in IWI. There are, however, a few high-income economies that show a negative growth from the IWI perspective: United Arab Emirates, Kuwait, Qatar, Saudi Arabia, and Trinidad and Tobago. These are all countries where the extraction of fossil fuels plays an important role in economic development, yet the depletion of these non-renewable resources and the relatively slow growth in human and produced capital leads to negative growth rates in IWI. The use of the IWI in conjunction with the GDP would highlight the need for these countries to pay closer attention to the use of the resources accruing from the extraction of non-renewable resources—depletion of natural capital—in the investment of human, produced capitals as well as in renewable resources in a manner such that the overall inclusive wealth increases.

Another key result emerging from the IWR 2014 having significant policy implications is the degree to which the present System of National Accounts covers the asset base of a country. The SNA reports relatively accurately the changes in produced capital. However, natural and human capitals are less comprehensively reported. There have been recent attempts at developing satellite accounts to track changes in some components of these two capitals (United Nations 2014). But this is not sufficient. The inclusive wealth accounts do not only reflect the stocks of capitals at any time period but also reflect the present value of future flow of goods and services from these capitals. This might be the distinctive feature that separates the present SNA and a possible system of inclusive wealth accounts (SIWA).

6 Gaps and the Recommendations for the Way Forward

The inclusive wealth accounts presented in IWR 2014 are without doubt incomplete. However, the strength of the framework is its theoretical foundations, which then allows us to know precisely what are the gaps, when and where we have to cut corners when making estimates, and what needs to be done to improve the estimates. Three major gaps emerge from the work done to date. These are non-trivial gaps but completely doable if we have the political leadership and commitment.

The first gap relates to data gaps in the existing capital accounts. These data gaps refer to both missing information on the physical stocks of capitals and the social prices of many of the capital asserts in particular for the natural and human capital components. For example, there is little information on the availability of surface and groundwater stocks. The same is for fisheries where there is little and scattered information on the stocks of fisheries even if many species are facing extinction.

The second data gap lies in the social pricing of many capital assets. The market prices of many goods and services accruing from natural and human capital are either missing or vastly underpriced. For example, the market prices of many natural capital services such as carbon sequestration, flood regulation and water purification of forest are missing and crude estimates form a scattering of case studies are used to estimate their social prices. The Millennium Ecosystem Assessment (MA 2005) made a strong case for a global systematic research agenda to be initiated, whereby the social prices of some of the key goods and services provided by natural capital can be estimated and used for policymaking.

The third gap lies in our knowledge of the uncertainty surrsounding the data used in the computation of wealth accounts (Indian Central Statistics Office 2013). There is uncertainty in the measurement of the physical stocks of both natural and human capital components. There is also a factor of confidence over the values people place on many of the goods and services that both forms of capital provide as these values are dependent on a host of sociocultural factors such as culture, religion, gender, caste and race. It would seem more appropriate to use bands over which estimates of inclusive wealth can range over each time period.

A number of key policy recommendations emerge from the IW reports of 2012 and 2014. These are:

(i) Identify key natural capital asset categories that have adequate albeit scattered data for land, forest and water and develop a set of comprehensive set of wealth accounts over the next 10 years.
(ii) Develop a set of education and health accounts to represent human capital and develop these in a systematic and comprehensive manner.

(iii) Initiate a systematic programme to compute the social prices of non-market goods and services accruing from natural and human capital components over the next 10 years.
(iv) Design a strategy to make a gradual transition from the present SNA to a set of inclusive wealth accounts and initiate band estimates to reflect the degree of uncertainty surrounding these estimates.
(v) Develop a strategy to use inclusive wealth accounts as the key fiscal policy tool to design investment strategies at the macroeconomic level.

There is no doubt that much needs to be done if the Inclusive Wealth Index is to become mainstream in decision making. The state of information on the stock of capitals and in particular for human and natural capital has to be significantly strengthened. Furthermore, the shadow values of these assets are still at an infant stage and much more coordination among the numerous initiatives undertaking these studies is urgently needed. However, the gains from such a programme outweigh the costs of gathering this data. The time has come for countries to begin moving away from a set of accounts that reflect just flows to a set of accounts that focus on stocks.

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The Millennium Ecosystem Assessment: Testing the Limits of Interdisciplinary and Multi-scale Science

Walter V. Reid and Harold A. Mooney

1 Introduction

The Millennium Ecosystem Assessment (2005) was created in an attempt to establish a global assessment process analogous to the Intergovernmental Panel on Climate Change (IPCC), but focused on the "other" global changes. Climate change will have profound consequences for humanity and global ecosystems, but it is far from the only environmental change that will have such consequences. Earth's ecosystems are also being dramatically altered through such factors as the loss of biodiversity, nutrient pollution, overharvest of species, unsustainable water withdrawal from rivers and aquifers, soil erosion, and chemical pollution. All of these "other" global changes will have major impacts on human well-being, and many of those impacts are being felt today.

Recognizing that the IPCC both helped to catalyze a response to climate change and to inform the nature of that response, it seemed reasonable to create one or more additional assessment mechanisms that could similarly catalyze and inform actions on the broader global change agenda. An initial attempt to create such an assessment process for biodiversity was not successful. In 1995, the United Nations Environment Program worked with the scientific community to produce the Global Biodiversity Assessment (GBA) (Watson et al. 1995), which was intended to inform the deliberations of the Convention on Biological Diversity (CBD), and other biodiversity-relevant conventions, much as the IPCC informed the deliberations of the UN Framework Convention on Climate Changes. However, because the

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GBA was carried out through a process that had not been authorized by the governments, the CBD, the principal target, did not accept it as a source of scientific input.

The design of the MA was informed by the experience of the GBA as well as by research that helped to identify the characteristics of successful science assessments (Cash and Clark 2001). The IPCC had benefitted from the fact that it predated the UN Framework Convention on Climate Change (UNFCCC). For that reason, while it had an intergovernmental authorizing environment and the bureau members were appointed by governments, it was independent of the UNFCCC itself. With its governmental authorization and its history predating the UNFCCC as the most authoritative and politically legitimate source of climate information, it was accepted by the UNFCCC as its primary source of policy-relevant scientific information.

In contrast, the creation of one or more new assessment mechanisms for other global environmental changes had to contend with the fact that intergovernmental conventions already existed with responsibilities for many of these issues, including the CBD, the United Nations Convention to Combat Desertification (CCD), the Convention on Migratory Species, and the Ramsar Convention on Wetlands. An assessment established for any one of these conventions would necessarily be established under the authority of the scientific and technical body of that convention and consequently would have far less scientific independence than was the case with the IPCC. Moreover, given the strong interlinkages among issues such as biodiversity loss, desertification, and wetlands conservation, it would have been extremely inefficient to launch multiple overlapping global assessments for different conventions.

The solution crafted by a planning committee organized by the World Resources Institute in 1998 was to create a single assessment process—the MA—that was authorized by each of four relevant conventions and had representatives of the conventions involved in its governance. The MA would carry out a single comprehensive integrated assessment, but then produce separate summaries for policy-makers that were tailored to each of the authorizing conventions and submitted through an agreed process for approval by each convention. The result was a process that was politically legitimate but could be carried out with the independence needed to ensure its scientific credibility. While the MA was governed by a non-governmental Board and relied significantly on philanthropic support, the expectation was that if the process proved to be useful to decision-makers, then governments would create a formal intergovernmental process modeled on the MA and fully funded by governments. This did in fact transpire through the subsequent establishment of a new cross-convention Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES).

2 Bridging Disciplines

Through extensive interactions between the scientists involved in the MA and the various intended user audiences among both international conventions and the private sector, it was clear by the time that the MA process was formally launched in 2001 that the assessment would be most useful if it could directly inform the core decisions that people were grappling with regarding social and economic development, human health, and human well-being. Rather than being an assessment narrowly focused on how humans are changing global ecosystems, the assessment panel decided at the outset that it needed to focus also on the consequences of ecosystem change for human well-being and the actions and responses that could be taken to better manage ecosystems to yield improved outcomes for people and the environment.

That framing of the assessment necessarily required a highly interdisciplinary analysis, drawing from physical and biological science, economics, public health, social science, and policy research. The assessment benefitted from the emerging field of research on ecosystem services which provided the core elements of the conceptual framework for examining how changes to ecosystems affect human well-being. This focus on human well-being was a principal element that subsequently engaged such a large and diverse community of adopters of the results of the MA.

Believing that the MA would only be taken seriously by decision-makers if it was as well grounded in economics as it was in natural science, the Board of the MA decided to appoint one economist and one natural scientist as co-chairs for each of the assessment's four working groups (current status and trends, scenarios, policy reponses, and multi-scale assessments). And, for each chapter in the assessment, an attempt was made to appoint a natural scientist and a social scientist or economist as the two coordinating lead authors.

Despite these conceptual and structural efforts to ensure interdisciplinary in the assessment, this goal proved to be much more difficult that we had anticipated. Several examples of the challenges that we encountered were the following:

- The initial phase of the MA involved the development of a conceptual framework for the overall assessment (MA 2003). At the outset, there were significant differences in the conceptual frameworks used by the various disciplines to characterize the proposed assessment. For example, natural and physical scientists regularly refer to "drivers of change" in systems (that is, the forces that cause a change in the biophysical system, such as "growing demand for agricultural commodities is a driver of deforestation"). This framework was not at all familiar to economists. It was only after lengthy discussion that the group could agree on a shared conceptual framework. (In one amusing moment, after the full group of authors of the report had reviewed the entire manuscript line by line and agreed on the final text, we discovered a number of striking disagreements over how different authors were defining terms when we reviewed the glossary. It became apparent that agreement on the text had been achieved in part by virtue of the fact that authors differed in their definitions of the terms.)

- It proved to be extremely difficult to recruit social scientists and economists as authors of chapters in the "Current State and Trends" Working Group, largely because of how we structured that portion of the assessment. To a natural scientist, it seemed logical for this portion of the assessment to include a set of chapters focused on individual ecosystems (e.g., forests, cultivated systems, wetlands) and a set focused on specific ecosystem services (e.g., food production, water provision). We then sought to recruit natural scientists with expertise on the ecosystem or service and social scientists with expertise on how the change in that ecosystem or service affected human well-being. What we found was that natural scientists readily identified with specific ecosystems or services, but this was not the case with most economists and social scientists. The assessment would have been much more successful in recruiting economists and social scientists if it had been structured around how their fields define the problems being addressed (e.g., resource economics, rights to resources, poverty alleviation).
- Although there had been a long history of interdisciplinary research on global environmental change by the time that the MA was initiated, and the concept of "coupled human natural systems" was well established, the assessment revealed that there was a surprisingly limited amount of research that directly addressed the central question of the assessment: What was the consequence of changes in ecosystems for human well-being? There was a substantial body of information on the biophysical changes to ecosystems and even the drivers of those changes. And, there was substantial research on economic and social issues associated with resource-dependent communities. But there was very limited research focused on the linkage between these: how ecosystem changes affect people.

3 Bridging Scales

The MA was the first global environmental assessment to take a "multi-scale" approach. One of the important characteristics of global environmental change is that changes at a local level that have beneficial impacts (e.g., forest clearing to expand agricultural production) may, in the aggregate, have harmful impacts at a regional or global scale (changes in regional rainfall or increased greenhouse gas concentrations). And, both positive and negative social and biophysical feedback may exist across scales. For example, increased agricultural productivity may result in regional in-migration, leading to greater forest loss; greater forest loss may lead to reduced regional rainfall resulting in reduced productivity. For that reason, it seemed essential to include a multi-scale dimension in the MA—to look not just at global environmental change, but also to examine how global changes were impacting local and regional human well-being and to examine how local and regional environmental change was influencing global environmental conditions and human well-being.

With no history of multi-scale assessments to build on, the MA Sub-global Working Group developed an assessment methodology and solicited applications from groups interested in contributing to the process. The sub-global assessments that were ultimately carried out were extremely diverse. Several lessons that we can derive from this experience are the following:

- The conventional wisdom during the MA process was that it would have been much better if the sub-global assessments had preceded the global assessment (as is happening in IPBES). While there are merits to that argument, one could also make the case that the global assessment should precede the sub-global assessments so that they could examine the sub-global impacts of global change. In retrospect, however, we see that there was considerable value in having those assessments running in parallel with the global process. The sub-global assessments tended to bring a much stronger "human face" to the overall assessment process. It was at this scale that the social scientists were most engaged in the process and their influence on the overall assessment conclusions was extremely important. In the end, there is probably no ideal sequencing for a multi-scale assessment.
- The link with "users" was largely absent in the MA sub-global assessments. By the time that the MA was conducted, it was well understood that a global assessment would not succeed in informing decision-making unless it was viewed as politically legitimate by the intended users. The assessment needed to have an "authorizing environment" from its intended users. The MA Sub-global Working Group assessment methodology did stress the importance of establishing this authorizing environment, but, in the end, the engagement of users was quite limited in the sub-global assessments. Two factors were probably at play. First, the individuals who spearheaded the sub-global assessments tended to view them more as research activities than as formal assessment processes. Second, it is inherently difficult to define the "authorizing environment" for a multi-scale assessment. If your goal is to inform decision-makers ranging from local community members to regional governments, who can adequately represent the multiple users at different scales?

4 Bridging Epistemologies

The MA was also the first global assessment to incorporate indigenous knowledge on par with scientific knowledge in the assessment process (Reid et al. 2006). A protocol was developed to enable the assessment to validate indigenous knowledge through a process equivalent to the validation that takes place with scientific knowledge through peer review and replication of results. In addition, one of the MA sub-global assessments was carried out by indigenous groups in Peru.

Indigenous knowledge about ecosystems and environmental changes is an extraordinarily valuable source of information. An assessment of global environmental change that excludes indigenous knowledge would be much less valuable to its users. At the same time, the consequences of global environmental change for indigenous communities will be significant and will differ in many cases from the impacts on other communities. For both of these reasons, the incorporation of indigenous knowledge in the assessment seemed to be essential. Several lessons from this experience were the following:

- If differences between the conceptual frameworks of scientific disciplines present barriers to carrying out interdisciplinary assessments, those differences pale in comparison to the differences in the conceptual frameworks between scientists and indigenous peoples. The final MA Summary for Policy Makers included an example of a conceptual framework developed for an indigenous MA sub-global assessment (Reid et al. 2005, p. 87). It would be difficult, if not impossible, to align the indigenous conceptual framework with the formal framework used by the MA. And yet, the overall process of the MA sub-global assessment still helped to inform decision-makers within the indigenous communities, and the presence of the indigenous sub-global assessment added value to the global process.
- The impact of indigenous knowledge in a global scientific assessment is seen most strongly in the definition of problems and in the recognition of the importance of a broad range of aspects of human well-being and value, and it has least impact in the technical details of the assessment. Indigenous knowledge is often the only information available on a site-specific basis (e.g., the historical pattern of animal migration in particular regions of South America), and it may inform local and regional decision-making, but it has only limited value in informing the technical findings of a global assessment. At the same time, the presence of indigenous voices in a global assessment process inevitably focuses more attention on both the issues that are relevant to those people (e.g., the spiritual importance of nature), and on some of the unique aspects of the how global change may affect indigenous communities in ways distinct from the impact on other communities.

5 Impact on Decision-Makers, the Public, and Science

Apart from the terminal evaluation of the MA, conducted in the year after its release, there has been no comprehensive study to determine the ultimate impact of the assessment. Our observations here are thus largely anecdotal.

The primary audience for the MA was intended to be decision-makers in governments and the private sector. In 2006, the MA terminal evaluation concluded that there was “widespread evidence that the assessment is having an impact on the intended audiences, but the extent of that impact is very mixed, with some institutions, regions, countries, and sectors significantly influenced by the MA while others have not been influenced at all" (Wells 2006). The evaluation found that "the MA and its implications are being discussed by various OECD government agencies and may be adopted in various forms. The MA also seems likely to have an impact on future [Global Environment Facility] programming."

The assessment also catalyzed a large number of sub-global assessments using the basic MA methodology and framework. Some 34 sub-global assessments were launched during the course of the MA (Wells 2006), and after the MA was completed, other assessments were carried out in the UK, Mexico, Canada, Japan, and elsewhere. And, the assessment had an impact within the private sector. For example, building on the MA Private Sector Synthesis Report, World Resources Institute, and the World Business Council for Sustainable Development (WBCSD) worked with a number of companies involved in the WBCSD to carry out evaluations of the risks and opportunities associated with ecosystem services that the companies either rely upon or that may influence their operations (Hanson et al. 2012).

The public was not a priority audience for the MA, although an effort was made to launch the assessment with sufficient media attention to ensure that decision-makers took the effort seriously. The results of the MA were announced, with simultaneous press releases and seminars in major cities (London; Washington, DC, Tokyo; Beijing; Delhi; Cairo; Nairobi; Rome; Paris; Stockholm; Lisbon; Brasilia; and Sao Paulo), resulting in coverage in major newspapers. The briefings were well attended. Each of the five synthesis reports (biodiversity, desertification, business and industry, wetlands, and health), which were targeted to specific audiences, also had separate launch events in which prime target audiences were involved.

The scientific community was also technically not a primary audience for the assessment, but arguably the most significant impact of the assessment has been among scientists. The MA is widely perceived to have taken the concept of ecosystem services, the focus on the linkages between ecosystem services and human well-being, and the importance of multi-scale research and made these mainstream topics for scientific research. The MA provided a conceptual framework and a vocabulary for these fields of research and involved such a large group of leading researchers that it both validated the work of many individuals already working in this area and guided many other researchers to important scientific questions that needed to be answered. Georgina Mace (Mace 2014), for example, noted that in the late 1990s:

> Conservation thinking moved away from species and toward ecosystems as a focus for integrated management, with the goal of providing sustainable benefits for people in the form of ecosystem goods and services—"nature for people." The work on the Millennium Ecosystem Assessment was a key driver of the widespread adoption of this way of thinking about the natural environment. Many of the ideas were quickly adopted into conservation practice and environmental policy, although not without strong and persistent detractors.

The impact of the MA on the scientific community can even be seen in the evolving structure for international global change research. At the time of the MA, the international global environmental change research programs were organized in distinct disciplinary units (climate, biodiversity, human dimensions, and geosphere/biosphere). But, following a process carried out by the International Council for Science (ICSU) and the International Social Science Council (ISSC), a new structure was launched in 2012 called "Future Earth" which adds a more multi-scale and interdisciplinary structure to the original core set of disciplinary programs. Both the research priorities that helped to define this new structure and the organization of Future Earth itself drew heavily on the findings and experience of the MA, and many of the leaders in the MA process were actively involved in the design of Future Earth.

Finally, the MA also had a significant influence on subsequent global assessments in related fields. For example, in 2007, the G-8 Environment Ministers called for an analysis of the economics of the loss of biodiversity; this led to the creation of The Economics of Ecosystems and Biodiversity (TEEB) project. The first TEEB report states that "Taking inspiration from ideas developed in the Millennium Ecosystem Assessment, our initiative, The Economics of Ecosystems and Biodiversity (TEEB), aims to promote a better understanding of the true economic value of ecosystem services and to offer economic tools that take proper account of this value" (TEEB 2008). And, the MA framework contributed to the creation of the Wealth Accounting and the Valuation of Ecosystem Services (WAVES) program at the World Bank which aims to promote sustainable development by ensuring that natural resources are mainstreamed in development planning and national economic accounts.

The MA was completed on time and within its budget, and it is unfortunate that as the findings were being released, none of the original funders were willing to support the MA secretariat for at least an additional year to carry out further outreach to decision-makers. As a result, the MA secretariat was shut down before the full assessment volumes were even released. (The synthesis reports and summaries for policy-makers were released six to nine months prior to the full volumes.) It is likely that a relatively small investment that would have enabled the staff to continue to hold briefings and outreach events could have significantly increased the impact of the assessment. That said the lack of investment in communications and outreach was not unusual for global assessments at that time. The IPCC, for example, had only a very limited communications budget at that time in the belief that all the necessary communications were handled by NGOs and governments interested in the process. That view has now changed dramatically as it has become apparent that the success of a global assessment of this nature is strongly aided by a strong communications capacity that can ensure that the right messages are heard by the right audience in forms that they can use.

6 Continuing Issues

6.1 The Valuation Debate

Although the MA contained a full account of the various forms of valuation of ecosystem functions, the main thrust was on the economic benefits to society and its use in decision-making. This was very powerful in that the results were then relevant to a whole new community of decision-makers from diverse sectors that had not previously had a direct interest in biodiversity conservation, including those in the business community and those involved in land use development. This was also of importance to economists who calculate the wealth of nations and who previously did not include natural capital in their accounting and thus did not note the continuing loss of inclusive wealth of many nations. The publication of the MA in 2005, however, brought a strong immediate criticism highlighted by a Nature commentary by Douglas McCauley, entitled “Selling out on nature” (McCauley 2006) and a continuing debate on this issue (Spash and Aslaksen 2015). Critics of the approach argued that efforts to place economic values on nature may provide tactical benefits, but could ultimately undermine conservation goals since those economic values may change with time. It was better, they argued, to base conservation on the intrinsic and aesthetic values of nature. This debate will certainly continue into the future. It can be noted that in decision-making at the local community level non-economic valuation (most cultural services) often figures prominently in valuation and decisions, whereas at higher spatial levels (regional), cultural services play a smaller role in decisions since many different cultures would be involved.

6.2 Improper Use of the Ecosystem Service Categories

An important contribution of the MA was the development of the categories of ecosystem services into three categories—provisioning, regulating, and cultural services—building on the earlier work of de Groot (1992). There was large discussion by the planning committee on how to categorize the ecosystem functions that led to the delivery of the three categories of services. It was decided that a figure depicting the elements of each of the service categories would be underpinned graphically by the functions underlying all of the services. The unfortunate decision was to label this box as supporting “services” rather than “supporting ecosystem functioning” or “supporting of services” categories. This led to misinterpretation (or at least unintended use) of the figure after publication of the MA by some economists who then noted that this structure led to double counting of services, e.g., primary production and food provisioning (Boyd and Banzhaf 2007) which was certainly not the intent.

7 Promoting the MA Follow-up

The goal of the MA was to establish an intergovernmental process modeled on the IPCC but focused on biodiversity, ecosystems services, and human well-being. In 2004, during the lead up to the release of the assessment in 2005, the MA Board agreed to a set of actions that could be taken in order to set the stage for the creation of a formal intergovernmental process after the approval of the summaries for decision-makers by the relevant conventions. In keeping with the user-driven approach of the MA, the Board felt that it would be premature to start an effort to create an intergovernmental process before the MA reports were adopted by the conventions, an evaluation of the use of the MA had been carried out, and there was clear evidence of the utility of the process for the intended users. The plan thus called for the project to be evaluated during 2006, and, pending a positive result from the evaluation, a series of regional consultations were to be carried out to establish whether there would be political support for establishing an ongoing intergovernmental process.

The institutional landscape became more complex, however, during the 2005 Conference of Parties of the Convention on Biological Diversity (where the MA findings were adopted by the Convention) when the government of France announced that the then President of France, Jacques Chirac, wished to launch an IPCC process for biodiversity (this announcement was not coordinated with the MA process). DIVERSITAS, an international program of biodiversity science, then organized a meeting in collaboration with the French Government (Loreau 2006) to explore this idea in greater depth. President Chirac, and the participants, made a plea for a new intergovernmental agreement for biodiversity analogous to the IPCC, which they called the International Mechanism of Scientific Expertise on Biodiversity (IMoSEB). With support from the government of France, IMoSEB then launched a series of regional consultations to build support for the process. Given that these consultations were underway, plans for separate consultations on the MA follow-up were put on hold.

By 2007, the terminal evaluation of the MA had been completed. In addition, the UK's environmental audit committee of the House of Commons undertook an evaluation of the MA and published its results in 2007. Both evaluations reported that the MA's technical objective of assessing the capacity of ecosystems to support human well-being proved both innovative and far-reaching. With that background, in October 2007, the United Nations Environment Program with support from the Swedish Ministry for the Environment established an MA Follow-up Advisory Committee. The group, involving individuals who had been deeply involved in the MA, then pursued a set of activities to lay the groundwork for the intergovernmental process. In parallel, the IMoSEB consultations were completed and the IMoSEB steering committee called for the creation of an ongoing intergovernmental process in November 2007.

At the CBD COP-9 in 2008, the parties to the convention agreed to a decision on the follow-up to the MA (CBD 2008). This decision:

- Took note "of the multitude of ongoing and planned subnational, national and regional assessments of biodiversity and ecosystem services that build on the conceptual framework, methodologies and outcomes of the Millennium Ecosystem Assessment"
- Noted "that a regular assessment is needed to provide decision makers with the necessary information base for adaptive management and to promote the necessary political will for action in addressing biodiversity loss and the degradation of ecosystems and ecosystem services and their implications for human well-being,"
- Noted "the outcomes of the consultative process towards an international mechanism of scientific expertise on biodiversity (IMoSEB)."
- And, welcomed "the agreement of the Executive Director of the United Nations Environment Programme to convene an ad hoc open-ended intergovernmental multi-stakeholder meeting to consider establishing an efficient international science-policy interface on biodiversity, ecosystem services and human well-being."

With this support from the CBD, UNEP then launched a series of intergovernmental consultations and meetings resulting in 2012 in the establishment of the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES). The legacy of the MA influenced this long process. It was agreed, as was done in the MA, that the new agreement would serve multiple international environmental conventions, rather than just the Convention on Biological Diversity. Ecosystem services were explicitly noted for inclusion in IPBES, and multiple scales were incorporated, both legacies of the MA. Then, a number of the participants in the MA assumed a leadership role in the new program (e.g. Robert Watson and A. M. Zakri became leaders of IPBES as they had been in the MA).

A comparison of the MA and IPBES shows the strengths and weaknesses of both models and the consequences of the operational decisions that were made. The MA was very nimble and quite efficient. This was due to full funding for the program from governmental and private sources before it became operational. In the MA, there were no protracted organizational debates (it took one year to design the MA, one year to obtain the authorization from the conventions, and one year to create the working groups), whereas in IPBES, it took a number of years of intergovernmental debates on both major and minor issues on operations and program goals before an agreement came to support the new program. Decisions on most issues in building IPBES were by consensus of all of the government representatives often the result of a very lengthy debating process with compromises being made along the way. In contrast, the issues that the MA chose were informed by two sources of input: First, a session was held during meetings of each of the partner conventions to identify specific information needs of the parties to the convention. Second, the MA scientific assessment panel debated what information was needed and could be provided on the basis of the status of scientific knowledge. The MA secretariat then synthesized those inputs, and the final selection of topics was approved by the MA Board.

The formal intergovernmental model of IPBES requires consensus to be achieved by all countries regarding the focus of the assessment, but in turn this gives greater weight to the findings of the assessment. In the case of both the IPBES and the MA, the final products (the summaries for decision-makers in the case of the MA) were negotiated by intergovernmental bodies (IPBES itself in the former case, and the conventions in the case of the MA). IPBES has the structure to continually add national funding to support the ongoing and evolving efforts of IPBES. The oversight of IPBES is purely governmental, whereas with the MA the Governing Board involved not only leading natural and social scientists, but also members from the international environmental agreements, the business communities, and leaders from indigenous communities. This was a remarkable mix and one that worked smoothly and typically came to consensus agreement easily.

8 Conclusion

The MA achieved many of its goals and led to impacts that had not been planned. The findings were widely used by governments and the private sector over the past ten years, and, as had been hoped, it proved the value of such an assessment and catalyzed and provided the model for the IPBES. At the same time, its impact within the scientific community was perhaps even greater. The MA both legitimized research at the interface between the natural and social sciences and provided a lexicon and lasting framework for characterizing work on ecosystem services and human well-being.

But perhaps the greatest impact of the MA was that it pushed the envelope in three dimensions of global environmental assessments by virtue of its strong focus on interdisciplinary science, its pioneering role in carrying out a multi-scale assessment, and its pioneering role in incorporating indigenous knowledge on par with scientific knowledge in its process.

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Climatic Change Impacts on Foodgrain Production in India

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1 Introduction

In the contemporary context of a global push for achieving sustainability as manifested in the formulation of the Sustainable Development Goals (SDGs) (UN 2015), climate change brings in serious issues for debate and discussion, even as the debate on what constitutes development remains far from settled (Chopra 2017). The 17 SDGs are meant to be interconnected—the environmental ones (land, water and climate), along with the ones addressing basic needs and economic growth, for instance—coming together to provide meaning to the SDG themes on people, prosperity, peace and so on. Presumably, the underlying idea is that this time around concerns about the environment or breaching planetary boundaries (Rockstrom et al. Rockström et al. 2009, 2013) will be mainstreamed as a part of attaining the other goals. While the approach to SDG formulation highlights the synergies amongst climate and other goals, the trade-offs in mainstreaming a climate agenda into development priorities especially in the near and medium term have to be tackled (Dasgupta 2016).

The question about how climate change impacts sustainable development, begs the reverse question on the ways in which sustainable development can influence climate change and how policies to address climate change can affect sustainable development. The Shared Socio-Economic Pathways (SSPs) approach provides one way of thinking about these questions, in its categorisation of the alternative socio-economic futures in terms of the extent of challenges these pose for adaptation

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and mitigation (O'Neill et al. 2015). While this sort of conceptual framing works well for thinking about the trade-offs and synergies among climate and other goals, it poses significant challenges in operational terms. The imperative for combining a qualitative narrative with a quantitative metric poses challenges across disciplines. This is illustrated in the context of the SSPs, where scholars have come up with varying numbers and storylines as they try to empirically operationalise the structure (e.g. Cuaresma 2017; Leimbach et al. 2017). The gap between the producers of knowledge and the users of knowledge persists (Lemos et al. 2012). While the academic literature increasingly acknowledges the need for co-production of knowledge, decision-makers in the policy domain continue to seek data that can be presented as "objective" in the face of increasing complexity.

If one were to construct future pathways for an economy such that it is conducive to addressing sustainability, the inter-linkages between various sectors of the economy have to explicitly be taken into consideration. This is rarely done in the literature that tries to address first the question on how climate change impacts an economy. In this chapter, a minimalist approach is taken to illustrate how inter-linkages lead to the possibility of adverse outcomes in one sector affecting markers of vulnerability in the rest of the Indian economy. The attempt is to construct scenarios for the future that integrate climate impacts from agriculture. Agriculture as a sector has been an important contributor to national income and economic well-being in most traditional societies and continues to play an important role in transition economies. A major concern today is of food security—the absence of which can be taken as a marker of vulnerability that is of concern for both global and national economy. The long-term challenge of avoiding shortfalls in food production is exacerbated with most studies concluding that climate change will have adverse impacts on agricultural production, particularly in developing countries (Dasgupta et al. 2014; Cline 2007; Evenson 1999; Lobell et al. 2008, Porter et al. 2014). The possibility of adverse impacts of climate change on food production assumes significant importance for the entire economy, with the implications being felt not just in rural areas, but in urban areas as well, especially given its importance in impacting the lives of the poor and hungry (Dasgupta et al. 2014; Morton et al. 2014, Hertel and Rosch 2010; Kumar and Parikh 2001; Mendelsohn et al. 2007; Parry et al. 2005; Olsson et al. 2014; INDC 2015).

Food insecurity can result from a variety of reasons which impact availability, affordability and accessibility to foodgrains. Stability in food production constitutes one major component of ensuring food security in general and for the Indian economy in particular which housed 28% of the globally hungry population in 2008, its rank was 97th among 118 countries in the Global Hunger Index, 2016 (FAO 2010; IFAD 2011; IFPRI 2010, 2016). This paper presents a simulation model, for constructing alternative future food production scenarios which take note of the socio-economic factors that are key drivers for food production in the agriculture sector and its response to climate change impacts. The mathematical structure of the model requires the estimation of parameters that is achieved through use of supplementary econometric models. The model is run using data for India. The macro data for the simulation exercise uses base year 2004–2005 data.

The econometric exercise for the agricultural sector is a panel data model, which uses data for a 30 year period, for ten major foodgrain producing states and for four major categories: rice, wheat, pulses and coarse grains.

Existing attempts at economic modelling for supply of foodgrains for India do not explicitly incorporate the impacts of climate change nor do most of these consider a sufficiently long-term horizon where impacts can potentially occur through multiple pathways. The model presented here incorporates climate change variables along with several economic ones which influence outcomes and decision-making in the production of foodgrains from both within and outside the agricultural sector.

The results reveal that the model is robust and flexible to the requirements of data and information availability. Production of foodgrains is sensitive to variations in climatic conditions, in particular, to temperature and precipitation in diverse ways. More importantly, the supply outcomes are significantly impacted by other economic factors, such as urbanisation, profitability of food versus non-foodgrain cultivation and water use efficiency. Climate change leads to shortfalls in food production ranging from 15 to 38 million tonne across a range of scenarios upon integrating these considerations in the model. A most worrisome aspect is that per capita availability falls consistently short of target consumption levels for foodgrains.

The paper is organised as follows. Section 2 details the methodology used for constructing alternative scenarios and the models used for parameter estimations. Section 3 discusses the data, assumptions and information requirements for the model. Section 4 provides insights from data analysis on some key variables and presents results from the 'base simulation model'. Section 5 concludes the paper with a discussion on the implications from alternative scenarios for future food security.

2 Methodology

The aim of the study is to build alternative scenarios for food production with the help of simulation modelling, in order to enhance the understanding of the inter-relationships between variables in the model. A simulation model is built for the agriculture sector, incorporating the likely behaviour pattern for key indicators for this sector. It determines the production of foodgrains. Using the system dynamic approach, variations in stocks and flows maintain the system in equilibrium; the purpose of the model is to understand the patterns of change that are likely to emerge.[1] The structure of the model shows how the system is likely to change over time and allows us to build in the limitations to growth arising from climatic change impacts, alongside any other production constraints. It also includes the

[1]System dynamics has been widely used to simulate climate systems and study policy impacts.

capacity for the system to overcome these impacts through adoption of new technologies and management strategies such as increased efficiency of water use, improved irrigation and crop yields. The key parameters affected by climate change are temperature and precipitation. The basic building blocks of the model are "stocks" and "flows" and variations in these maintain the system in equilibrium.[2]

2.1 Construction of the Model

The primary purpose in constructing the model was to permit simulations that allow variables to vary and impact behaviour of the system. Since the present model seeks to produce a possible pattern of behaviour in the future, the reference mode for the model is a hypothesis mode (Randers 1980). The conceptualization of the model, the qualitative part, leading to the identification of stocks and flows (and subsequently converters) and construction of causal loop diagrams were followed by the quantitative stage, involving estimation of parameters and computer simulations as per standard procedures (Ford 1999; Wolstenholme 1990).

There are three types of variables which are used in the model: stocks, flows and converters. The two stocks, land or area under foodgrain cultivation in the agricultural sector and foodgrains produced, are key variables which represent where the total accumulation in the system takes place. Stocks tend to display sluggishness or are typically slow to change since they get impacted by various flows. Flows add or diminish stocks and represent actions that change the status of the stock while directly influencing them. The direction of the flows gets determined by their relationship with the stocks which is based on an a priori understanding. For area under cultivation, the flows are relative profitability and technology. Yield of food crops and extent of irrigation are flows that interact with area under cultivation to obtain the foodgrain produced. Finally, converters are added to complete the model. The converters are variables that help to describe flows and provide model inputs. Each converter is connected to a flow. The proportion of cultivated area under irrigation, which is connected to the flow variable–area cultivated under irrigation–is an example.

Causal loop diagrams are also used to capture the positive and negative feedbacks in the system. Positive feedback loops tend to magnify the impact of changes in the system (for instance, from total stock of land under foodgrain cultivation to an increase in land under cultivation in the subsequent period) and provide the system with the ability to grow over time. Negative feedback loops act over time to negate the influence of disturbances (for instance, a growth in population would impact negatively on per capita foodgrain availability). The model is described by a set of mathematical equations that define the relationships among the variables and run at annual intervals of time. The system variables are discussed below.

[2]The mathematical model and its numerical simulation are done using VENSIM software.

2.1.1 Stock Variables

(i) Area under food crop cultivation

Total area under foodgrain cultivation (Area FC) is impacted by the change in area under cultivation in each period. This change is determined by the relative profitability (RP) of cultivation of foodgrain versus non-foodgrain, while controlling for the effect of other variables. In each period, the Area FC in the previous period provides a causal feedback influencing the Area FC in the current period. An independent flow variable is also specified to capture shifts in technological (or institutional) progress.

(ii) Food Production

The stock of foodgrains produced is determined by the yield and the Area FC. Both these flows are distinguished on the basis of irrigated and non-irrigated cultivation.

2.1.2 Flow Variables

Change in Area under cultivation and Relative profitability

A change in the area under cultivation for food crops is an impact that arises due to changes in RP of food versus non-food cultivation in the model.[3] Profitability for foodgrains (as also non-foodgrains) is defined as the ratio of total revenue to total economic cost. It incorporates both the managerial costs and the imputed valuation of own factors of production such as rental on land and wages for own labour. The RP of foodgrains as a ratio to non-foodgrains is subsequently calculated.

2.2 Subsidiary Econometric Model[4]

The parameter for change in area due to change in RP is estimated using a subsidiary econometric model. The variables used in the estimation are relative profitability, rainfall, irrigation, relative share of primary sector in the economy and educational infrastructure. A panel data estimation is conducted, and a fixed effects

[3]The use of profitability as a factor in determining changes in area under cultivation for a particular crop has been debated in the Indian context. However, note that in the present formulation, it is relative (not absolute profitability) that is being defined; key variables that input into decision making are captured in the subsidiary econometric model. Recent literature finds that the allocation of land resources is increasingly driven by a price responsive non-foodgrain sector in agriculture, including crops such as sugarcane and oilseeds.

[4]A detailed description of the econometric model and its use in deriving temporal and spatial variations in climatic impacts by crop and region is provided in Dasgupta (2013).

model is performed as well. The Nerlovian framework[5] is adopted with area in the previous period impacting area cultivated in the current period. A recursive estimation on profitability is done to estimate the impact of the change in RP.[6]

Area under Irrigated and Non-Irrigated food crop cultivation

The parameter for proportion of land irrigated is used to distinguish between cultivated area under foodgrains which is irrigated and that which is not. This separates the total area under foodgrain cultivation in each period.

Yield for irrigated and non-irrigated cultivation

Similarly, parameters are taken for yield in irrigated areas as distinct from yield in non-irrigated areas. These yield variables are then interacted with their respective areas under cultivation to obtain the total foodgrain production in each period.

Population

Population is given from outside the system. Total production of foodgrains, aggregated across irrigated and non-irrigated cultivation, is used with time series data on population to arrive at the per capita production in each period.

Constraints

The model also specifies constraints, to accommodate realistic assumptions and targets for the future on key input variables.

Figure 1 presents the stock–flow diagram of the model.

System Equations

The mathematical structure of the model that follows from the previous text is as follows:

- Area FC (t) = *f* (Area FC(t − 1), Change in Area FC)
- Change in Area FC = *f* (Change in Area due to change in RP, Change in RP, Technology)
- Proportion of land irrigated = *f* (Initial value, Time)
- Irrigated area under foodgrain = *f* (Area FC, Proportion of area irrigated)
- Non-irrigated area under foodgrain = *f* (Area FC, Irrigated area under foodgrain)
- Food production = *f* (Irrigated area under foodgrain, Yield from irrigated area under Foodgrain, Non-irrigated area under foodgrain, Yield from non-irrigated area under foodgrain)
- Per capita production = *f* (Food production, Population).

[5]The use of Nerlovian adaptive and partial adjustment to model supply response has been used widely in the empirical literature for estimating agricultural production.

[6]Elasticity being defined as change in proportionate area due to a proportionate change in relative profitability (Δ Area/Area)/(Δ RP/RP).

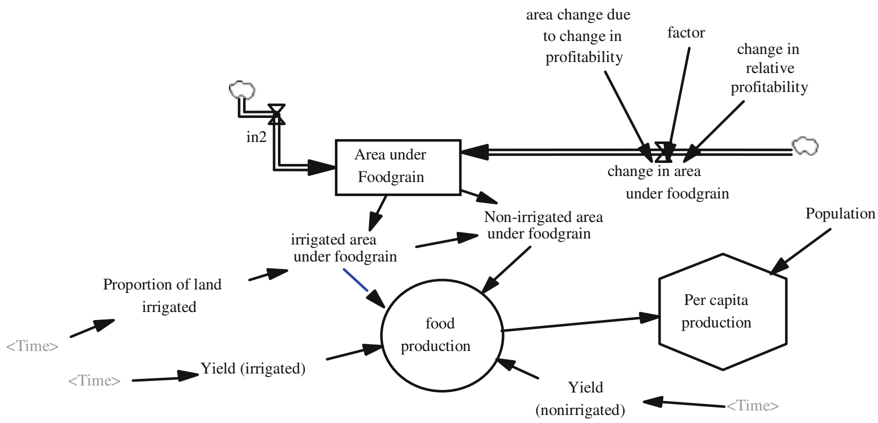

Fig. 1 Environment–economy stock–flow model

Subsidiary econometric equations:

- Area under food crop = *f* (relative profitability, rainfall, irrigation, educational infrastructure, relative share of primary sector)
- Relative profitability = *f* (relative profitability in past period)
- Yield= *f* (average of past 3 years, decadal growth rate).

Alternative mathematical formulations have been used in the study to arrive at the best representation. Time-bound target values are specified for the maximum proportion of area cultivated that can be under irrigation at different points in time. Logistic growth curves were fitted as appropriate to incorporate limiting cap values, for instance, in the case of proportion of area under cultivation for foodgrains. Constraints are also defined for changes in yield in irrigated and non-irrigated areas under cultivation. To retain flexibility for incorporating shocks to the system that may cause turning points to occur, quadratic functions were fitted for the yield and proportion of area under irrigation beyond 2030 for accommodating climate change impacts. An exogenous time variable captures factors that may impact the scenario but remain otherwise unspecified in the formulation.

The model allows the incorporation of several non-environmental factors including geographic, technological, economic, social and demographic ones. While some variables are taken as exogenous in the model, others are determined within the model. The model formulation allows the identification of critical variables that will influence the system and can be used as policy variables to influence outcomes in the future. However, in view of the model being a simplification of a complex real-world situation it has its limitations, being restricted to the specific context of the present study.

2.3 Scenario Construction

Several alternative runs were made. Four alternative scenarios which were finally selected as relevant for the analysis are presented here. The scenarios allow for the calculation of the costs of climate change through a comparison of with and without climate change scenarios. The model is simulated over the period 2004–05 to 2050 in deriving trajectories for the movement of specific variables.

(a) Reference Economic Growth Scenario (Reference Scenario)

The scenario is based on parameter values, time frames and assumptions that are considered as per current trends and expectations for the future. There are no major deviations from the trend growth rates. Thus, this scenario does not allow for nonlinear (major) changes over time in the key variables influencing the model, say, through either technological or policy changes and nor does it take into account the impacts of climate change.

(b) Accelerated Economic Growth Scenario

As compared to the reference scenario, this one allows for a higher level of productivity and achievement of targeted performance levels in converter variables (such as proportion of area irrigated) earlier than currently planned for. Technological, institutional and policy changes, envisaged here, lead to changes in crop yield and increased water use efficiency.

Both these scenarios are subsequently simulated allowing for variations in climatic factors. Two scenarios are generated thereby, which are based on simulations that incorporate (a) projected changes in area under cultivation due to projections on changes in precipitation and (b) projected changes in yield due to predicted changes in temperature. While the former impacts through the subsidiary equations, the latter changes the yield parameters used in the model. This has direct impacts on area cultivated and on yield. Thus, these scenarios vary due to the incorporation of time series data on projections of rainfall and temperature over the time period under study, for all the states included in the study. The two scenarios are labelled as follows:

(c) Climate Change in Reference Growth: Realistic Scenario

(d) Climate Change in Accelerated Growth: Optimistic Scenario.

3 Data and Assumptions

3.1 Estimation and Simulation of the Model

Parameter values were estimated or collected from existing studies and available sources of information in the public domain. Initial values were provided for the variables. The information spectrum included a wide range of sources including time series and cross-sectional data, statistical and econometric estimations based on these, and expert estimates from secondary sources.

The model was first run to get the reference mode, with the simulation result matching the target pattern. The model was run several times with variations in parameter values, particularly those which had a range of values attached to them. The robustness of the model was established, with the same general pattern emerging in spite of variations in parameter values. Variations were made by assigning different values to variables (such as the proportion of gross irrigated area) and sensitivity analysis done (Ford 1999). Thus, an iterative process was used to ensure that the model that was accepted generates a behavioural pattern where the stock and flow structure was reasonable and the causal loops helped in explaining the behaviour of the system in a manner that was consistent with theoretical expectations regarding these feedbacks.

To gain confidence in the model, validation checks were carried out (Forrester and Senge 1980; Kitching 1983; Richardson and Pugh 1981). Following Greenberger et al. (1976) to judge whether the model was able to closely reproduce data on observed past behaviour of the reference system, three types of validation were considered. Face validity was ensured as in repeated iterations for improving the model, the direction of the flows, and the signs of the parameter values were consistent with the expectations. The historical behaviour test was demonstrated since when inputs to the model were set at known past values, the model runs generated patterns that were found to correspond reasonably closely with the actual past observations/data on the key indicators for the agricultural sector. The extreme behaviour test was also used as reality checks could be performed. Major changes were made following these tests in certain parameter values[7], and the output was checked to confirm that the response of the model was a plausible one.

It is to be noted that the base year for which agricultural sector data was consistently available was 2004–05. Time series data on major food and non-food crops was taken for top ten major producing states for a time period of 35 years, from 1970–71 to 2004–05 (for more details see Dasgupta 2013).

For estimating profitability, data on the costs incurred for cultivation and the revenue earned were considered. The cost measure includes all expenses in cash and kind incurred in production by owner, the interest on value of owned capital assets (excluding land), rental value of owned land (net of land revenue) and rent paid for leased–in land, and the imputed value of family labour.[8] To account for the value of managerial functions performed by the farmer household, a markup is added in order to arrive at a full economic cost. Revenue is calculated as the sum of the value of the main product and the value of the by-product. Profitability for each foodgrain and non-foodgrain was computed for each state on an annual basis.

[7]Such as setting proportion of gross irrigated area as 0 or 100%.

[8]This measure corresponds to what is known as a C2 measure of costs as per cost of cultivation data published by the Government of India (GOI 2009).

Where multiple food or non-foodgrains are grown, weighted averages based on production were taken in computing the profitability for each group. Relative profitability was subsequently computed.

Data on various other variables, included in the baseline for 2004–05 and time series data for the econometric model, were gathered from various secondary sources (GOI 2007, 2008, 2009). For differentiating between yield from irrigated and non-irrigated lands for the same crop, the average yield level for a crop in states with maximum irrigation and the average yield levels in states with minimum irrigation were assumed as benchmarks.

3.2 Socio-Economic Characteristics

The socio-economic variables used in the model include urbanization, population, share of the primary sector in national income and educational infrastructure. The educational infrastructure variable is the percentage of villages having educational facilities and seeks to capture the effects of increasing education and awareness in the economy. Data on urbanisation and population projections are taken from the UN projections (UN 2009, 2010). The share of the primary sector in national income is based on estimates from the National Accounts Statistics (NAS 2008). The baseline and initial values for 2004–05 as used in the model are presented in appendix Table 3.

3.3 Data on Climate Variables

The Hadley Centre portable regional climate model (PRECIS—Providing Regional Climate for Impact Studies) provided data on climatic variables for 1960–2098. The raw data which was made available to the researcher[9] provided rainfall, temperature, relative humidity, wind speed at 10 m, transpiration, mean surface temperature and various other parameters at different timescales. For the present study, monthly data on Rainfall (in mm), Maximum Temperature (in °C) and Minimum Temperature (in °C) were extracted corresponding to the A1B SRES scenarios of the IPCC (IPCC 2000); annual and seasonal rainfall and temperatures were calculated across districts for each of the 10 states included in the present study.

The A1 scenario postulates rapid economic growth and rapid introduction of new and more efficient technology, low population growth and substantial reduction in regional differences in per capita income. The A1B scenario has a balanced emphasis on all energy sources. This scenario was selected, given the current

[9]The raw data on climatic variables were provided under the NATCOMM project. Model data represent grid cell averages over a 2500 km^2 (50×50) grid cell.

outlook and long-term planning for the Indian economy which seeks to increase the share of renewable energy in total installed capacity, alongside a substantial dependence on fossil-based sources for purposes of the near- and short-term future (till 2030).

3.4 Impact on Yields

A number of studies are available on the impact of climate change on yield of various crops. These have mostly been based on crop simulation models linking climatic factors such as temperature to plant growth processes. A range of estimates have emerged with majority of the findings showing adverse impacts on productivity of crops under increased temperature conditions. For purposes of the current study, region- and state-specific impact estimates for temperature changes of 2 °C or more were considered relevant for estimating yield changes in the climate change scenarios. Estimates for changes in rice and wheat yields for a 2 °C rise in temperature (Aggarwal and Mall 2002; Aggarwal and Sinha 1993; Geetalakshmi and Dheebakaran 2008; Hundal and Kaur 2007; Saseendran et al. 2000) fall in the range 11–28% for wheat in northern India; 10–15% for rice in southern India; and 7% for rice in northern India. Wheat yields fall by 20 kg/ha/°C as per one recent estimate (Aggarwal and Rani 2009). Coarse cereals and pulses have been relatively less researched (Mandal 1998; Chatterjee 1998) but nevertheless lend themselves to fair evidence on a 10–15% fall in production.

3.5 Simulation Assumptions

In the reference mode, the model is run assuming stability of the recently observed structural patterns and expectations in the economy. For obtaining the impacts of climate change, the model is simulated with alternate parameters estimated from changes in area cultivated due to changes in rainfall and projections of climate change impacts on yields. It is assumed that population growth is as per the low fertility projections of the UN and this remains invariant to the scenarios. A logistic growth curve is fitted for the proportion of cultivated area under irrigation, reaching a maximum of 65% by 2050. Improvements in water use efficiency in agriculture are assumed to be as per the preceding decade for the reference scenario. For the accelerated growth scenario, the target of the National Water Mission (NWM 2009) to achieve 20% improvement by 2020 is adopted, and extended further to 30% by 2050. Based on existing trends and projections, the proportion of area irrigated is assumed to reach 65% by 2050 in the reference case while the same is achieved earlier in the accelerated growth scenario. Although a maximum of 75–80% irrigated area can theoretically be set, this is considered infeasible in practise (FAO 2012).

An alternative run for an accelerated growth scenario allows for several features in promoting higher agricultural productivity for foodgrains. There are three main channels for this: by allowing technological change (reflected through changes in cropping intensity and yield); through institutional change (improvement in water use efficiency by 20% in 2020 and by 30% thereafter over and above trend rates of growth, and a closing of gap between actual and potential yield); allowing the gross irrigated area to reach a maximum potential of 65% by 2030 instead of 2050.

4 Results

4.1 Climate Change

Average annual rainfall did not show very large deviations from past trends over the run timelines. The standard deviations were also low. However, seasonal variations were observed for some states. For temperature, apart from Andhra Pradesh and West Bengal, the eight other states did not show more than 2 °C rise in temperature till 2030. In 2040, Andhra Pradesh, West Bengal and Gujarat experienced 2 °C or more rise in temperature, whereas for 2050 this was observed for Gujarat, Haryana, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh and West Bengal (see Appendix Table 4).

4.2 Scenarios for the Agricultural Sector

Table 1 presents findings for two time points, 2030 and 2050, from the reference growth and accelerated growth simulations in the absence of climate change. Foodgrain production is higher by approximately 8 and 7% in 2030 and 2050, respectively, for the accelerated growth scenario.

Notwithstanding this, there are significant shortfalls in per capita foodgrain production during the major part of the time period. The per capita production figures fall short of most existing estimates on targets for per capita foodgrain consumption (223.35 kg as per XIth plan; GOI 2001, 2008). The difference between the reference and accelerated growth scenarios widens till 2040, and subsequently declines, recovering to 2030 levels by only about 2050, with the accelerated growth scenario production being approximately 16 kg per capita higher than in the reference case. The year-on-year picture till 2030 is presented in Fig. 2.

There is a marked difference in per capita food production between the two scenarios. The reference case clearly indicates a fall in per capita production, primarily driven by growth in population, till about 2025 followed by a just visible

Table 1 Scenarios for agricultural production

Variables	Reference growth scenarios		Accelerated growth scenarios	
Year	2030	2050	2030	2050
Foodgrain production (million tonne)	261.55	306.58	284.03	329.13
Total Area under foodgrain (million ha)	125.01	129.67	127.91	144.39
Proportion of area irrigated	0.55	0.65	0.65	0.65
Water use efficiency improvement	As per preceding decade		20% improvement by 2020; 30% thereafter	

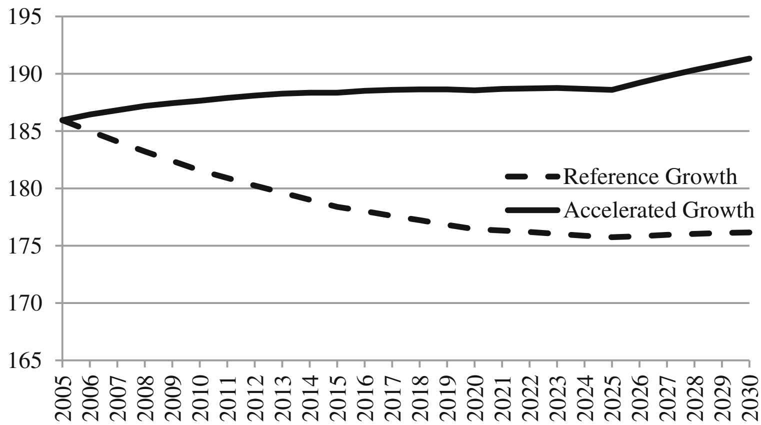

Fig. 2 Per capita foodgrain production without climate change impacts

turning point thereafter. In contrast, in the accelerated growth scenario, per capita foodgrain production rises and in fact markedly so after 2025–2026.

4.3 Climate Change Impacts

Changes in climatic factors impose costs on the economy through adverse impacts on foodgrain production. Changes in parameter values for rainfall and temperature in the model can impact both directly or indirectly, such as on gross cropped area and yield or on water use efficiency and irrigation. As reported earlier, literature suggests that the changes in yield due to changes in temperature are likely to be adverse in aggregate, and changes in seasonal rainfall can potentially impact area cultivated. Deviations between the reference scenario and the same scenario incorporating climate change impacts increase by 2.43 times between 2030 and 2050 and persist at 1.82 times for the accelerated growth scenarios. The four

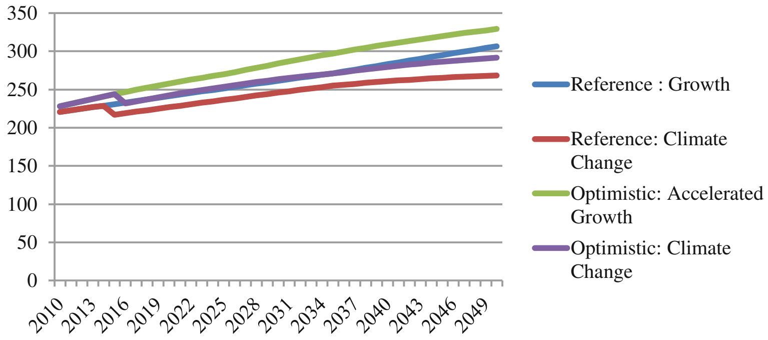

Fig. 3 All India foodgrain production under alternative scenarios (million tonne)

scenarios under discussion are presented in Fig. 3. It shows that yield changes impact crop production till 2030, with marginal changes in area cultivated. More pronounced impacts operate through changes in area under cultivation along with yield changes by 2050.

The implication seems to be that the dependence on imports would increase substantially with the incorporation of climate change impacts. Annual shortfalls in per capita availability, attributable to climate change, vary from 9 to 15 kg for 2030 scenarios and 27 kg for the 2050 scenarios. In percentage terms, incorporation of the climatic change impact creates a shortfall from the target consumption level of approximately 21–15% for 2030 and 13–6% for 2050, across the selected scenarios.

5 Conclusion

Falling foodgrain production at state and regional levels is likely to emerge from 2030 onwards due to climate change. Although it does not seem to have a major impact at the national (aggregate) level, the impact is none the less significant in terms of a deteriorating per capita availability of food. The results indicate that by 2050, several states will be affected including UP, West Bengal and Madhya Pradesh which have accounted for a large number of food insecure people in the country over the years. Taking account of impacts due to climate change converts a healthy state of a surplus of 19.1 million tonne into a dismal state of a deficit of 18.5 million tonne by 2050 in the accelerated growth scenario.

Comparison across scenarios with and without climate change simulations allows the imputation of the implicit costs of climate change. The costs of climate change emerge as clear deviations from the desired paths in our model. These can be alternately specified in terms of total foodgrain production, per capita foodgrain production and the imports that would be required to make up for any shortfalls or deficits in meeting desired consumption targets. Table 2 summarises the deficits.

Table 2 Production, requirement and shortfalls in agricultural foodgrains

Scenarios	Year	Production (million tonne)	Requirement[1] (million tonne)	Deficit (million tonne)
Reference growth scenario	2030	261.55	312.02	50.47
	2050	306.59	310.01	3.42
Reference growth with climate change	2030	245.86	312.02	66.16
	2050	268.45	310.01	41.56
Accelerated growth scenario	2030	284.03	312.02	27.99
	2050	329.13	310.01	−19.12
Accelerated growth with climate change	2030	263.31	312.02	48.71
	2050	291.47	310.01	18.54

[1]The foodgrain requirement has been calculated on the basis of the target for consumption as per the eleventh plan document. The XI Plan states 223.35 Kg per person as the requirement. Total requirement is calculated by multiplying population (low variant) with this target value. Deficit is the difference between requirement and production

Despite variants with growth factors built into the model, foodgrain production is majorly impacted at the aggregative level, with a fall of 15.7–20.7 and 38.1–37.6 million tonne in 2030 and 2050, respectively, attributable to climate change. In other words, a loss in production of 7.3 and 11.4%, respectively, for 2030 and 2050 is implied in the most optimistic case with accelerated growth factors built into the model. Shortfalls between target consumption and foodgrain production naturally widen. Note that these shortfalls occur despite a fall in the total requirement due to falling population. In terms of crops, output in paddy growing areas is adversely affected early on (Andhra and West Bengal being two major producers), followed by major impacts in areas growing wheat and other coarse cereals by 2050.

The reference scenarios and the accelerated growth scenario are distinct from each other in several ways. While the reference scenario is constructed using past trends and likely values for key parameters based on expert studies, the optimistic case creates a scenario in which it is feasible to go beyond current trends through technology or policy interventions. These could range from higher public investment in research and development, extension activities and interventions leading to intensification of input use such as improved water use efficiency or technological progress beyond past decadal trends in parameters such as increase in yield or cropping intensity and a higher overall GDP growth rate. It also allows for profit-based incentives to determine allocation of land to food versus non-food cultivation, and through macro considerations that determine access to land for cultivation purposes in competition with different sectors in the economy such as urbanisation and industrialization. The findings are meant to be indicative, of the alternative choices that can be made and the implications of interactions between the socio-economic variables, even as the climate variables are held. Appropriate interventions to impact these variables can provide the potential for adapting to the costs posed by climate change and transitioning to sustainability as for instance articulated in India's Nationally Determined Contribution (NDC 2015). There is a two-way link between sustainability and adapting to climate change. While achieving the SDGs independently of climate considerations maybe possible for certain states at specific time periods, sustaining the gains maybe and ensuring that these are not eroded over time requires careful consideration of the climate impacts and accordingly putting in place adaptive responses.

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Appendix

Table 3 Baseline Values for India (2004–05)

Area under foodgrains (million hectare)	120
Proportion of irrigated area under foodgrain	0.44
Irrigated area under food (million hectares)	53.04
Average yield for foodgrain in irrigated area (kg/hectare)	3031
Average yield for foodgrain in non-irrigated area (kg/hectare)	1158
Total gross cropped area (million hectare)	190.42
Gross irrigated area (million hectare)	80
Cropping intensity	1.35
Average growth rate of yield (1994–95 to 2005–06)	1.49%
Decadal change in cropping intensity (1995–96 to 2004–05)	0.023
Population (million numbers)	1095
Sectoral share in GDP—Primary:Secondary:Tertiary	22.4:24.03:53.56
Foodgrain production (million tonne)	198.4
Urbanisation	27.8%
Educational infrastructure index (1999 base)	1.124

Note The population estimate for 1st October provided by the Registrar General of India was adjusted to capture the period 2004–2005

Table 4 Temperature changes under an A1B scenario

State	2030	2040	2050
Andhra Pradesh	+	+	
Gujarat		+	+
Haryana			+
Karnataka			
Madhya Pradesh			+
Maharashtra			
Punjab			+
Rajasthan			+
Uttar Pradesh			+
West Bengal	+	+	+

Note + denotes a temperature increase of 2 °C or higher by the corresponding year

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Part II
Institutions for Environmental Governance

Analyzing Institutions in Resource and Development Econometrics: Recognizing Institutions, Exploring Levels, and Querying Causes

Vikram Dayal

1 Introduction

Many resource and development economists use econometrics and microeconomic theoretical models but do not explicitly use institutional economics. Often, their formal training, like mine, does not include institutional economics. They may, like me, have read institutional scholarship and feel that institutions are important. For example, one type of institutions—norms—is of fundamental importance in the labor market, with implications not just for the labor market but also for the wider economy (Solow 1990):

> I want to make the case that the labor market really is different … it cannot be understood without taking account of the fact that participants, on both sides have well developed notions of what is fair (p. 3) … Among economists, it is not obvious at all that labor as a commodity is sufficiently different from artichokes (p. 4).

Economists wanting to be more inclusive need to do things differently. Schmid (2004) discusses different methods of institutional analysis, claiming that econometrics and case studies are equally valid, a view shared by Rodrik (2008). Here, I concentrate on certain issues at the intersection of resource economics, institutional analysis, and econometric analysis. We can begin an institutional analysis by recognizing institutions (Ostrom 2005). After we recognize institutions, we have to convert them into variables before we use econometrics to analyze them. Among institutional scholars, Ostrom has stressed multiple levels through her career; the paper by Gibson et al. (2000a, b) details questions of scale and associated levels in different disciplines. I link the theoretical aspects of multiple levels with the statistical technique of multilevel modeling. Although economists frequently use panel data econometrics, they use multilevel modeling with cross-sectional data less

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often. Recent years have seen a great renewal in questions of causality, and economists have come to rely on experiments and quasi-experiments, while structural equation models have been a key area in traditional econometrics. I draw on recent developments in causal graphs (Morgan and Winship 2007) to discuss causal issues.

I suggest the following three strategies to further institutional analysis in resource and development econometrics, which I discuss in turn in the paper: (1) recognizing institutional variables; (2) using multilevel thinking and estimation; and (3) drawing causal graphs. I will illustrate these strategies with examples from the following three previously published studies: (a) referred as "Firewood extraction study" (Dayal 2006); (b) "Air pollution study" (Das et al. 2009); and (c) "Carbon and livelihoods study" (Chhatre and Agrawal 2009). I was the author of the first study and a co-author in the second.

In the "Firewood extraction study," Dayal (2006) studied the extraction of forest biomass by village households. A microeconomic model of the decisions regarding levels and sources of extraction of forest biomass was developed. Biomass extraction behavior in a sample of 227 households living in, and close to, Ranthambore National Park, India, was empirically examined. An empirical measure of spatial aspects of extraction was investigated. Village location, ownership of biogas, and caste were key variables explaining forest biomass extraction.

In the "Air pollution study," Das et al. (2009) developed a theoretical model to guide the empirical examination of data on time allocation and exposure in different microenvironments (outdoors, indoors, cooking, and workplace); and to study the effects on respiratory health. Their sample was drawn from different clusters with different histories and extent of mining in the state of Goa, India. They found that age and gender played a significant role in time allocation. Households that used biomass fuels only were likely to experience indoor concentrations of air pollution that were greater than outdoor concentrations. Factors affecting fuel choice were education, wealth, and availability. Finally, after accounting for endogeneity and measurement error, they found that the use of biomass fuel and smoking were statistically significant factors explaining chronic respiratory symptoms, even when they accounted for exposure indoors, outdoors and in the workplace.

In the "Carbon and livelihoods study," Chhatre and Agrawal (2009) focused on factors that affected trade-offs and synergies between the level of carbon storage in forests and their contributions to livelihoods. They found that larger forests were more effective in enhancing both carbon and livelihoods outcomes, particularly when local communities also had high levels of rule-making autonomy. They used the International Forestry Resources and Institutions (IFRI) research program's data drawn from different countries.

In this paper, I will be intuitive and informal, and will discuss different theory and data interactions related to resource and development econometrics.

2 Recognizing Institutions

Vatn (2005) distinguishes between three different kinds of institutions: conventions, norms, and formally sanctioned rules. According to Vatn (2005), there is a tension between the individualist and social constructivist positions in the social sciences. Perhaps we can see this in terms of the direction of causality between individuals and institutions. Hodgson (2000: 326) writes: “In the writings of Veblen and Commons there is both upward and downward causation; individuals create and change institutions, just as institutions mold and constrain individuals.” Ostrom (2005) says that the institutional analyst has to probe beyond the surface; the analyst has to recognize institutions that are often intangible, and not easily measurable. Alston (1996) also draws attention to the difficulty of observing institutions quantitatively, pointing out that we may not have good numerical data on institutional changes, and may have to rely on historical records.

The difficulty of observing institutions was a matter of debate in the carbon storage and livelihoods study. It aimed to study institutions (Chhatre and Agrawal 2009) using variables such as rule-making autonomy and ownership. Observing rule-making autonomy quantitatively is difficult, and Chhatre and Agrawal (2009) used perceptions of rules by users, and assumed that when it was “about the right level of conservation,” the variable “AUTONOMY” equaled one, and “AUTONOMY” was otherwise zero. Ternstrom et al. (2010) objected—autonomy should not be assumed—and appeared to think that the variable underlying autonomy reflected sustainability. Chhatre and Agrawal (2010) responded that the underlying variable was the perception of rules. I think the perception of rules is a crucial variable. The debate between Tersntrom et al. (2010) and Chhatre and Agrawal (2010) draws attention to a feature of regression analysis: We are often forced to compress something varied and complex into something binary. While analyzing institutions quantitatively, we often translate a subtle social process into a variable. If prior thought about institutions goes into the research design, we can use a more nuanced approach—Chopra and Gulati (1998) captured the evolution of institutions over time by making distinctions in dummy variables.

Even though institutional analysis was not an objective of the fuelwood case study (Dayal 2006), it contained important institutional elements, especially caste. The fuelwood extraction study examines the fraction of a household’s extraction of fuelwood from Ranthambore National Park. The study recognizes that a household can choose to source its gathered fuelwood from private land, village common land, and the national park—it does not assume that a household near a forest will only extract fuelwood from the forest. This is modeled in the microeconomic theoretical component (first stage: level, second: source/where) that guided the empirical analysis.

Dayal (2006) regressed the fraction of fuelwood sourced from Ranthambore National Park on the following explanatory variables:

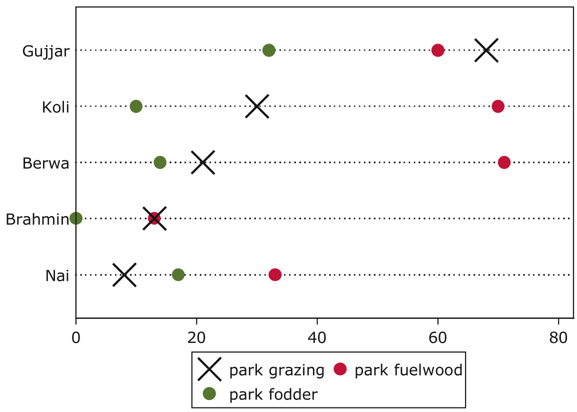
- caste dummy (Brahmin), statistically significant at 1% level;
- village dummy (Indala), also statistically significant at 1% level;

- quantity of land, statistically significant at 10% level; and
- housetype (a proxy for wealth), household size, fraction of males, cattle owned, goats owned, all of which were not statistically significant.

These results motivated a closer examination of the role of castes. There are several difficulties in analyzing castes. An economist using a microeconomic model and econometric analysis is uncomfortable with the bewildering variety of castes encountered in the field. Because the multivariate regression analysis could only use a dummy for one or two castes (here Brahmin and low caste), the analysis treats the variety of castes in a coarse manner. In another paper, Dayal (2008) conducted a nonparametric small sample investigation of diverse castes in one village. This paper (Dayal 2008) did not have a formal model and did not use sophisticated econometrics. It showed that there was plenty of heterogeneity among the castes in their biomass extraction patterns (fuelwood, fodder, and grazing; see Fig. 1).

During the analysis, my mind went back to conversations in the field—to a key respondent saying that Gujjars were very comfortable with rearing goats, and to a Brahmin respondent who said that his cows gave him high yields, and he knew more than the other castes about this. In the microeconomic model of Dayal (2006), caste does not have a role, and it enters the econometric model because applied economists control for "household characteristics." We recognize caste as a social norm that operated with great force in the traditional rural economy. It is a slow-moving variable, with zero measurement error, in contrast to other variables, and that partly explains its statistical significance. Caste and ecology have coevolved over centuries in much of India (Gadgil and Malhotra 1998). Dasgupta (2011) reminds us that this evolution can have a dark side, for as he says, "exploitation can masquerade as cooperation." Reflection on caste helped me appreciate the tension in the social sciences between the individualist and social constructivist positions (Vatn 2005).

Fig. 1 Caste and use of park (Faraya Village)



3 Using Multilevel Thinking and Estimation

Intuitively, we can relate to levels and their role in different processes. For example, a child studies along with other children in a class, and different classes are nested in a school. The child's learning is an outcome of the child as an individual at a lower level, but also by the nature of the school at a higher level.

We can be more specific about levels by first thinking about scales. Gibson et al. (2000b) define scale as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon. They define levels as the units of analysis located at the same position on the scale. They distinguish between conceptual levels and spatial levels. For example, international treaties are at the conceptual level of constitutional choice and spatially at the international level, while buying land is at the conceptual level of operational choice and spatially at the level of the household. According to hierarchy theorists, understanding a complex system requires zooming in and out to a higher and lower level. We can enrich economic analysis by examining institutions at different levels.

In the example case studies, the units of analyses are nested in higher levels. In the fuelwood paper, households are nested in villages. In the air pollution paper, individuals are nested in households that are nested in villages that are nested in mining clusters. In the carbon and livelihoods paper, forests are nested in countries.

In the fuelwood case study (Dayal 2006) in Ranthambore National Park, we can think about levels related to caste and the Wildlife Act (Fig. 2). The legal rule, the Wildlife Act, determines the boundary of the Park. In the air pollution study (Das et al. 2009) in the mining regions of Goa, the institutions are the mining regulations and gender norms related to cooking (Fig. 2).

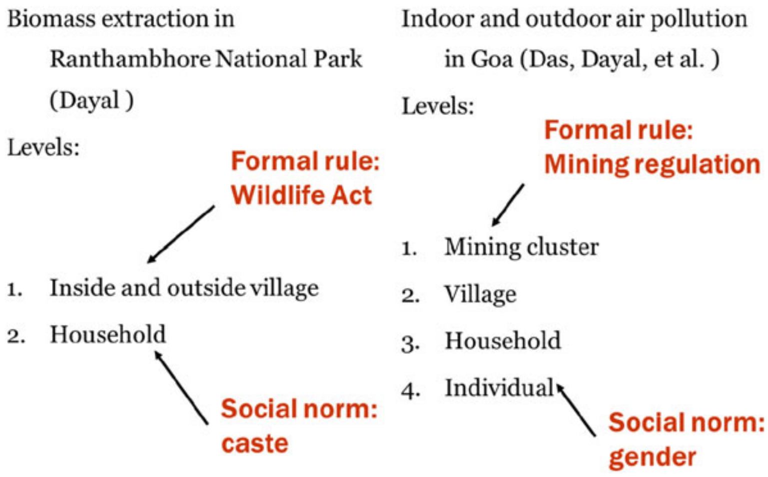


Fig. 2 Levels and institutions in the fuelwood and air pollution case studies

We can use statistical multilevel modeling to examine institutions at different levels. Multilevel modeling generalizes regression methods, and can improve prediction considerably (Gelman 2006). Intuitively, one can think of a simple regression of y on x, with an intercept. The observations on x may come from different groups, and we could run a simple pooled regression where we ignore the grouping. We could then use a simple multilevel model where the intercept of the simple regression varies by group.

Multilevel modeling also helps us unpack variation into between and within groups—Fig. 3 shows that the variation in carbon storage between countries is substantial in comparison with the variation within countries. The bold line in the boxes shows the median. The median for India and that for Mexico differs greatly. The width of the box shows the interquartile range. Graphically, we can see that the difference in values between India and Mexico is substantially relative to the variation within these countries.

More sophisticated and detailed multilevel models can be used. I will only provide an example from Luke (2004): with reading score of a child as the dependent variable (*Y*), study time put in by the child (*X*), and size of class (*W*). A possible multilevel model would be:

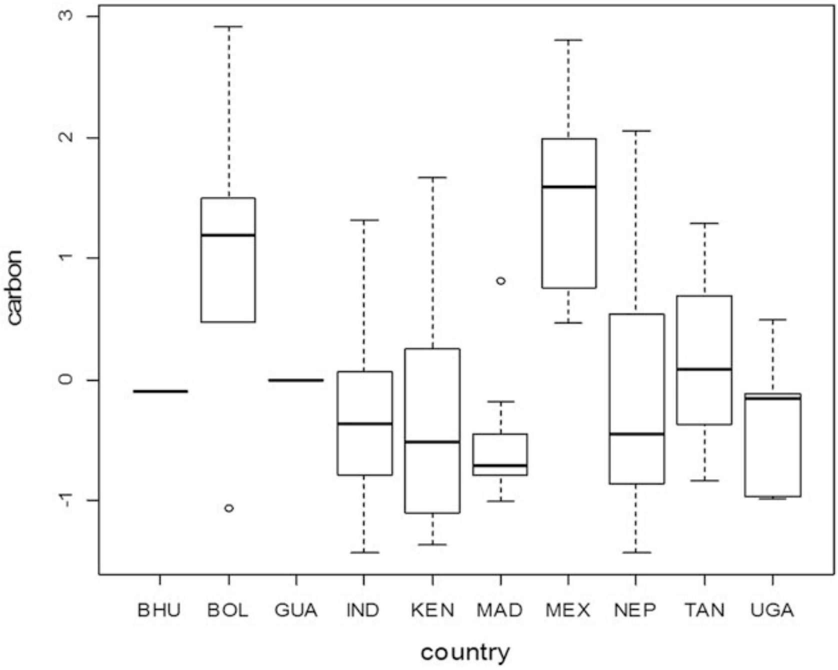


Fig. 3 Box plots of carbon storage by country, data from Chhatre and Agarwal (2009)

$$\begin{aligned} \text{Level 1}: Y_{ij} &= \beta_0 + \beta_{1j}X_{ij} + r_{ij} \\ \text{Level 2}: \beta_{0j} &= \gamma_{00} + \gamma_{01}W_j + u_{0j} \\ \beta_{1j} &= \gamma_{10} + \gamma_{11}Wj + u_{1j} \\ i \text{ indexes children}&;\ j \text{ classrooms} \end{aligned}$$

The slopes and intercepts in the Level 1 equation can vary across classrooms. Luke (2004) says that there are theoretical and statistical reasons for using multilevel variables. Because phenomena are multilevel and depend on context, there is a theoretical justification. Because regression coefficients can vary across contexts and errors can be correlated within contexts, there is a statistical justification.

All three examples—the fuelwood study, the air pollution study, and the carbon storage and livelihoods study—do not use multilevel modeling. The carbon storage and livelihoods study has 10 groups, and if the number of groups at the higher level is small, as in the fuelwood study (four villages), multilevel modeling is not useful. While we can get richer predictions with multilevel modeling, Gelman (2006) cautions that if we are using observational data, we may not be able to interpret the results causally.

4 Drawing Causal Graphs

4.1 Causality and Causal Diagrams

When we advocate certain policies, we are implying that they will have certain effects; we are asserting not merely associations but also causality. We can distinguish between regression that is predictive or descriptive (conditional expectation) and causal. Econometric textbooks often do not discuss causality. However, several texts do. Gelman and Hill (2006) and Stock and Watson (2010) make a clear distinction between models for prediction and for causes.

Economists often think of the causal issue in terms of the identification of the parameters of a structural equation. Manski (2006) provides an example of an identification problem relevant to this paper. People in groups tend to behave similarly; this could be because of group norms (i.e., endogenous effects) or because they have similar characteristics and environment (correlated effects). To achieve identification in such problems, empirical observations by themselves are not enough. We can divide the problem of inference into statistical and identification components. The identification component consists of what we can or cannot conclude even with unlimited data. The statistical component is about how sampling variability affects our conclusions. Manski (2006) stresses that identification is more fundamental.

Causal graphs help us see causal issues, which are easier to see but harder to resolve. Some statisticians, like Freedman (1991), have warned us about the pitfalls of using regression analysis for causal inference. Freedman (1991) praised John Snow's careful work on cholera, which relied on field work and logic rather than statistical technique.

What questions we ask and how complex the systems we are studying determine how difficult causal analysis is. For example, we can contrast the following two questions: (1) Does providing school bags or blackboards have a greater effect on educational outcomes versus (2) What are the causes of deforestation in different countries?

According to Greenland and Brumback (2002), there are four major types of causal models that are complementary. First, graphical models can illustrate qualitative population assumptions and sources of bias. Second, sufficient component cause models can illustrate hypotheses about mechanisms of action. Third, potential outcome (or counterfactual) models can provide a basis for the quantitative analysis of effects. Fourth, structural equations models can provide a basis for quantitative analysis of effects.

Greenland et al. (1999, 38) advocate using causal diagrams because they avoid making strong parametric assumptions, and instead focus on causal direction. I like causal graphs because they help me "see." They are qualitative, so statistical detail does not swamp me. Since I have used system dynamics-type simulation, I am aware of causal feedback loop diagrams. I think causal graphs can foster communication between different groups of scholars.

Spirtes et al. (1993) and Pearl (2000) are key publications in the modern development of causal graphs, more specifically, of directed acyclic graphs used for exploring causality. Pearl (1999, 1) emphasizes the distinction between causal thinking and probability theory:

> The word *cause* is not in the vocabulary of standard probability theory. It is an embarrassing yet inescapable fact that probability theory, the official language of many empirical sciences, does not permit us to express sentences such as "Mud does not cause rain"; all we can say is that the two events are mutually correlated, or dependent—meaning that if we find one, we can expect to encounter the other. Scientists seeking causal explanations for complex phenomena or rationales for policy decisions must therefore supplement the language of probability with a vocabulary for causality, one in which the symbolic representation for the causal relationship "Mud does not cause rain" is distinct from the symbolic representation for "Mud is independent of rain."

To summarize, we use probability thinking for empirical work, but causal thinking requires us to put in a directional arrow: rain → mud.

Two relatively accessible and applied expositions move between the models of causality that Greenland and Brumback (2002) discuss. Shipley (2000) moves between structural equation models and causal graphs in biology; and Morgan and Winship (2007) move between the potential outcome model and causal graphs, with examples from social science. I draw a lot on Morgan and Winship (2007) while discussing causal graphs, and also later, when I discuss the interpretation of an instrumental variable.

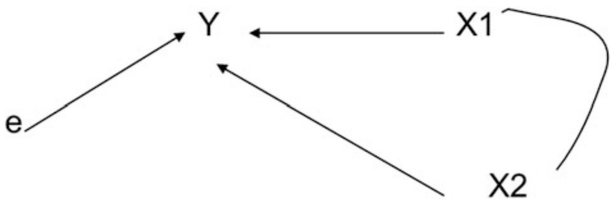


Fig. 4 Implicit causal graph for regression $Y = a + b\ X1 + c\ X2 + e$

A regression $Y = a + b\ X1 + c\ X2 + e$ can be interpreted predictively or causally. Predictively, we say the regression gives us the conditional expectation of Y. If we interpret it causally, we have in mind an implicit causal graph (Fig. 4), and whether this causal interpretation is correct depends on whether the implicit causal graph is correct for the situation that we are studying. If the causal pathways are not as represented in Fig. 4, then the causal interpretation is problematic.

Following Winship and Morgan, if we want to explore the effect of *X* on *Y*, we can list the key ingredients of causal graphs as follows:

- Common cause (controlling for *M*, the common cause, will block path): $X \leftarrow \mathrm{M} \rightarrow \mathrm{Y}$
- Mediator (controlling for *Z*, will block path): $X \rightarrow \mathrm{Z} \rightarrow Y$
- Collider (controlling for *B*, opens path): $X \rightarrow B \leftarrow Y$

Whether we should control for a variable depends on whether it is a common cause, a mediator, or a collider. However, we need to see the causal graph as a whole. Figure 5 illustrates three specification options for studying the effect of *X* on *Y*, given the causal graph.

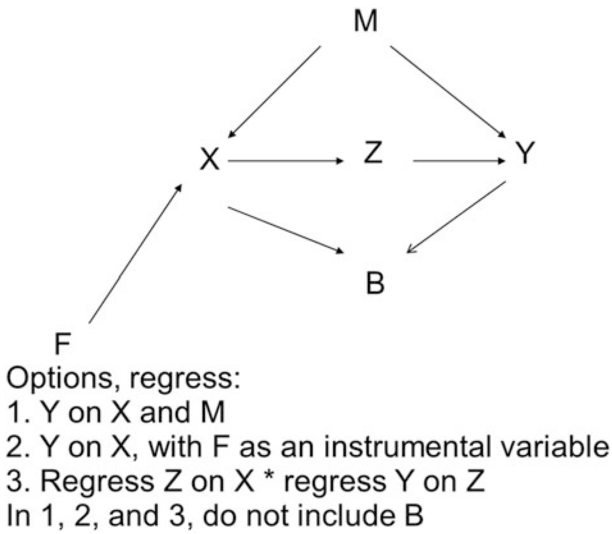


Fig. 5 Possible regression specifications while estimating the effect of *X* on *Y*

An example helps us to understand the intuition for excluding the collider. Petrol in the tank of a car and very cold weather are uncorrelated, but are common causes of a car not starting. The car not starting is the collider. Whether there is petrol in the car or not tells me nothing about cold weather. But if my car is not starting, and there is petrol in the tank I can guess that it is cold weather that is the cause. Petrol in the tank conditional on knowledge of the car not starting is not independent of cold weather.

Thus, directed acyclic graphs can be used to understand specification, the use of instrumental variables, the design of experiments, etc. However, they are not cyclic, i.e., do not include instantaneous feedback, and feedback complicates causal enquiry by this means (Shipley 2000). This is a serious limitation, for according to Dasgupta (2009) feedback is central to resource and development economics, for example, to understand how poverty may persist in world that is experiencing economic growth. Structural equations modeling can handle instantaneous feedback. Feedback is central to system dynamics, which simulates causal stock and flow structures, with the simulations based on a spectrum of information—case studies, experiments, etc. Timmins and Schlenker (2009) argue that structural modeling and reduced-form modeling are complementary with one advantage of the former over the latter being its ability to engage with feedback processes. Chopra and Gulati (1998) had used a structural equations system to capture some of the feedback aspects.

However, we can overcome this problem of representing feedback if we can make the time ordering explicit and we can slice time. In such situations, the instantaneous cyclic representation can be converted into a an acyclic one: Instead of $X \leftrightarrow Y$, we can have $X1 \rightarrow Y2$ and $Y1 \rightarrow X2$, where 1 and 2 represent time.

4.2 Causal Issues in Chhatre and Agrawal (2009)

Chhatre and Agrawal (2009) appear to interpret their regressions in causal terms, and talk about causal pathways, etc. In an empirical enquiry, we could think of a causal graph, but where would that come from? It could be from a microeconomic model or theory. However, different disciplines have different styles of theorizing and tend to concentrate on certain kinds of causal pathways. People from different disciplines could brainstorm and think about possibilities.

For illustration, I thought about Chhatre and Agrawal's (2009) paper, used my past work (Dayal 2006) and knowledge of similar economic studies (e.g., Pattanayak et al. 2004), and drew on Gibsonet al. (2000a). In Fig. 6, there are different categories of pathways: institutional, economic, sociological, contextual, and biophysical. The causal link (I1 in Fig. 6) between rules in use and extraction and thereby forest stock is one of the key insights of the volume about *People and Forests* edited by Gibson et al. (2000a). Schweik (2000) found that institutional factors—such as the caste system and monitoring of rules—along with factors such as distance and geographical barriers played a role in the spatial distribution of

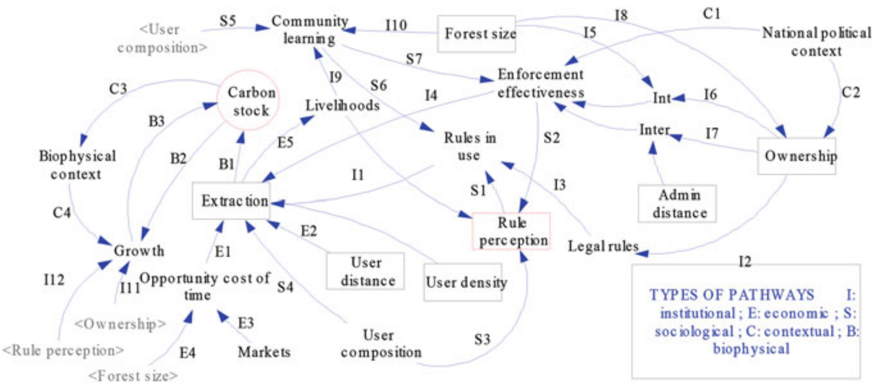


Fig. 6 Variety of pathways linking livelihoods and carbon

Shorea robusta in the Chitwan District of Nepal. Agrawal (2000) studied village forest councils in Almora District in India. He empirically found that smaller forest councils were less successful in collective action than larger forest councils—suggesting the causal paths I5 and I6 in Fig. 6. Economic studies such as those by Pattanayak et al. (2004) and Dayal (2006) emphasize the causal pathway E1. The variables that are enclosed in Fig. 6 are observed in the Chhatre and Agrawal (2009) dataset. We could decide to focus on how carbon stock is affected by rule perception. So carbon stock is in a circle. We can then focus on pathways relating to these variables. It might be fruitful to do a causal EDA, i.e., explore data with a causal graph such as Fig. 6.

Apart from the numerous causal pathways, there is also the issue of complicated feedbacks, and also the issue that some causal arrows might be time and context specific. Also, there might be path dependence and evolution.

At times, some pointed potential outcome-type studies can be done (e.g., Somanathan et al. 2009); these focus on potential outcomes, and abstract from the diverse causal processes. In clinical trials of a new pill, the pill is ingested, some complex things happen inside the treated person, over some time, and the person's headache may or may not be cured, and we may be satisfied with the causal inference that on average the pill cures headaches.

4.3 Reinterpreting a Causal Tool (Instrumental Variable)

I now move to an intriguing example using the air pollution study—an institutional reinterpretation of the instrumental variable meant to unpack causality. Das et al. (2009) worked several summers trying to examine the effect of total exposure (indoor plus outdoor, etc., weighted by time spent). We struggled because it was not "right" in our judgment; we knew we had measurement error, and we suspected

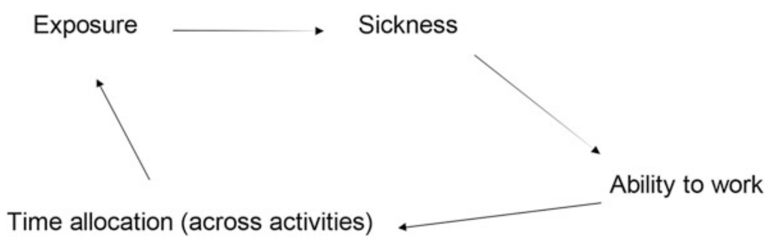


Fig. 7 Endogeneity of exposure with respect to sickness

endogeneity. In Fig. 7, exposure is a cause of sickness which is a cause of the ability to work, which in turn affects the allocation of time and exposure. And then we saw the paper by Pitt et al. (2005), which uses female hierarchy as an instrumental variable. We used the same instrumental variable, and our empirical results were now fine. In the theoretical model we used, like Pitt et al. (2005) we assumed that the household was optimizing. That guided the empirical research. Things appeared satisfactory, and we felt triumphant.

However, Agarwal (1997) wrote a detailed paper discussing how, although economists have improved on unitary models by developing bargaining models of the household, they may neglect social norms. Social norms, Agarwal (1997) maintains, are exogenous in the short run but endogenous in the long run, and (1) set limits to the domain of bargaining, (2) determine bargaining power, and (3) influence the conduct of bargaining. Agarwal (1997: 2–3) has a methodological suggestion:

> I both use and emphasize the usefulness of what I term ‘analytical description’ for capturing the complexity and historic variability of gender relations in intra- and extra-household dynamics. By analytical description I mean a formulation that seeks to comprehensively spell out both qualitative and quantitative factors that might impinge on outcomes, without being preconstrained by the structure that formal modeling imposes, or by data limitations.

Similarly, Akerlof and Kranton (2010) argue that gender matters in the workplace in the USA, and argue that careful observations rather than statistical tests are more enlightening in studying identity. Following Friedman’s (1953) ideas about “The Methodology of Positive Economics” broadly, Das et al. (2009) did not worry about whether the household was actually optimizing; what mattered was the prediction or getting the regression “right.” But the efficacy of the instrumental variable—female hierarchy—should make us ponder, and I think it lends support to a view of the household, in tune with the role of norms and identity.

A disadvantage of an analytical description could be that we may be uncomfortable about its validity. So that should ideally inform the design of further studies. In a fine paper on “Behaviour, Environment and Health in Developing Countries: Evaluation and Valuation,” Pattanayak and Pfaff stress the importance of social interactions, and the difficulty in identifying them empirically (2009).

5 Conclusions

Though experiments and quasi-experiments are sweeping economics, observational data is rich with different processes, and slow-moving variables related to institutions might have the time to leave their imprints in cross-sectional data. Norgaard (1989) had pleaded for methodological pluralism. We need to recognize institutional variables, which may not exist in our theory, and may be hard to measure. Institutional variables may be there in our regressions, but need to be interpreted carefully. We can balance the tension between macro and micro, agency and structure, to some extent with multilevel modeling. We can describe data with regression, and graphs and multilevel models can help. We can use causal graphs to help further understand causal paths. We can exploit thick descriptive historical case studies (when we expect path dependence), sociological studies (that may report on social construction), potential outcome studies, simulation studies of social ecological systems (that may make some strong causal assumptions), and synthesize from these. Two of the most outstanding resource and development economists can be our inspiration. Ostrom has used varied methods, including meta-analysis of case studies with the Institutions and Development Framework (see Ostrom 2009), while Dasgupta (1993) made use of ideas and information drawing on such varied disciplines as anthropology, demography, ecology, and economics while using theoretical models.

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Environmental Management: Choice Between Collective Action and Government Action

M. N. Murty

1 Introduction

It is well known that the presence of economic externalities creates problems for market efficiency. Externalities are present when decisions of consumers (producers) affect other consumers (producers) over which the latter have no control. The externality problems arise most prominently in use of environmental resources[1] either as producer goods (inputs in production) or as consumer goods. We call them as environmental externalities. The examples of the former are water pollution by paper and pulp industry and air pollution by coal-fired thermal power generation. The examples of the latter are solid waste from households and chlorofluorocarbon (CFC) emissions from air conditioning.

I was a colleague of Professor Kanchan Chopra at Institute of Economic Growth (IEG), Delhi for almost three decades. From the very beginning of pursuing research at Delhi School of Economics (DSE), we both had a common research interest in Social Cost Benefit Analysis. Since her Ph.D. work on the subject precedes mine, I got maximum benefit from it. Ever since I joined IEG in early 1980s my research interest has gradually been shifted from Public Economics to Environment and Resource Economics. This in turn helped me since Professor Kanchan Chopra and some other colleagues at IEG have already chosen this subject as an area of their research. We have done successful collaborative research at IEG on the subject matter of this paper which has produced a book entitled 'Participatory Development' and some research papers published in international journals.

[1]By this term, we mean resources of natural origin.

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The presence of environmental externalities results in the violation—in one way or the other—of all the conditions that are to be fulfilled for the competitive equilibrium to be Pareto optimal.[2] These violations—which are widely acknowledged in the literature—arise from three sources: (a) the problem of missing markets, (b) asymmetric information and (c) non-convexity in production and consumption. They are discussed below.

1.1 Problem of Missing Markets

A lucid and clear exposition of missing markets or incomplete set of markets in the economy (when environmental externalities are present) could be found in Kenneth Arrow's thought experiment involving a hypothetical economy with consumption externalities.[3] Consider the externality in the form of smoke arising out of consumption of a good by an individual. Here, smoke becomes a separate individual specific commodity differentially affecting utilities of each. Thus, consumption of a commodity generates a new set of commodities as there are a number of individuals. In an economy with N number of people and M consumer goods, the presence of consumption externality results in having $N \times M$ commodities with as many markets. Alternatively, each consumer of a commodity is also a producer of N commodities. The competitive equilibrium of this hypothetical economy is Pareto optimal *only* with $N \times M$ well-functioning markets.

Arrow points out that any Pareto-optimal allocation may be sustained as a competitive equilibrium with an appropriate price, associated with each and every commodity. If we interpret externalities as additional commodities in this way, they can be accommodated within the framework of competitive equilibrium theory for fulfilling the first fundamental theorem of welfare economics.[4] Conversely, equilibrium may fail to yield Pareto optimality in the absence of a sufficiently rich set of markets.

The reasons for the absence of such markets are (a) the absence of property rights and (b) the high cost of operating such markets. If the cost per unit transacted exceeds the difference between supply and demand prices, voluntary transaction will not take place and it follows in turn that the existence of a competitive market becomes difficult if numbers of buyers and sellers are small. In Arrow's framework, each commodity has only one buyer and one seller.

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[2] See Bator (1958).

[3] See Arrow (1969).

[4] It states that if every commodity can be exchanged in a market, a competitive equilibrium is Pareto optimal.

1.2 Asymmetric Information

The presence of environmental externalities in the economy makes availability of information about characteristics of goods and individuals uncertain. As a result, consumers and producers fail to act in a manner so as to take welfare maximizing decisions. This leads to a situation of asymmetric information in which only one of the agents, either a consumer or a producer having full information about the characteristics of commodities and actions of people. As is well known, the presence of asymmetric information in the economy creates two types of problems: moral hazard and adverse selection for market efficiency.[5]

People demand environmental quality by expressing their respective willingness to pay directly for environmental improvements or indirectly by paying relatively higher prices for commodities produced with clean technologies and also by encouraging firms using these technologies through buying their equity capital at a relatively higher price. Under the presence of uncertain information, the adverse selection problem may arise if buyers could not distinguish between clean and dirty products so that producers of clean products could not be offered higher prices to compensate for the additional cost of production. Buyers offer only average or expected prices for cleaner products which eventually drive the respective producers out of market.[6] A moral hazard problem may arise if people could not observe the activities of firms engaged in natural resource conservation or environmental quality management. In this case, firms doing a better environmental management could not be provided with the required incentives either by the public or the government in contrast to those firms that are not doing it. Consider an example of insurance market for firms offering them an option to insure against environmental risks for accidents. Moral hazard problem occurs when the insurer has uncertain information about precautions that the firms are to take to avoid accidents. In this case, firms have incentives to be biased towards making choices of high premium and high insurance coverage combinations and not taking adequate precautions to avoid accidents.[7]

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[5]Adverse selection problem arises when characteristics of commodities and individuals are not observed in the market. Moral hazard problem could be there when activities of people are not observable.

[6]Akerlof (1970) was the first to explain the asymmetric information and adverse selection problem with a lucid example of US market of used cars (lemons). If buyers could not distinguish between used cars and new cars in the market, they offer only an expected market price for cars, thus eventually driving new cars out of market.

[7]Arnott and Stiglitz (1988) have shown that in this case the moral hazard problem creates non-convexity in firms' choices of combinations of premium and insurance cover.

1.3 Non-convexity

Mere presence of environmental externality could create the problem of non-convexity in both production and consumption. Consider an economy producing two private goods—the production of one of them is causing air or water pollution. Example of one such combination is production of laundry services and air polluting electricity generation; a second one is harvesting of fish by fisherfolks from a lake and pollution from paper and pulp production reaching the same lake. The laundry can spend on indoor driers to avoid the damage from air pollution; similarly, fisheries can spend on lake cleaning to avoid reduction in fish production. Given the resource constraints, the level of production of private goods in each case is determined by the strength of externality of the respective pollution.[8] The strength of externality in this context can be taken to measure the mean addition to the resource cost of cleaning a given batch of laundry (harvesting a tonne of fish) that occurs when an added unit of electricity output (a tonne of paper) causes smoke (lake pollution) to increase. For a given amount of polluting commodity produced, an increase in the strength of externality means that with a given amount of electricity and given amount of resource, a smaller amount of laundry output can be produced than before. As the strength of externality increases, the production possibility set of two private goods becomes non-convex. As it increases further and takes a very high value that corresponds to very high amount of smoke or lake pollution, no quantity of resource can get laundry clean and fisheries to produce fish. It is a case of irreversibility in production caused by a very strong pollution externality.

The hypothetical economy of Arrow's thought experiment considering separate markets for externalities as commodities is Pareto optimal if these markets exist in reality as discussed earlier. However, even in such an economy, mere presence of non-convexity in production can make it difficult to attain Pareto optimality. Considering pollution as a commodity along with laundry services and fish production in earlier examples, there remains a possibility, however, for existence of markets and market prices for pollution with the property right of pollution assigned either to polluting agent or to the agent affected by pollution. Given the property right to clean air to laundry, it has an incentive to sell this right (increase the supply of pollution) at a price in the market. There could be a market equilibrium at which supply and demand for pollution are equal. However, this is not a stable equilibrium since there could be always an incentive for the laundry to sell all its rights to pollution and maximize its profits by exiting from the market and production. Thus, the feasible production set defined in the space of laundry services and pollution is non-convex. This is known as fundamental non-convexity[9] in the literature that is caused by environmental externalities.

[8]See Baumol and Bradford (1972).

[9]See Starret (1972).

The literature suggests various regulatory instruments that can be used by the government (taxes and permits) and by the communities (collective action) for ensuring market efficiency in this context. Collective action, in particular, has the potential to successfully deal with many problems that one encounters for the efficient management of environmental resources. For instance, it offers decentralized solutions with low transaction costs in comparison with very high transaction costs of regulatory instruments in the disposal of the government. Further, while the presence of problem of asymmetric information creating moral hazard and adverse selection could make the regulatory instruments inefficient, it may not pose the same problem vis-à-vis the collective action. In short, collective action could ensure both production and environmental efficiency even in the presence of non-convexities in producer and consumer choices involving environmental resources.

The literature shows that the collective action-based instruments and institutions could successfully deal with two closely related problems created by environmental externalities: management of both pure public goods (air and water quality) and collective goods or impure public goods (common grazing lands, common lake fisheries, common groundwater aquifers, etc.). Samuelson (1954) defines public goods as goods of joint consumption with non-excludability and indivisibility properties. On the other hand, collective goods are goods of collective provision and collective use by a group of people. They are known as common pool or common property resources in the literature having characteristics of both public and private goods.[10] Like private goods, they are divisible and rival in consumption but like pure public goods they are non-excludable. Because they are non-excludable the externalities associated with the supply and use of these resources create familiar free rider problem.

Ronald Coase's original contribution to deal with the problem of social cost (Coase 1960) through bargaining by two groups of people (polluters and affected people) and ensuing the literature on this subject shows that collective action could be successfully used to deal with pure public goods type of problems.[11] The literature that started with the pioneering work of Olson (1965) that expressed pessimistic views about the management of collective or semi-public goods by a group of people has moved a long way. Contributions of Wade (1987, 1988), Ostrom (2000) and Chopra et al. (1999) among others[12] have provided empirical evidence contradicting Olson. The role of collective action and participatory approaches for the sustainable use of environmental resources is better understood now. It has particularly assumed importance due to a rather limited success of government centred environmental policy instruments. The recent literature on the subject christens collective action as informal regulation by local communities and groups of people. A large number of studies provide empirical evidence for success of informal regulation in efficiently controlling industrial pollution and management of

[10] Cornes and Sandler (1984, 1989).

[11] Also, see Nlebuff (1997).

[12] See Wade (1987, 1988), Ostrom (2009, 2000) and Chopra et al. (1999).

common property resources. This paper while attempting to provide a brief review of the literature of the subject provides some insights into the potential use of collective action in dealing with a wide range of environmental management problems.

Section 2 describes briefly the regulatory instruments of taxes and permits used by government and the reasons behind their failure to adequately deal with the problems of asymmetric information and non-convexities. Sections 3 and 4 discuss the role of collective action in dealing with collective goods and pure public good type of environmental externalities, respectively.

2 Government and Environmental Externalities

The most prominent instruments that national governments traditionally use for regulating environmental externalities are pollution taxes and subsidies (Pigou 1962); more recently, it has been marketable pollution permits (Dales 1968). These instruments are designed to create markets for environmental externalities for addressing the problems of missing markets and asymmetric information discussed above. They could—potentially—make the competitive equilibrium Pareto optimal even in the presence of environmental externalities. Pollution tax provides incentive to the producer for reducing pollution to the optimum level by making the tax liability higher than the cost to abate pollution. Marketable permits provide opportunities to the producers to trade in pollution permits. Such possibilities are higher the larger is the difference between the costs of reducing pollution between the two polluters. This instrument minimizes the cost of achieving optimal level of pollution. The choice between these instruments depends both on their efficacy in achieving the target level of emissions and on the relative size of welfare losses they result in.[13]

There are two main problems that limit the efficacy of taxes and permit instruments:

(a) Complete Pareto optimality could not be attained by using either of these instruments in the presence of asymmetric information. In this case, there could still be welfare losses in comparison with a Pareto-optimal state. This means that there could be only Pareto improvements by using these instruments.
(b) They are ineffective to deal with the problem of non-convexity (discussed above).

It is known that the choice between tax and permit instruments will depend on how the costs and benefits of pollution abatement change with the level of pollution and the degree of uncertainty about costs and benefits. It is shown in the literature that for the presence of uncertainty about the measurement of benefits and costs of pollution abatement, there will be efficiency losses with both tax and permit

[13] See Baumol and Oates (1988).

instruments. Efficiency loss is less for pollution tax in contrast to the permits if marginal cost of abatement function is relatively steeper than marginal benefits of abatement function; it is less for permits in contrast to tax if marginal benefits function is relatively steeper than marginal cost function.[14]

For example, if there is uncertainty or incomplete information about pollution abatement cost functions of producers, for its inability to distinguish between a low-cost and a high-cost producer, the regulator (government) is faced with the adverse selection problem in the matter of taking a decision on pollution tax. In this case, there are incentives for high-cost producers to declare itself as a low-cost producer for reducing its tax liability, while a low-cost producer has no incentive to declare itself as a high-cost one. The literature suggests that a mixed instrument consisting of a tax on and a payment to the polluters can make the tax instrument efficient. However, the payment made should be higher than the tax savings of high-cost polluter that arise from providing incorrect information. But this payment should not be higher than the extra tax liability to low-cost producer by declaring itself as a high-cost producer.

An example of incomplete information creating moral hazard problem could be found in solid waste management where the regulator (municipality) may know the total quantity of waste to be disposed but could not distinguish between the wastes disposed safely and unsafely.[15] A general tax on waste to be disposed cannot ensure safe disposal of all the waste. It could create an incentive to unsafe disposal only if there are cost savings net of tax from unsafe disposal. The literature shows that a mixed instrument consisting of a tax on waste to be disposed and a subsidy for safe disposal reduces efficiency losses. This subsidy should be at least equal to the cost savings net of tax from unsafe disposal.

Next, consider the policy instruments of tax and permits for climate change mitigation.[16] Uncertainty and incomplete information about benefits and costs of reducing greenhouse gases could be a serious problem in making a choice between these instruments. The marginal benefit function is flatter in the short run given smaller reductions in emissions and steeper in the long run given larger reductions in emissions. On the other hand, the marginal abatement cost function is steeper in the short run and flatter in the long run owing to technological progress over time in abating greenhouse gases. Incomplete information about quantity of emission reductions from climate change mitigation and technological changes over time could make instruments of carbon tax or tradable permits inefficient. This suggests use of carbon tax in the short run and tradable permits in the long run as policy instruments for climate change mitigation. However, the most debated problem of doubts about the relationship between greenhouse gas emissions and climatic change in the scientific world could make the choice between these instruments difficult.

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[14]See Wietzman (1974, 1978).

[15]See Kolstad (2004).

[16]See Stern (2006).

As explained above, the regulatory instruments of government action are inefficient in dealing with many real environmental externalities problems. The regulations of using mixed instruments to deal with specific problems are infeasible due to high transaction costs. The failure of government action in many country contexts could be also attributed to doubtful quality of government. The collective action as described in the following sections is found to be successful in dealing with environmental externalities in all-weather situations.

3 Collective Action and Collective Goods

3.1 Evolution of Theories

Market inefficiency in the management of environmental resources arises because these resources supply public goods and collective goods type of services, as discussed earlier. Olson (1965) argues that due to the free rider problem, provision and use of collective goods voluntarily by individuals to achieve their group interest are not possible and there is a need for coercion by an outside agency to achieve this objective. In his own words: '…when a number of individuals have a common and collective interest—when they share a single purpose or objective—individual unorganized action[either will] not to advance that common interest at all, or will not be able to advance that interest adequately' (Olson 1965, p. 7).

Aristotle himself highlighted this problem of non-cooperation: 'what is common to the greatest number has the least care bestowed on it'.[17] Hardin (1968) explains this phenomenon as 'tragedy of commons'[18] which may happen when the rate of exploitation of a resource exceeds physical or biological rate to renew itself. In other words, in the case of management of commons, the free rider problem frustrates the voluntary collective action. The literature quite lucidly explains the free rider problem as a two-person prisoners' dilemma game. This non-cooperative game shows that even though the strategies (cooperate, cooperate) in limiting resource use for both the parities provide higher benefits to both, they both end up choosing (defect, defect) strategies of unlimited use of the resource that provide lower benefits to both.

Olson argues that the probability of a successful collective action in a group depends on group characteristics. The problem could be better understood by explaining the free rider problem in the management of collective goods with help of N person non-cooperative game. Three types of groups are considered by Olson: privileged, intermediate and latent. A privileged group is a small group in which one or two members receive disproportionately high benefits from the collective good. It is like a centralized provision of producing optimal amount of a collective good by one individual without any organization.

[17]As pointed out in Ostrom (2009).

[18]Here, the word 'commons' used by Hardin refers to open access resources given that the term 'common property' refers to an efficiently managed resource in the current literature.

The intermediate group on the other hand consists of a small number of individuals who could coordinate their actions for a successful cooperation. For the group being small, the actions of an individual can considerably affect the benefits of the other members. This in turn provides incentives for strategic interactions between individuals as in repeated prisoners' dilemma type of games. The folk theorem suggests that in such repeated games with interaction between individuals and credible punishments, rewarding and monitoring the probability of cooperative outcome may increase.

Latent groups being too big could not have cases of individual actions that can considerably affect the benefits of others in the group. For the incentives necessary for a strategic interaction between members in repeated games being limited, the supply of the collective good may be nil. The institutions for bestowing rewards for cooperation and imposing sanctions for non-cooperation are absent here due to negligible effects of each individual's actions on others. In short, the repeated non-cooperative prisoners' dilemma game with a large number of players for the provision and use of collective goods—as in this case—produces a non-cooperative equilibrium outcome with a zero supply of the collective good. That means that the collective action in a larger group context is frustrated by the free rider problem.

However, there is evidence in the literature that the provision of collective goods is in fact possible in many cases even with larger or latent groups. It is contrary to the theoretical prediction of a Nash non-cooperative game.[19] This happens when some mechanisms help or incentivize people even in a larger group to cooperate. There are number of studies in the literature looking into such mechanisms that govern the group behaviour for successful cooperation in managing collective goods. One such mechanism is to overcome the non-excludability problem through selective incentives. A pertinent example of positive incentives is offering group members a private good for consumption subject to the fulfilment of the condition that each member supplies a minimum amount of collective good—it can avoid free riding by making exclusion possible. Not adhering to the norm could deprive the individual or the household of private good consumption (exclusion), while adherence to it could provide more benefits/utility than to not adhering. Negative incentives like imposition of sanctions in case a group member is not providing at least a threshold level of collective good could also make the cooperation possible even in the case of latent group a la Olson.[20]

Possibility of provision of collective goods in larger groups has been shown by analysing strategic behaviour of people as in the case of dynamic games incorporating repeated interactions among players in the presence of required institutions to contain free riding. The Nash equilibrium in infinite games with repeated unlimited interactions of members in the group is shown to predict cooperation even in a larger group.

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[19]See Ernesto (2003) for a good discussion on this evidence.

[20]For experimental evidence, see Fehr and Gächter (2000).

The institutional approach to tackle the free rider problem considers the incentives to players to cooperate towards the provision of collective goods. In a two-person non-cooperative game, a player has two incentives to defect: for the fear of getting the lowest pay-off (by cooperating) when the other defects and for the greed to get the highest pay-off when the other cooperates. Therefore, an institution that controls defection (fear or greed) in either way may control the free rider problem it is argued. The literature points to a couple of institutional mechanisms that can undertake this.[21] One such mechanism is a kind of 'money-back' policy (returns the individual's contribution in case the other does not cooperate) that eliminates the 'fear' of receiving the lowest pay-off. Second is a system of 'enforced contribution' (a fine such that defecting while other cooperates does not result in higher pay-off than in the case of cooperation) that may eliminate a player's 'greed'. Many other institutional alternatives for dealing with the free rider problem can be found in the literature.[22] A particular mention may be made to those studies that show that if the domain of individual preferences also contains social aspects such as ethical concerns and well-being of others,[23] the free rider problem in the provision of collective goods could be overcome without invoking institutional mechanisms described above.

3.2 Institutional Characteristics for Successful Cooperation

A number of empirical studies found evidence for some communities creating institutions that facilitate cooperation in the provision and use of collective goods through rules. Some of the pioneering studies highlighting the requirements for successful cooperation include Wade (1987), Chopra et al. (1999), Ostrom (2009) and Baland and Platteau (1996). Wade (1987) and Ostrom (2009) term them as operating principles and design principles, respectively. Some others, for example Chopra et al. (1999), Murty (1994) and Kadekodi (1998), called them as limits to collective action.

Some of the institutional characteristics identified for successful cooperation in these studies are as follows:

(a) The characteristics of user groups: the presence of a smaller user group (Olson's intermediary group) with well-identified boundaries or the presence of a more powerful subgroup (Olson's privileged group) who receives relatively more benefits from the resource,
(b) Institutional arrangements for discussion of common problems and the extent to which users are bound by mutual obligations,

[21]See Dawes et al. (1986).
[22]See Agrawal and Goyal (2001).
[23]See Fehr and Fischbacher (2002).

(c) Mutually agreed rules for sharing of costs and benefits from the resource and using local rules to decide about the amount, timing and technology of harvesting and distribution of benefits in proportion to inputs provided by members of the group,
(d) Regular monitoring of participants actions and credible sanctions for violators of rules,
(e) Mechanisms to resolve conflicts and modifying rules to accommodate outside changes and
(f) The relationship between the State and user groups and nature and extent of acceptance on the part of the government vis-à-vis rights of local communities to the resource.

3.3 Some Examples of Successful Cooperation

Ostrom (2009) reported existence of communal tenures in Swiss villages dating back to early thirteenth century:

> Written legal documents dating back 1224 provide information regarding the types of land tenures and transfers that have occurred in the village and the rules used by the villagers to regulate five types of community owned property: the alpine grazing meadows, the forests, the waste lands, the irrigation systems, and path roads connecting privately owned properties. (p. 62)

It is reported that both communal and private land tenures coexisted with types of land tenures matching with the types of land use. Communal tenures are mostly confined to the relatively less productive lands, especially high mountain meadows and forests. It is also reported that in Japan common lands have regulated by local village institutions for centuries. In seventeenth and eighteenth centuries, rural villages in Japan have managed collectively as many as 12 million hectares of forests and uncultivated mountain meadows. Even now, millions of hectares of these lands have been managed by village communities in Japan.

In Indian context, Wade (1987, 1988) has reported successful cases of management of common property by village communities in South India. Also, there are evidences of successful management of forests and mountain meadows as common property in North-eastern India and Nepal and other countries in the Indian subcontinent. A detailed study by Chopra et al. (1999) provides evidence of successful collective action in the management of local village forest lands and pastures in foothills of Himalayas belonging to states of Punjab and Haryana in India. In the context of field studies reported in this study, Murty (1994)[24] writes

[24]Murty (1994).

(1) The preserved grass lands and forest areas in a village economy will increase the supply of fodder grass and forest produce. Unless, house-holds own sufficient live stock, the improved supply of fodder can not be converted into their incomes. Many rural households in the developing countries are not having adequate household assets to harness increased resources from collective management of commons.
(2) The community investment on irrigation dams and tanks are complementary to preservation for the irrigation potential of these structures depends upon the preservation of their catchment. Many village communities in the developing countries can not mobilize resources for these investments.
(3) Also, the household asset distribution is skewed such that only a few households can appropriate benefits from cooperation. For example, only land holding households get benefits from the community irrigation structures and therefore landless households have no incentive to preserve the catchment of these structures.
(4) Very high population growth rates within the communities managing common property resources will make the benefits from preserved resources to each member of the community negligible so that people have no incentive to voluntarily participate in preservation. (Murty 1994, p. 584)

Empirical evidence of evolution of common property regimes points to the processes of pooling open access and less productive lands for managing them as a common pool resource. Ostrom (2009) reports that private property regimes for managing productive lands and common property regimes for managing less productive lands are found to coexist for a long time in some village economies in Europe, especially in the management of irrigation systems. In a detailed study of some villages in Palamau district of Bihar state in India, Kadekodi (1998) has provided empirical evidence of institutional factors required for the evolution of open access resource as a common pool resource. This study also highlights factors similar to those mentioned above limiting the pooling of less productive lands for translating them as a common pool resource.

It follows that the failure of collective action to effect voluntary cooperation in the local village economies in many developing countries may be attributable to the presence of above-mentioned factors. Certainly, there are possibilities for an outside agency or government to act as an enabler in facilitating collective action in such situations. Subsidy towards creation of community assets that can complement preservation from the government or providing loan to village communities for such purposes is one such example. The other can be undertaking land reforms towards the same end. Provision of alternative livelihood opportunities 'in excess of threshold levels' by the government is another possibility. In each case, the government acts only as a facilitator and without engaging in any kind of coercion or an act that can infringe individual rights.[25]

Many examples could be found in the literature of how and which way a relationship between the State and user groups and nature and type of acceptance on the part of the State of rights of local communities over resource can matter for successful cooperation. A pertinent example is the involvement and participation of local communities in the forest management in some developing countries

[25]See Murty (1994) for details.

including India. Empirical evidence shows that nature of forest resource management is determined and influenced by the characteristics of different property rights regimes: State property, common property and private property.

These regimes differ with respect to primary decision-making units: for the State property regime, it is the government while for the common property regime it is the group of people. The experience in both developed and developing countries points to the lack of success for the former in managing the forest lands and other natural resources.[26] The literature suggests that it is due to the prohibitively high cost of 'policing' the forest lands without active and effective participation from the locals. With the population growth, the cost of policing increased too. As a result in most cases, a State property regime was turned into an open access regime.

For the State property regime to be the most predominant form of management of forest resources in many countries, field studies show that participation from the local communities in forest management is facilitated only when their interests are in sync with that of the government. Voluntary participation from the local communities may not warrant coercive action from the government as suggested by Olson; as argued earlier, its role can be limited to be a catalyst or just an enabler. A classic example of such a possibility is the system of joint forest management (JFM) in India. In it, people and government share the responsibilities of forest management. The bedrock of JFM is an agreement between the government and the people about the mutually beneficial sharing arrangements. The arrangement can be either on the allocation of property rights ranging from use to access or just for sharing the benefits from forest produce. In the latter case, the ownership rights remain with one of the parties. However, in most cases it remains with the government. Village communities having ownership rights over the spatially closer forests and grasslands and government having it for the distant location are one example of the former. There are instances where there is a quid pro quo agreement in which government allows sustained harvesting of forest produce by local communities in return for their participation in the preservation of forests. This is an example of the latter. The examples of both these types of arrangements are abundant in the developing countries.

Examples of managing irrigation systems as common property could be found as early as fifteenth century in Europe and some other places. About Huerta Irrigation Institutions in Spain, Ostrom (2009) reports about an agreement signed on May 29, 1435, by 88 irrigators benefitted by canals in Valencia, Spain, approving formal regulations for the managing irrigation as a collective good. In her words,

> these regulations specify who had rights to water from these canals, how the water would be shared in good years as well as bad, how the responsibilities for maintenance would be shared, what officials they would elect and how, and what fines would be levied against anyone who broke one of their rules. (Ostrom 2009, p. 73)

[26]See Bromley and Chapagain (1984) and Chopra et al. (1999).

She also points out some of these rules found in this agreement could be informally observed even in the earlier practices of irrigation management in the region.

Another example of managing irrigation as a collective good reported by Ostrom is about Zanjeera Irrigation Communities in the Philippines. The earliest reference for the existence of irrigation societies in the Philippines could be found in writings of early seventeenth century. The modern Zanjeeras could have drawn from a mixture of local traditions as well as experiences of Spanish colonial rule. The striking similarity between Spanish huerta and the Philippines zanjeera is the central role given to small-scale communities in irrigation. The contract signed by irrigators called 'sharing of land' allows landowner to retain ownership, while user rights are given to dependent farmers on the condition of continued maintenance of irrigation system managed by the latter.

Irrigation has been managed a collective good in many irrigation systems in India, especially in South India. In the context of managing collective goods either as State property or as a common property, empirical studies report the lower quality of management if government is a primary decision-making unit in comparison with the local community or a group of people. In a study of irrigation systems in India, Bardhan (2000) finds that the villages where State or a State agency decides on allocation, distribution and pricing of water among farmers are also the ones reporting more rule violations and lower contribution of farmers to the village fund.

4 Collective Action and Pure Public Goods Type of Externalities

4.1 Pure Public Goods Type of Environmental Externalities

In the collective goods problem discussed in the last section, collective action by a group of people means efficient provision and the use of the resource by the same group. In the case of many environmental externalities problems, there is a duality in the resource management, one group causing externality and another group affected by it (Coase 1960). There could be also multiple stakeholders to deal with environmental externality problems (Becker 1983). The groups of people who have stakes in the environmental resource being considered—polluters, affected people, politicians and bureaucrats—can work in tandem for efficient control of externality or efficient provision of public goods. These could be cases in which environmental externality creates problems similar to provision and use of pure public goods type of services.

4.2 Duality in Environment Management and Coasean Bargaining Problem

It was the seminal contribution from Ronald Coase (1960) that has argued that through creation of specific property rights among the concerned parties many types of externalities can be optimally controlled. For example, in case of air pollution, the property rights can be either with the affected party or receivers of pollution for enjoying clean water and air or with the producers and consumers or the generator of pollution to pollute the atmosphere. What is commonly known as 'Coase theorem' states that provided that if the property rights to the resource (say atmosphere or river) are clearly defined (either with the generator of the externality or to the affected party) and if the transaction cost of bargaining is zero or sufficiently close to it, bargaining between the two parties will result in the optimal control of externality. More importantly, the final outcome of bargaining is invariant to the initial distribution of property rights.

Arguably, there are several limitations for the Coasean bargaining to be practiced.[27] First under the more realistic positive costs of bargaining, the resulting pollution load (through bargaining) can be higher than the optimal one. Moreover, initial distribution of property rights will yield different levels of pollution load questioning the invariance axiom. Second, seldom all the externalities are captured in the value of property rights. It influenced the incentives for gainful bargaining. Admittedly, the 'theorem' can work for the externalities which are at a reasonably smaller scale and/or externalities are of local types with a limited number of pollution generators and receivers.[28] However, there are many environmental externalities for which none of these conditions are satisfied: they occur on a large*r* scale and usually are with many receivers and often with a reasonably large number of generators (e.g. pollution of a river and the atmosphere). This makes defining property rights and facilitating bargaining difficult. One of the ways of dealing this problem is through creation of a common property right to the river and two 'groups'. One of such groups can consist of all the affected people, while an association of polluters can be the other. This arrangement can improve chances of bargaining between the generators and receivers. This, by construction, increases transaction cost, causing the first problem. The third one arises vis-a-vis assigning of property rights for a resource. An environmental resource, in general, is a stock that affects the welfare of both present and future generations. For the absence of the latter group in the present bargaining process, it is often argued that it is difficult to ensure capitalization of future benefits. Considering the government as the representative of future generations can address this matter. More specifically, it can participate in the market for property rights on behalf of the future generation. Towards buying such rights, say, for clean air in the future, it can issue a debt

[27]See also Murty (2010).

[28]Coase's example of a building that blocks wind mill's air currents or a confectioner's machine that disturbs doctor's quiet, etc., is one such.

instrument to be serviced by the future generations. An alternative possibility is present generation having a bequest motive to the future ones vis-a-vis the resources. However, both these possibilities are outside the scope of Coase's framework.

As discussed earlier, there could be non-convexities in production sets with polluting commodities[29] and fundamental non-convexity in pollution reduction[30] that cause problems for using governmental instruments of taxes and permits. However, the non-convexity of pollution abatement cost function and benefits function from pollution reduction could not be a problem for collective action a la Coase for efficient control of pollution externality. The bargaining in Coasean case requires only the differences between total benefits and total cost of pollution reduction to start with but not the difference between the marginal benefits and marginal costs. As Nlebuff (1997) points out there is nothing marginalist in Coasean approach and in Coasean words, one should consider all the effects, 'those in the margin and those in total'.[31]

It follows that in the Coasean framework, government can have only a minimal role, just to create property rights and protect them. It is assumed that the bargaining between the agents can yield an optimal result vis-a-vis the externality. Following this approach, a number of institutional alternatives have been considered involving some elements of market mechanism with a limited role for the government. For the uncertainty on the part of the government to effect such a bargaining scenario and the transaction costs involved with government instruments, it may make sense to look for new institutions towards controlling environmental externalities. The collective action involving all the stakeholders of a given externality has been found to be one such new institution.

4.3 Collective Action: A Deterrent to a Colluding Industry and a Corrupt Bureaucracy[32]

A government action to address the problems of market failure assumes a benevolent role on the part of this institution. Reality in many developing countries and even of some developed countries questions such an assumption. In the case of control of pollution externalities, the corrupt bureaucracy (considered as a stakeholder) of developing countries has shown incentives to collude with the polluters (another stakeholder) in violating environmental standards; this exasperates the externality problem rather than controlling it. The industry simply bribing the regulator to misreport its effluent quality or not report it at all is one such

[29]See Baumol and Bradford (1972).

[30]See Starret (1972).

[31]See in Nlebuff (1997) example of half bell-shaped benefit function for lake pollution.

[32]The discussion in this section is drawn from Murty (1995).

possibility. In such situations, there is hardly any option left to the party affected by the externality (another stakeholder) other than taking recourse to collective action and to seek support of elected representatives (another stakeholder) for dealing with this matter. Becker (1983) has shown that the political influence exerted by pressure groups can have similar effects as having a benevolent government to deal with market failure.

> The same analysis of competition among pressure groups, without the introduction of social welfare function or benevolent government, explains expenditures on defence and other public goods, taxes on pollution, and other government activities that raise efficiency, even when some groups are hurt by the activities. (Becker 1983)

However, bargaining cannot be costless as Coase proposes, and the transaction costs are important in the world of Coase and Becker. Further, even in the presence of significant transaction costs, there are possibilities for significant net welfare gains from collective action. The case for collective action is stronger under a non-benevolent government is. Trajectory of industrial water pollution abatement in India offers some illustrations in this regard. Several decades since enacting environmental legislation, the government has not imposed either a pollution tax or pollution permits instruments. The command and control instruments that are being used are yet making any dent in the level of industrial pollution. Experience of many other developing countries is no different. Lack of awareness among the recipients of pollution about the extent of damage from it is one of the reasons. The inability of the recipients to organize themselves as pressure groups to participate in the decision-making on the management of pollution abatement is the other reason. Arguably, incentives for a sub-coalition of agents—like a coalition of affected people and elected representatives—exist. It follows that in case the presence of politically active pressure groups can be facilitated, competition among these groups can yield the optimal amount of pollution.[33]

4.4 Coase and Becker in Practice: Some Examples from India

Empirical evidence captured by a survey of some industrial estates in India[34] provides some glimpses on the presence of active pressure groups for the control of industrial water pollution. The survey offers insights into empirical aspects of the economic and non-economic processes leading to collective action in abatement of pollution. Such a collective action involved various agents like recipients of water pollution, elected representatives, industries, NGOs and the bureaucracy.

[33] See Murty (1995).

[34] A survey of 17 highly water-polluting industries in India conducted by the Institute of Economic Growth, Delhi, in 1996.

The survey reported deposit of untreated wastewater from factories in the industrial estates on surface and in local streams. The former resulted in the degradation of cultivable lands and the latter in contamination of groundwater. The impacts were obvious: locals suffering from crop and cattle losses besides contacting a variety of waterborne diseases. These recipients held the collusion between factories and bureaucracy responsible for these impacts. More precisely, it was for saving the costs by the industry from not complying with the pollution standards and also for the failure on the part of the government to take cognizance of the damages.

Initial organized efforts by locals involved persuading the factory owners even with physical threats. Unfortunately, it did not yield any result. A legal action by an organized group was initiated in terms of filing public interest litigation (PIL) cases in the courts.[35] Further, this group also sought and received active support from their elected representatives (members of local State Assembly and Union Parliament) on this matter. Eventually, local industrial pollution and its control could find its place in the election manifestos. Ultimately, Common Effluent Treatment Plant (CETP) technology was adopted by the factories in each industrial estate. It is an example of a coalition of recipients of pollution and elected representative competing with another coalition of factories and bureaucracy vis-a-vis level of industrial water pollution. Interestingly, collective action of affected people had induced factories to organize themselves as a 'club' to construct and manage a CETP. Later, elsewhere in India, the government has played a catalytic role rather than its conventional coercive role, through provision of financial and other incentives to a group of factories for having a CETP.

Data from the survey of industries mentioned above shows that there are scale economies in pollution abatement which makes abatement costly for small factories. This could also be an additional reason for a club of small factories in an industrial estate for having a CETP. This apparent non-convexity found in pollution abatement technologies could pose a problem for using government instruments of taxes and permits even if government is benevolent. However, as observed earlier, it could not be a problem in this case for using Coasean bargaining a la collective action to control pollution.

In the case of using policy instruments for controlling pollution by big factories, pollution taxes or permits could be efficient in the absence of non-convexity (increasing returns to scale) in pollution abatement. However, as explained above in

[35]There have been a number of such PILs on the matter of industrial water pollution abatement in the Supreme Court. In one such case, constitution of an expert committee was ordered concerning an industrial estate in Hyderabad. The terms of reference included studying the problem of water pollution and to make recommendations not just about the extent of compensation to be paid to the recipients by the generators of pollution in the pertinent case but also remedial measures that the industries and the government have to take for preventing water pollution in future. Later, acting on these recommendations the Supreme Court has directed the factories to pay compensation to the recipients and the government to take action against factories in case they violate the pollution standards as per the existing environmental laws.

this case also collective action could be preferred because it provides a decentralized and cost-effective solution with minimum role of government. Some empirical studies conducted by World Bank group of economists in East Asian countries like Indonesia[36] and parallel studies done in India around the same time by some Indian economists[37] provide evidence of success of collective action in this context. In a situation of ineffective formal regulation by government, some big factories are still found to comply with environmental standards with the pressure exerted by the collective action of local communities. The analysis of data collected shows that the compliance of a big factory to standards is related to the characteristics of local community. It is found that the more educated and wealthier the local community and the higher its political participation, the higher is the compliance to the standards by the factory.

5 Conclusion

Environmental externalities arising from consumption and production decisions create market inefficiency. The literature on design of environmental policy points to the use of instruments and institutions that facilitate either government action or collective action for ensuring market efficiency even with environmental externalities.

The doubtful quality of government, the problems of asymmetric information and non-convexities related to environmental externalities, and high transaction costs make governmental instruments of pollution taxes and permits inefficient. There could be efficiency losses of using these instruments due to the presence of moral hazard and adverse selection problems arising due to incomplete or uncertain information about the agents causing the externality and environmental goods supplied and demanded. The transaction costs of market efficiency increasing mixed or hybrid instruments (taxes and payments, permits and penalties, etc.) suggested in the literature to deal with the incomplete information problem are very high.

There is a lot of evidence to show that institutions designed for collective action of groups of people to deal with environmental externalities have proved to be efficient in all-weather situations. They provide decentralized solutions with low transaction costs. Non-convexity and asymmetric information could not be problems for these institutions to efficiently control the externality.

Environmental externalities create problems for the optimal supply of collective goods or goods supplied and used by a group of people (common grazing lands, common lake fisheries, etc.) and the supply of pure public goods (air and water quality, recreation, etc.). There are two types of collective action dealing with each

[36]See Pargal and Wheeler (1996) and World Bank (1999).

[37]See Murty et al. (1999) and Murty and Prasad (1999).

of these problems. The first shows that with institutions providing incentives for rightful actions and penalties for wrongful actions of group members, the collective action by a group provides optimal supply of collective good. The second type explains that there is dualism in dealing with pure public good type of externality involving two groups of people, group creating pollution externality and the group affected by it. Also, there could be multiple groups of stakeholders to this type of externality and the competition among them could result in optimal control of externality. The literature provides empirical evidence of successful collective action for the efficient provision and use of collective goods and the optimal supply of pure public good type of environmental goods.

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Conservation Beyond Protected Areas: The Challenge of Landraces and Crop Wild Relatives

Charles Perrings

1 Introduction

In 2010, the Secretariat of the Convention on Biological Diversity (CBD) reported particular concern about the loss of diversity in the varieties and breeds of plants and animals used to provide humankind with foods and fibers. It is noted that there was underinvestment in the conservation of genetic diversity on farms, including landraces and their wild relatives (Secretariat of the Convention on Biological Diversity 2010). More recently, the CBD Secretariat has underscored concern over domesticated livestock and the wild relatives of domesticated crop species (Secretariat of the Convention on Biological Diversity 2014). The driver behind the genetic erosion of both livestock breeds and landraces is farmer adoption of the modern high-yielding varieties and livestock breeds developed as part of the Green Revolution. In places where adoption has been rapid and widespread, high-yielding varieties have largely displaced the landraces that were previously cultivated. While modern varieties have not always displaced landraces (Brush 2000a; Perales et al. 2003; Brush and Perales 2007; Lipper and Cooper 2009), many landraces and their wild relatives are now at risk of extinction (Villa et al. 2007; Plucknett and Smith 2014).

Historically, landraces have been the primary source of the genetic material used to produce modern varieties—conferring benefits in terms of yield, drought resistance, pest and disease resistance, salt tolerance, and other traits. For example, a single spring wheat variety developed by the International Maize and Wheat Improvement Center (CIMMYT) that was widely planted during the 1980s, VEERY, was the product of 3170 different crosses involving 51 parent varieties from 26 countries (Moore and Tymnowski 2005). Landraces are currently conserved largely through national and international ex situ collections of plant genetic

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material, primarily the Consultative Group on International Agricultural Research (CGIAR) collections gathered during the 1970s and 1980s (Perrings 2014; Plucknett and Smith 2014). It has long been recognized that this is not enough. The main characteristic of landraces is that they are genetically dynamic—evolving in response to changes in environmental conditions. Previous accessions of landraces in ex situ collections may not therefore reflect the genetic characteristics of current crops. The only way to keep ex situ collections up to date is to conserve landraces and their relatives in situ, and to deposit new samples at intervals. While there have been a number of initiatives to promote the in situ conservation of landraces and wild relatives (Meilleur and Hodgkin 2004), there is a strong sense that more needs to be done (Bradshaw 2017; Phillips et al. 2017).

This paper considers three intertwined problems. The first concerns the opportunity cost of the disappearance of landraces or the risks associated with their extinction. This problem raises the question of when it is socially optimal to conserve landraces in situ and when it is socially optimal to convert to modern varieties. The second concerns the institutional failures that lead to underinvestment in in situ conservation. This problem concerns the incentives faced both by individual farmers and by nation-states. For individual farmers, there is no incentive to take account of the wider benefits conferred by their own planting decisions. At the international level, it turns out that landraces and their wild relatives fall between the stools of in situ conservation of endangered wild species (the purview of the Convention on Biological Diversity) and ex situ conservation of crop genetic material (the purview of the International Treaty on Plant Genetic Resources for Food and Agriculture—The Plant Treaty). The third problem concerns the impact of these institutional failures and the resulting landrace extinction on the wealth of nations and nationals. I conclude by considering potential solutions to the problem.

2 The Opportunity Cost of Landrace Extinction

Does it matter if landraces are subject to genetic erosion, or if they disappear completely? The general characteristics of landraces are that they are of historical origin, have high genetic diversity, local genetic adaptation, and a recognizable identity, that they lack of formal genetic improvement, and that they are typically associated with traditional farming systems (Villa et al. 2007). The most important of these characteristics are genetic diversity and adaptation. Landraces are genetically dynamic, being readily adaptable to human and natural selection. They are thus an important source of rare alleles. The genetic erosion of landraces is accordingly of concern because it is associated with loss of alleles.

There is now considerable evidence for the declining genetic diversity of landraces due to displacement by modern varieties in many parts of the world (Brush 2000a; van de Wouw et al. 2010). A study of lima bean (*Phaseolus lunatus*) landraces in the Yucatan peninsula, Mexico, for example, found that the diversity of the genetic pool declined by 72% (Nei index) between 1979 and 2007 due to allelic displacement (Martínez-Castillo et al. 2012). Similarly, a study of tetraploid wheat landraces in Ethiopia found the loss of diversity to be 77%, principally due to the introduction and expansion of bread wheat varieties (Tsegaye and Berg 2007). Analogous results have been found for sorghum (Shewayrga et al. 2008) and maize (Dyer et al. 2014). The story for rice is more mixed. While there is evidence for genetic erosion of rice landraces in some areas (Gao 2003), there is less evidence elsewhere (Ford-Lloyd et al. 2009). Based on the number of countries reporting examples of genetic erosion to the FAO, the crop groups most affected are cereals and grasses, fruits and nuts, food legumes, and vegetables. The crop groups least affected are stimulants and spices, medicinal and aromatic plants. Overall, there is a consensus that genetic erosion has followed the shift from traditional production systems depending on farmer varieties to modern production systems depending on released varieties (Food and Agriculture Organization 2010).

The main concern for the future lies in the loss of genetic adaptation to changing environmental conditions when landraces are no longer cultivated. The genetic material from many (not all) landraces has been sampled in the past and deposited in ex situ collections, primarily the CGIAR collections, but if those landraces are no longer cultivated, they are also no longer able to adapt to changing environmental conditions. The same concern applies to the wild relatives of landraces. A study for the FAO Commission on Genetic Resources for Food and Agriculture, for example, expressed serious concern for the wild relatives of 14 of the world's major food crops including: in Africa, finger millet (*Eleusine* spp.), pearl millet (*Pennisetum* spp.), garden pea (*Pisum* spp.), and cowpea (*Vigna* spp.); in the Americas, barley (*Hordeum* spp.), sweet potato (*Ipomoea* spp.), cassava (*Manihot* spp.), potato (*Solanum* spp.), and maize (*Zea* spp.); in Asia and the Pacific, wild rice (*Oryza* spp.) and the cultivated banana/plantain (*Musa* spp.); and in the Near East, the garden pea (*Pisum* spp.), wheat (*Triticum* spp. and *Aegilops* spp.), barley (*Hordeum spontaneum* and *Hordeum bulbosum*), faba bean (*Vicia* spp.), chickpea (*Cicer* spp.), alfalfa (*Medicago* spp.), clover (*Trifolium* spp.), pistachio (*Pistacia* spp.), and stone fruits (*Prunus* spp.) (Maxted and Kell 2009).

From an economic perspective, the decision as to whether or not to conserve land in some state (say agricultural land in some crop and crop management regime) or to convert it to another state (to a different crop and crop management regime) depends on the expected rate of growth in the value of the system under each alternative. In the simplest of all cases, if the value of the land in some state at time t is denoted p_t and its expected value at time $t + 1$ is p_{t+1}, then if the growth in its value if converted to an alternative state is r, the decision maker should be indifferent between conserving and converting the land if and only if

$$\frac{p_{t+1} - p_t}{p_t} = r$$

This is the Hotelling arbitrage condition (Hotelling 1931). In providing a simple criterion for deciding when to maintain some stock in its current state, or to convert it to a different state, Hotelling also provided a powerful general theory of conservation. Neglecting any external effects of production, it implies that for crop type, s, the ith farmer will maintain production of s as long as

$$\frac{p^i_{st+1}(s^i) - p^i_{st}(s^i)}{p^i_{st}(s^i)} > r$$

and if the best alternative option is to convert the land to crop type q, the farmer will maintain production of s as long as

$$\frac{p^i_{st+1}(s^i) - p^i_{st}(s^i)}{p^i_{st}(s^i)} > \frac{p^i_{qt+1}(q^i) - p^i_{qt}(q^i)}{p^i_{qt}(q^i)}$$

From a social perspective, however, the value of particular crop types depends not only on the direct market value of the crop, but also on its conservation value—the value of the gene pool associated with the crop. The gene pool is a public good whose value stems from the importance of any rare alleles it contains in conferring desirable traits through either conventional plant breeding or genetic engineering. The value of the crop can thus be thought of as the sum of the value to the producer, usually the market price of the crop, and the in situ conservation value of the crop. The value of the land committed by the ith farmer to crop type s is thus $p^i_{st}(s^i, S)$ where $\mathrm{S} = \mathrm{s}^1, \ldots, \mathrm{s}^i, \ldots, \mathrm{s}^m$ is aggregate production of s by all m producers. It follows that at the margin

$$\frac{\mathrm{d}p^i_{st}}{\mathrm{d}s^i} = \frac{\partial p^i_{st}}{\partial s_i} + \sum_{j=1}^{m} \frac{\partial p^j_{st}}{\partial S}\frac{\partial S}{\partial s^i}$$

The marginal value of the ith farmer's decision to plant s includes both the direct benefit of production and the indirect benefit of the contribution the ith farmer makes to the public good—the crop gene pool.

There are two points to be made about this. The first is that in the absence of dedicated payment mechanisms the farmer has no incentive to take account of the indirect benefit they confer on all other beneficiaries of the crop gene pool. That is, if there are m beneficiaries of the production of S, the farmer has no incentive to take account of the benefits conferred on others, $\sum_{j=1}^{m} \frac{\partial p^j_{st}}{\partial S}\frac{\partial S}{\partial s^i}$. This is the classic reason for the undersupply of public goods. The second point is that if we consider s to be a landrace and σ to be a modern variety, then we would also expect

$$\sum_{j=1}^{m} \frac{\partial p^j_{st}}{\partial S}\frac{\partial S}{\partial s^i} > \sum_{j=1}^{n} \frac{\partial p^j_{qt}}{\partial Q}\frac{\partial Q}{\partial q^i}$$

That is, we would expect the in situ conservation value of landraces to be greater than the in situ conservation value of modern varieties. Indeed, we would generally expect that $\sum_{j=1}^{n} \frac{\partial p_{qt}^{j}}{\partial Q} \frac{\partial Q}{\partial q^{i}} = 0$. So if farmers neglect the wider conservation benefits of their planting decisions, they will make a simple comparison between the private value of land committed to landraces relative to modern varieties.

The more rapidly environmental conditions change, the more rapidly will landraces adapt, and the greater will their in situ conservation value be. It is ironical that farmer comparisons between landraces and modern varieties are leading to the abandonment of landraces at just the moment when their conservation value is most rapidly increasing.

3 National and International Institutions for the Conservation of Crop Genetic Diversity

It is well understood that farmers' crop and crop management choices generate both positive and negative environmental externalities. Aside from the genetic externalities that concern us here, agricultural production is associated with a wide range of offsite effects on human, plant, and animal health; water, soil, and air quality; biodiversity; and natural resources (Pretty et al. 2000, 2001; Lankoski and Ollikainen 2003; Almasri and Kaluarachchi 2004; Tegtmeier and Duffy 2004; Diaz and Rosenberg 2008; Cobourn 2015). Genetic externalities operate at larger spatial and temporal scale. They frequently transcend national boundaries, and their effects extend into the far-future stresses. Nor is there a ready way to compute the value of externalities that involve the uncertain loss of adaptive capacity, varietal development opportunities, or heightened vulnerability to disease and other environmental stresses (Lipper and Cooper 2009).

The institutions established to address the genetic externalities of agriculture are typically international—either intergovernmental or non-governmental. During the last four decades, these institutions have been revamped in ways that have had an important effect on the national incentive to conserve crop genetic diversity, as well as the form that conservation takes. The earliest international agreement bearing on crop genetic diversity was the International Undertaking on Plant Genetic Resources adopted in 1983. The basic proposition behind the International Undertaking was the assumption that plant genetic resources were 'a heritage of mankind and consequently should be available without restriction' (Rose 2004). Under the International Undertaking, traditional crop genetic material from landraces was systematically sampled and lodged in ex situ collections, the most important of which were the CGIAR collections. Over the next two decades, however, the International Undertaking was dismantled and replaced by two instruments—the Convention on Biological Diversity, 1993, and the International Treaty on Plant Genetic Resources for Food and Agriculture, 2004. These instruments reversed the common heritage assumption and replaced it with an assertion that 'States have *sovereign rights* over their own biological resources' (Convention on Biological Diversity 1992).

Under the International Undertaking, the CGIAR system created an international network of ex situ collections in gene banks under the control of the Food and Agriculture Organization. The network was charged with holding active collections of plant species for the benefit of the international community on the principle of unrestricted exchange. The FAO's Commission on Genetic Resources for Food and Agriculture (CGRFA) subsequently took responsibility for the network, building on the collections developed by the (then) twelve centers of the CGIAR (Moore and Tymnowski 2005). Since the International Treaty on Plant Genetic Resources for Food and Agriculture came into force, it has regulated access to the resources of the network.

There are two points to note about the conservation priorities established under the International Undertaking, and the way they have evolved under the Plant Treaty. The first is that the system privileged ex situ over in situ conservation. This was not surprising in the wake of the Green Revolution. Nor was it necessarily wrong. It was argued that farmers could not be expected to plant landraces when modern varieties offered much higher yields in average conditions. There were also no resources available to compensate farmers who did choose to plant landraces (Brush 2000a). By treating ex situ conservation as sufficient, however, the system also weakened any incentive that nation-states might have had to conserve in situ.

The second point to make is that at the time the International Undertaking was replaced by the Plant Treaty, the common heritage principle was replaced by the national sovereignty principle. This had the effect of weakening any incentive that nation-states had to contribute material to the international ex situ collections. Individual countries have instead developed their own ex situ collections. These are typically quite different from the CGIAR collections. The CGIAR Centers hold only 12% of ex situ accessions globally, but are the most important repository of landraces and wild relatives, which account for 73% of all CGIAR accessions. By contrast, landraces and wild relatives together account for only 16% of national collections. Since the CGIAR ex situ collections are freely available to contributors, they have largely supplanted in situ collections as the primary source of genetic material from developing countries. At the same time, the incentive for individual countries to contribute material to the CGIAR system has been weakened. The ratio of samples requested to samples contributed by developing countries has been more than 60 to 1 for much of the last two decades (Moore and Tymnowski 2005; Galluzzi et al. 2016).

The main cost of the current approach to the conservation of crop genetic resources is the weakening of incentives to conserve in situ. The FAO and the scientific community have long recognized the problem this poses. In recent years, growing awareness of the implications of climate change for agriculture has heightened international interest in the in situ conservation of landraces and crop wild relatives. It is argued that if landraces and crop wild relatives are able to evolve under climatic selection pressure, they may develop traits that are not just helpful but critical to future plant breeding efforts (Food and Agriculture Organization

2010). There has, however, been no change to the priority given to national ex situ collections or to the accession strategies of national collections. Nor has there been any change to national policies to promote adoption of modern varieties and hence to drop landraces (Brush 2000a, b).

The point here is that ex situ collections are only as good as in situ conservation allows them to be. Unless ex situ collections are routinely updated, they cannot capture the genetic dynamism of landraces. Nor can they be updated unless landraces are conserved in situ. Wild crop relatives are particularly at risk. The assumption is that they will be addressed through protected areas, but while the land committed to protected areas has increased significantly, no protected areas have been selected with crop wild relatives in mind. Most have been selected to protect rare and endangered fauna (Food and Agriculture Organization 2010).

It follows that there are two reasons for underinvestment in in situ conservation of landraces at the farm level. First, since the public good is effectively in the hands of nation-states, individual governments have no incentive to take account of conservation benefits accruing to the rest of the world. While national governments may have more incentive than individual farmers to take account of the term $\sum_{j=1}^{m} \frac{\partial p_{st}^{j}}{\partial S} \frac{\partial S}{\partial s^{i}}$ in the Hotelling arbitrage equation, they have no stronger incentive to take account of any of the m potential beneficiaries who are not nationals. The public good served by local conservation efforts is global, but absent a system of international payments to national governments, it will be undersupplied. Figure 1 shows that if only local benefits are taken into account, local conservation is at S_L and the value is the area between the local benefit curve and p_L. If global benefits

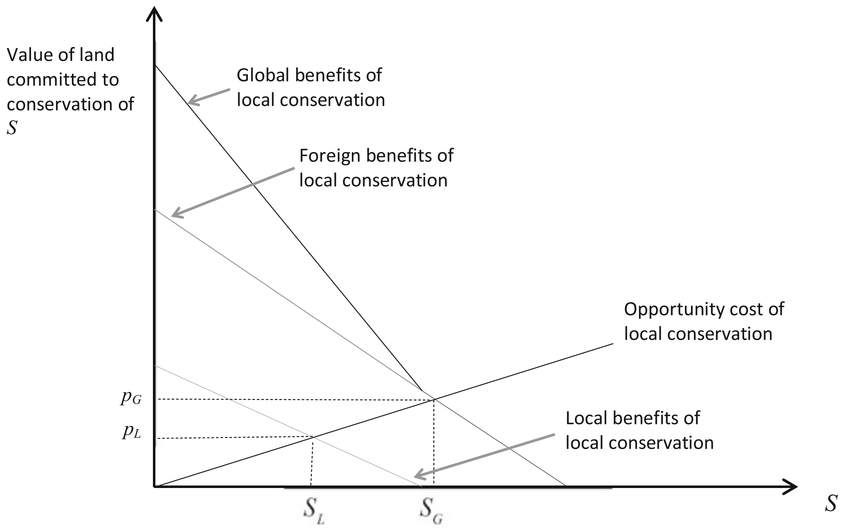

Fig. 1 Value of land committed to the conservation of a global public good

are taken into account, local conservation is at S_G and the value is the between the local benefit curve and p_G.

The second reason for underinvestment in in situ conservation of landraces relates to the rights that farmers themselves have in landraces. By asserting sovereign rights over genetic resources in the CBD and the Plant Treaty, national governments effectively expropriated farmers and in doing so changed the incentives they face. It is recognized that different intellectual property rights regimes offer different conservation incentives (Timmermann and Robaey 2016). Traditionally, farmers have employed both selection and breeding to improve crop varieties—by breeding out undesirable traits and breeding in desirable traits such as drought or disease resistance, or improved yields. Farmers have also been involved in the exchange of seeds to maintain the intraspecific genetic diversity needed to protect crops against environmental fluctuations. In many traditional systems, the relation between wild and domesticated species was socially regulated. Rules were established that conserved wild relatives of cultivated species. In Ethiopia, for example, where the staple food of the Ari people is a banana relative (*Ensete ventricosum*), areas where wild relatives of the plant grow were protected (sacred), ensuring their availability for cross-pollination with cultivated plants (Kingsbury 2009).

In traditional systems, the size of the gene pool and the specificity of the traits sought by plant breeders depend on the size of the group to which breeders belong. The smaller the group, the smaller the gene pool, and the more specialized the traits sought. It is the relative isolation of social groups that lies behind the historic development of landraces. A reduction in the isolation of communities has both increased the gene pool available to breeders and reduced the specificity of the traits sought in crops (Kingsbury 2009). Traditionally, the historic range of landraces also defined the community having rights in the genetic resources they contain. The property rights now evolving are more varied, including patents, a wide range of *sui generis* systems (singular systems involving the creation of specific entitlements or obligations), and a range of farmers' and livestock keepers' rights.

Under the Plant Treaty, farmers are asserted to have rights 'to save, use, exchange and sell farm-saved seed and other propagating material, and to participate in decision-making regarding, and in the fair and equitable sharing of the benefits arising from, the use of plant genetic resources for food and agriculture' (International Treaty on Plant Genetic Resources for Food and Agriculture 2009). However, responsibility for implementing farmers' rights rests with national governments. Farmers' rights are also subject to the caveat that they should be in accordance with national needs and priorities and subject to national legislation.

The benefit-sharing system described in the Plant Treaty stipulates that benefits arising from the use of plant genetic resources for food and agriculture can be shared via exchange of information, access to and transfer of technology, capacity building, and the sharing of the benefits arising from commercialization. There are several models for national legislation to protect farmers' rights (and through them landraces and wild crop relatives), the best of which recognize that farmers have inalienable rights to genetic material and to the establishment of mechanisms for the protection of those rights. One example of *sui generis* legislation that identifies group rights is India's Protection of Plant Varieties and Farmers Rights Act (2001), which defines a breeder to be 'person or group of persons or a farmer or group of farmers or any institution which has bred, evolved or developed and plant variety,' and gives farmers, as breeders, the same rights as are given to professional breeders. However, most national law focuses on intellectual property rights attaching to the products of modern plant breeding and/or genetic modification of plants and neglects the rights of the farming communities that account for the majority of the world's rural population (Santilli 2012).

4 Wealth Effects

Lacking property rights to the genetic material in landraces and their wild relatives, and lacking other signals about the importance of conserving these species in situ, it is not surprising that farmers have opted to displace landraces in favor of high-yielding modern varieties. While a few studies have found landraces to persist in locations where widely adapted varieties may fail completely in some environmental conditions (Cavatassi et al. 2011), or where cultural practices and social norms favor particular food types (Perales et al. 2003; Brush and Perales 2007), the general pattern has been for landraces to be abandoned. The advantages to the farmer of adopting modern varieties and crop management practices are immediate and substantial, including gains in crop incomes, consumption expenditure, and food security (Khonje et al. 2015). The experience with rice in South and South East Asia showed that the short-term benefits of adoption tended to decline over time for various reasons, including declining yields due to long-term changes in soil conditions and soil biota, and the increasing uniformity of cultivars (Pingali et al. 1997). Nevertheless, where farmers in developing countries have switched to modern intensive methods, there is evidence that they will not then switch back to less-intensive farming methods that deliver longer-term benefits without incentives. A study of farmers' willingness to adopt conservation agriculture in Malawi, for example, found adoption of conservation agriculture methods to be contingent on payment of subsidies (Ward et al. 2016).

It follows that the short-term benefits of the in situ conservation of landraces and wild crop relatives would have to be substantial for farmers to forgo the advantages of modern methods and crop varieties. The privately capturable benefits of landraces and wild crop relatives relate to the management of environmental risk. Diversification both within and between landraces of different species, and breeding strategies that retain wild crop relatives in situ and evolve multiple landraces of each cultivated species, is calculated to reduce the risk of crop failure—even in extreme conditions. The displacement of landraces by high-yielding modern varieties has increased mean output, but has not been as effective in reducing vulnerability to environmental shocks. It has also increased the spatial correlation of risk. If all farmers cultivate the same varieties, the probability that they will simultaneously fail increases.

One reason that this is a concern, even at the farm level, is that risk management critical to poverty alleviation in rural areas. If farmers have managed risk through crop diversification (and non-farm activities) and have been unable to accumulate enough financial resources to buffer shocks, then adoption of modern varieties can leave them more exposed (International Fund for Agricultural Development 2010). Add to this the 'new' risks of natural resource degradation, climate change, insecurity of access to land, greater volatility of food prices, the diminishing effectiveness of traditional common property management regimes, and the erosion of traditional support networks, the expected net benefits of modern varieties over landraces may be significantly reduced (International Fund for Agricultural Development 2010).

The second reason for concern is the fact that the introduction of modern varieties has implications for the genetic properties of both landraces and wild relatives. A particular concern has been raised about the probability that genetically modified crops. When these are introduced in their center of domestication—the location where wild relatives are present—it will result in gene flow from the transgenic crop to the wild relatives (Gepts and Papa 2003; Stewart et al. 2003). There is also a concern about the effects of gene flow from transgenic crops to landraces. If the presence of transgenes reduces the diversity of alleles in local landraces, or morphological variants of those landraces, then the introduction of transgenics will have a potentially negative impact. As of now, there is little evidence for such an effect, although it remains a possibility (Bellon and Berthaud 2004). Introgression between modern varieties in general and either landraces has been observed, but is not considered to have led to their genetic erosion (Raven 2005; Bitocchi et al. 2009, 2015).

At the national and international levels, there are other reasons for concern. At the global scale, the loss of landraces and crop wild relatives might have few short-term consequences, but it can permanently exclude the genetic resources they contain from future asset portfolios. The point has already been made that what makes landraces and wild crop valuable in conditions of global change is precisely that they are genetically dynamic, potentially enriching the pool of alleles over time. Since the changes that occur in landraces are induced by an adaptive response to altered environmental conditions, they can be helpful in strengthening the capacity of other species to respond to similar changes in environmental conditions. The displacement of landraces accordingly reduces their expected value, particularly as source material for the improvement of other species.

In summary, the loss of landraces and wild crop relatives from production landscapes directly impacts the wealth of farmers by removing biological assets that help cope with fluctuating environmental conditions locally. It also affects genetic resources available to the rest of the world. Since farmers are able to capture only the private insurance value of crops, that is all they take into account. Since nation-states are able to capture only the benefits of conservation to nationals, they likewise make decisions that balance the costs of in situ conservation against the gains offered to nationals.

5 Conclusions

The conservation problem in agriculture is not limited to the problem of landraces and wild crop relatives. There is a wider set of concerns relating to agrobiodiversity more generally defined (Jackson et al. 2007; Pascual and Perrings 2007; Smukler et al. 2010). These relate to changes both in the diversity of species that influence the production of foods, fuels, and fibers, and in the diversity of wider agricultural landscapes. Nor is the conservation problem of landraces and wild crop relatives unique. The loss of genetic diversity in landraces and wild crop relatives limits the capacity of those species to adapt to future environmental changes. The loss of genetic diversity in any of the other species that are now threatened by habitat loss, habitat fragmentation, climate change, and other anthropogenic stressors has the same effect.

What makes the problem of landraces and wild crop relatives of special concern is its central role in the future food security of the world's poorest regions. The population in Africa is currently around 1.2 billion, and is expected to grow to 4.6 billion by the end of the century. Africa is currently the least food secure region on earth. It has yet to experience a Green Revolution as intense as that in Asia, but will have to do so if it is to meet the demands of population growth, whether or not per capita incomes grow. The intensification of agriculture in the region and the adoption of modern varieties will generate the same pressures on landraces and wild crop relatives that have occurred elsewhere. Unless there are institutional and policy reforms introduced to support in situ conservation of landraces and wild crop relatives in the region, we can expect the value of the gene pool provided by traditional varieties to erode in similar ways. The issue, as in other parts of the world, is that the private incentive to adopt new technologies will lead to the loss of the very assets on which the new technologies are based.

The current strategy of conservation through ex situ collections is not enough to maintain the value of the genetic basis for agriculture. It needs to be supplemented by a strategy of targeted in situ conservation of the genetically dynamic crops and their relatives required to provide the genetic raw material for future crops. From an economic perspective, neglect of the albeit uncertain future value of locally common but globally rare alleles embodied in landraces and wild crop relatives leads to inefficient conservation by individual farmers that compromises national wealth. In the same way, neglect of the international benefits of national conservation compromises global wealth. All biodiversity conservation ultimately involves a global public good, the global gene pool, but all biodiversity conservation is necessarily implemented at the local scale. The challenge is to develop the institutions and incentives that will induce farmers in genetically important locations to conserve the species that matter.

This requires a tiered response. Given the structure of rights established under the Plant Treaty and the CBD, the first tier is payments from the global community to nation-states to cover the incremental cost of in situ conservation of selected landraces and wild crop relatives. The second tier is payments from national governments to targeted farmers to induce them to plant the selected crops. The challenge on the first tier is that while a global fund has been established under the Plant Treaty to support in situ conservation, it is vanishingly small relative to the amount that is warranted by the benefits. The challenge on the second is that neither existing agri-environmental schemes nor the newer payments for ecosystem services schemes have a good track record in delivering intended benefits. Farmer contracts that include the delivery of seed to the CGIAR would at least allow for international monitoring of genetic changes in crops, but getting the incentives right at both national and farm levels would be essential. The stakes are high. While there are other components of natural capital that are similarly at risk, there are few with as significant implications for future human well-being.

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Water Quality in Indian Rivers: Influence of Economic Development, Informal Regulation, and Income Inequality

Bishwanath Goldar and Amrita Goldar

1 Introduction

Pollution of water in Indian rivers is a matter of concern because of its adverse effects on health, agricultural yields, and aquatic ecology. There are also the related issue of sustainability of water resources in the country in terms of adequate availability of usable water for agriculture, industries, and rural and urban households, especially if an accelerated growth in manufacturing is to be maintained in the coming decades.[1]

An indication of the magnitude of problem currently being encountered in India is provided by the water quality data collected under water quality monitoring networks of the government. According to the Report of the Central Pollution Control Board (CPCB) on the status of water quality in India in 2012 (CPCB 2013),[2] the organic pollution measured in terms of biochemical oxygen demand

[1]There have been a number of studies on the effects of river water pollution on health and agricultural yields in India. The findings of some of these studies are briefly discussed in Sect. 3 of the paper. The issue of sustainability of water resources in India in the context of water pollution caused by urbanization and industrialization is discussed in Chopra and Goldar (2000, 2003). Also see, Chopra et al. (2003) and IDFC (2011).
[2]The report is based on water quality data on rivers, lakes, ponds, tanks and groundwater locations being collected by the CPCB under its water quality monitoring network. Data from about 2500 water quality monitoring stations are used in the Report.

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(BOD) is above the specified standard of 3 mg/l[3] in about 37% of the observations, between 3 and 6 mg/l in 19% of the observations, and above 6 mg/l in 18% of the observations.[4] Another important indicator of organic pollution of water bodies is total coliform and fecal coliform (*F-Coli*) counts. According to the guidelines of the CPCB, for outdoor bathing, total coliform count should be equal to or less than 500 Most Probable Number per Hundred milliliter (MPN/100 ml). The CPCB data on water quality in 2012 show that in about half of the observations, the total coliform count is above 500 MPN/100 ml, and for *F-Coli c*ount, the corresponding figure is about 35%.

Another set of data on water quality in Indian rivers is available from Central Water Commission (CWC), Ministry of Water Resources. According to a report of CWC dated 2011 (CWC 2011), out of the 371 key locations where the commission was monitoring water quality, the level of BOD was found to be above 3.0 mg/l in 36 cases and the level of dissolved oxygen (DO) was found to be less than 5 mg/l (outdoor bathing standard is 5 mg/l or more) in 17 cases.

According to the Annual Report of the CPCB for 2014–15 (CPCB 2015), 302 polluted river stretches have been identified in India, which are on 275 rivers. Of these polluted stretches, 34 are in priority class I (BOD level of more than 30 mg/l), 17 in priority class II (BOD level, 20–30 mg/l), 36 in priority class III (BOD level, 10–20 mg/l), 57 in priority class IV (BOD level, 6–10 mg/l), and 158 in priority class V (BOD level above 3 mg/l and up to 6 mg/l). Taking all the priority classes together, the estimated polluted riverine length is about 12,363 km. In the following states, there are ten or more polluted river stretches (in descending order, number of stretches in parentheses): Maharashtra (49), Assam (28), Madhya Pradesh (21), Gujarat (20), West Bengal (17), Karnataka (15), Kerala (13), Uttar Pradesh (13), Manipur (12), Orissa (12), and Meghalaya (10) (CPCB 2015, page 9).

The CPCB Report on Status of Water Quality in 2012 mentioned earlier provides information on the highest observed BOD levels in rivers (CPCB 2013, Table I, page 7). In several cases, it is more than 100 mg/l. Some of the rivers where relatively high levels of BOD have been found include (BOD level in parentheses): Vasista (500), Kala Amb (185), Sukhana (180), Mithi (170), Musi (165), Sarabanga (126), Tambiraparani (115), and Yamuna (113).

In the CPCB Annual Report (CPCB 2015, page 12), it is noted that there are many urban centers along polluted river stretches. According to this report, there are

[3]Bureau of Indian Standard, BIS, has recommended 3.0 mg/l concentration of BOD for outdoor bathing. This is the standard adopted by the CPCB. This is the requirement for the specified B class of water which is meant for outdoor bathing (organized). Other criteria for B Class water are: pH between 6.5 and 8.5, Dissolved Oxygen (DO) of 5 mg/l or more and Total Coliforms Organism of 500 MPN/100 ml or less. For water of Class A, which is a superior water class, the criteria are: BOD 2 mg/l or less, DO 6 mg/l or more, pH between 6.5 and 8.5 and Total Coliforms count 50 MPN/100 ml or less. This is the standard for a surface water body that may be used for drinking water source without conventional treatment but after disinfection.

[4]An analysis of the river water quality data of the CPCB for 2012 undertaken in this study reveals that in about 8% of the observations, the BOD level is more than 10 mg/l.

650 towns along the 302 identified polluted river stretches. Further, out of 46 metropolitan cities (Census 2011), 35 are located along polluted river stretches.

It is evident from the above that there is widespread pollution of water in Indian rivers. This is well recognized. The *State of Environment Report* of the Ministry of Environment and Forests for 2009 (MOEF 2009, page 42) observes that almost 70% of the surface water resources in India and a growing percentage of ground water resources are contaminated by biological, toxic, organic, and inorganic pollutants. This is obviously a matter of concern because of the adverse effects of water pollution on health, agricultural yields, and aquatic ecology.

2 Objectives of the Study and Organization of the Paper

While there are a number of studies dealing with the consequences of river water pollution (i.e., costs imposed on the society by pollution of river water in India, taken up later in the next section), this paper focuses on the causes of pollution of water in Indian rivers, going into the economic factors (such as industrialization and urbanization) that influence or determine or are the source of water pollution in rivers in India, and particularly the role played by informal regulation[5] in containing pollution of Indian rivers. The paper also looks at the impact of income inequality on water pollution in rivers. The regional variation in water quality in Indian rivers in 2012 (also, change between 2003 and 2012) is utilized to analyze econometrically the influence of industrialization, urbanization, informal regulation, and income inequality. The econometric analysis is preceded by two simpler analyses: an analysis of trends in water pollution in Indian rivers and a preliminary statistical analysis attempting to relate regional variation in water quality to the extent of urbanization and industrialization in different districts of India.

The rest of the paper is organized as follows. The next section, i.e., Section 3, briefly discusses the findings of some of the studies that have been undertaken on the effect of water pollution on health and agricultural yields in India. Section 4 is devoted to an analysis of trends in water pollution in Indian rivers. In Sect. 5, an attempt is made to relate data on water quality at various monitoring points (for 2012) and urbanization and industrialization in different districts of India. The question asked is whether water quality in Indian rivers at various monitoring points bears a relationship with the extent of urbanization and industrialization in the districts in which the monitoring points are located. The analysis is done with the help of graphs and computation of correlation coefficients. Section 6 presents an econometric analysis of determinants of water quality in India. It has three subsections. Section 6.1 contains a brief discussion on factors that are expected to

[5]The concept of informal regulation is discussed later in Sect. 6.1. For information on the formal regulation of water pollution in India, see Pargal et al. (1997b), Kuik et al. (1997, Chap. 4), Murty (1999), Sankar (1999), Goldar and Pandey (2001), and Murty and Kumar (2011), among others.

influence river water pollution, with a focus on informal regulation and income inequality. It covers econometric studies undertaken on river water pollution in India. This is followed in Sects. 6.2 and 6.3 by multiple regression analysis in which an attempt is made to explain cross-sectional, regional variation in water quality in rivers by using a set of explanatory factors including variables representing income inequality and informal regulation of pollution. Finally, Sect. 7 summarizes and concludes.

3 Losses Due to River Water Pollution

A number of studies have brought out that the pollution of water bodies in India (caused by industrial pollution or sewage or other sources) is imposing significant costs or losses on the society (these include Shankar 2001; Dasgupta 2004; Murty et al. 1999; Markandya and Murty 2000; Sekar 2003; McKenzie and Ray 2004; Reddy and Behera 2006; Appasamy and Nelliyat 2006; Srinivasan and Ratna Reddy 2009; Shanthi and Gajendran 2009; Brainerd and Menon 2012; Pullaiah 2012; Poddar and Byahatti 2015; and Do et al. 2014, 2016). The findings of some of these studies are briefly discussed below.

Reddy and Behera (2006) have examined the cases of two villages in Andhra Pradesh—one affected by industrial pollution and the other not affected (control village). Based on a comparison of the two villages, they have concluded that the adverse impact of industrial pollution on the local communities is quite substantial in monetary terms. They have considered for their analysis the impact of water pollution on (i) health, (ii) crop production and other activities, and (iii) livestock. They have found that about 45% of the cultivable land in the affected village has become uncultivable. In addition, the use of polluted water has led to corrosion of agricultural equipment, damage to pump-sets, etc. Also, a portion of the cattle in the village has died due to drinking of polluted water.

Srinivasan and Ratna Reddy (2009) have studied the impact of water pollution on human health using data for six villages which are irrigated with wastewater along Musi River in Hyderabad and a control village with is irrigated with normal water. They have found that a significantly higher morbidity exists in villages irrigated with wastewater than that in the control village.

Poddar and Byahatti (2015) have examined the effect of water pollution by comparing two affected villages with two non-affected (control) villages, in the Bhima River Basin (Bhima River is an important tributary of the Krishna River). The results of their analysis indicate that the use of polluted water for irrigation has led to a fall in yield of sugarcane crop. Another finding is that water pollution has adversely affected the health of villagers (causing increased morbidity) in the villages affected by pollution, which is in conformity with the findings of Srinivasan and Ratna Reddy (2009) noted above. Another study that has found adverse effect of water pollution on agricultural yields is Appasamy and Nelliyat (2006), who have also reported loss of fisheries due to water pollution in their study of Nayyal River Basin in Tamil Nadu.

Do, Joshi, and Stolper have undertaken an analysis of the effect of water pollution on infant mortality in two papers, one dated 2014 and the other dated 2016. Their paper dated 2014 presents a more comprehensive analysis in terms of geographic area covered than the paper dated 2016.

Do et al. (2014) have considered the water quality data (focusing on *F-Coli* count) across various monitoring points in India during the period 1986—2004 and the infant mortality rate in the districts where the monitoring stations are located. They have found a strong relationship between river water pollution and infant mortality. According to their estimates, the average effect of a one-percent increase in *F-Coli* count is an additional 3–5 deaths per 100,000 births in a given month. Their results indicate that the first month of birth is by far the most dangerous when it comes to the adverse impact of river water pollution, and such a strong relationship between mortality and water pollution does not exist in months two through twelve of a child's life.

In their 2016 paper, Do, Joshi, and Stolper have confined their analysis to the Ganga River Basin and have come up with findings similar to their 2014 paper. The results of the analysis indicate that river pollution has a significant adverse effect on infant health in India. The newborn babies in the first month of their life are particularly susceptible to river water pollution which is in conformity with the findings of their earlier paper. Do and associates have also found that water pollution flows downstream to other communities living along the river affecting the likelihood of infant survival.

It should be pointed out here that the findings of Do et al. (2014, 2016) are in conformity with the findings of Brainerd and Menon (2012) who have studied, in the Indian context, the impact of water pollution caused by agricultural sources and found that exposure higher concentration of agrochemicals leads to worse health outcomes on a variety of measures such as infant mortality, neonatal mortality, height-for-age *z*-scores, and weight-for-age *z*-scores.

The upshot of the above discussion is that there are serious consequences of river water pollution, especially by industrial wastewater. Hence, containment of pollution of river water is very important.

4 Trends in Water Quality in Rivers

Water quality data for the period 1995–2012 available in the aforementioned Report of the CPCB on the Status of Water Quality (CPCB 2013) give the impression that there has been a slow/modest improvement in water quality in Indian rivers between 1995 and the mid-2000s, and a gradual deterioration thereafter. Figure 1 shows trends in water quality in terms of level of BOD. Data for six select years between 1995 and 2012 are presented. Three ranges for BOD are considered: less than 3, 3–6, and above 6 mg/l. It is seen from the figure that the proportion of

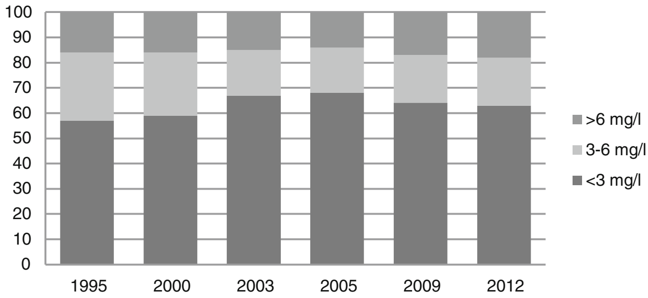

Fig. 1 Water quality, BOD (mg/l), distribution of observations (%)
Source Prepared by authors using data from CPCB (2013, Fig. 2, page 42)

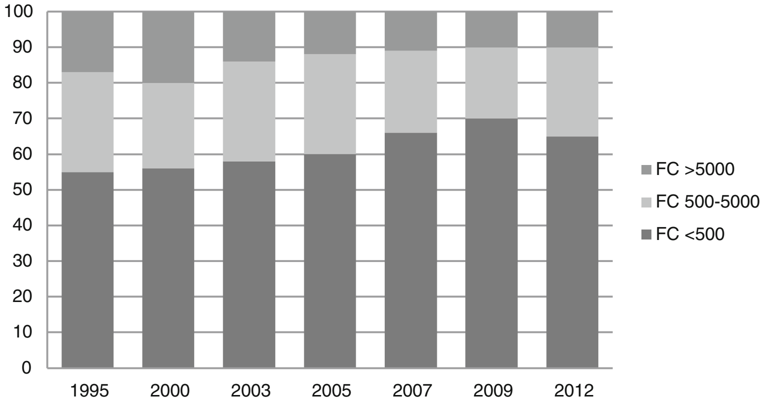

Fig. 2 Water quality, fecal coliform (MPN/100 ml), distribution of observations (%)
Source Prepared by authors using data from CPCB (2013, Fig. 4, page 43)

observations with BOD level less than 3 mg/l increased between 1995 and 2005 and declined between 2005 and 2012. On the other hand, the proportion of observations with BOD level above 6 mg/l fell between 1995 and 2005 and increased between 2005 and 2012. This suggests a slight improvement in water quality in terms of BOD between 1995 and 2005 and a slight deterioration between 2005 and 2012.

Figure 2 shows trends in water quality in terms of *F-Coli* count. In this case, there is an indication of improvement between 1995 and 2009 and a slight deterioration thereafter. Thus, the trends in BOD level and those in *F-Coli* count do not match. Nonetheless, going by the data presented in Figs. 1 and 2, it may be inferred that only gradual changes have taken place in water quality over time, and there has been neither any marked improvement nor a marked deterioration in water quality in India rivers between 1995 and 2012.[6]

It is important to draw attention to the fact that there have been, over time, substantial increases in the number of water quality monitoring stations of CPCB in India. In 1995–96, there were 480 monitoring stations, which increased to 784 in 2000–01, and then to 1700 in 2009–10 (CPCB 2013, Graph 2.1, page 22). In 2012–13, there were 2500 monitoring stations. The implication is that the comparison of water quality status in different years presented in Figs. 1 and 2 above may be affected to some extent by data incomparability arising from the changes in the number of monitoring stations. More reassuring would be a comparison of water quality based on a common set of water quality monitoring stations. Such a comparison is presented below using data for two years, 2003 and 2012, in respect of a common set of monitoring stations. This analysis is confined to water quality data for rivers only. The basic data source is the CPCB.

Figure 3 provides an indication of the change that has taken place in BOD level in river water under various monitoring stations between 2003 and 2012. Data on BOD level (average for the year, taking for each station observations on BOD obtained at different points of time during the year) for about 420 monitoring stations are used for the graph. The monitoring stations are first arranged in ascending order according to the BOD level (annual mean) in 2003. Then, the monitoring stations are divided into ten almost equal groups. For each group, the mean BOD level is computed for 2003 and for 2012. These are shown in Fig. 3. A similar analysis has been done for DO. This is shown in Fig. 4.

Data on BOD and DO levels in Indian rivers presented in Figs. 3 and 4 indicate that there has not been much change in the level of BOD or DO if one considers groups of monitoring stations, categorized according to the level of water quality in 2003. Yet, overall, there is an indication of a slight deterioration. The mean BOD level for several groups is higher in 2012 than that in 2003. Similarly, it is seen that the mean DO level is lower in 2012 than that in 2003 for several groups.

It should be pointed out, however, that within a group, there are marked variations. Consider the first group in Fig. 3. This group includes those monitoring stations for which the observed BOD level for 2003 was less than 0.9 mg/l. In some cases, this level was not exceeded in 2012. But, in some other cases, there was a significant increase over the 2003 level, reaching a BOD level of more than 1.5 mg/l or even reached 2.7 mg/l.

Table 1 provides a summary of the changes in BOD level that has taken place in respect of stations that recorded BOD level below 3 mg/l in 2003 and those that

[6]It should be pointed out that Figs. 1 and 2 are based on data on water quality that includes lakes, ponds, tanks and groundwater locations along with rivers. However, the observations on river water quality dominate, and therefore the conclusions drawn would apply to water quality in rivers. Out of the total 2500 monitoring stations in 2012, 1275 were on rivers, 190 on lakes, 807 on ground water locations and the rest on other water sources such as ponds, canals, creeks, and industrial drains (CPCB 2013, Table 2.4, pages 26–28).

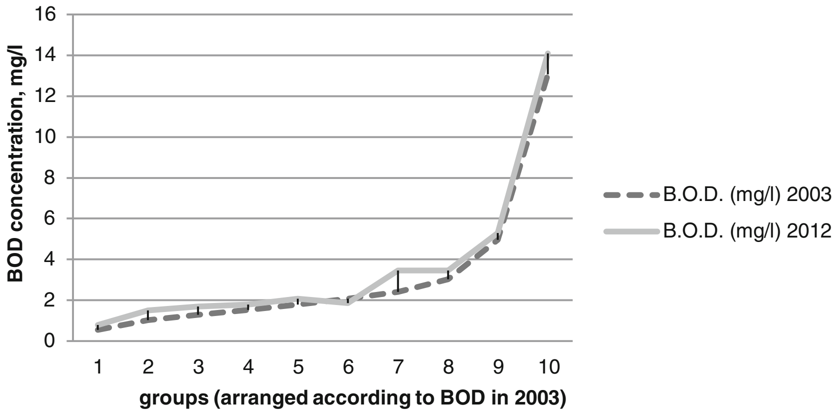

Fig. 3 Comparison of levels of BOD (group means), 2003 and 2012, common monitoring stations
Source Computed by authors using CPCB water quality data

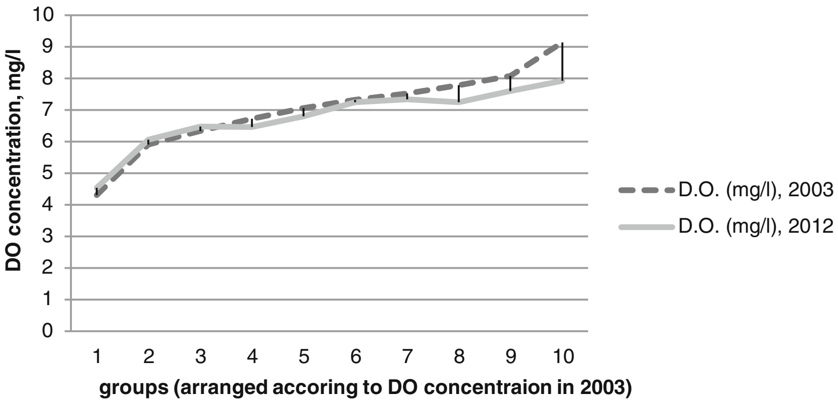

Fig. 4 Comparison of levels of DO (group means), 2003 and 2012, common monitoring stations
Source Computed by authors using CPCB water quality data

recorded BOD level above 6 mg/l. For the former group which includes 300 monitory stations, 85% of the stations remained in the same range of BOD in 2012. But, in 38 stations (about 13%), the BOD level rose to the range of 3–6 mg/l, and in another 7 stations (about 2%) it reached above 6 mg/l. This may be contrasted with the monitoring stations in which BOD level was found to be more than 6 mg/l in 2003. While in a majority of cases, the BOD level remained in this range in 2012, in 13 stations (about 22%) there was a decline, bringing the BOD level to less than 6 mg/l (in a few cases below 3 mg/l). Despite these changes in the BOD levels of individual monitoring stations, the averages for the two groups did not undergo any major change. For the first group (BOD level below 3 mg/l in 2003), the average BOD level across stations was 1.62 mg/l in 2003 which increased to 1.97 mg/l in

Table 1 BOD concentration level in monitoring stations, changes between 2003 and 2012 (number of monitoring stations)

BOD level in 2012	BOD, below 3 mg/l in 2003 (no. of stations)	Percent	BOD, above 6 mg/l in 2003 (no. of stations)	Percent
Below 3 mg/l	255	85.0	2	3.4
3–6 mg/l	38	12.7	11	19.0
Above 6 mg/l	7	2.3	45	77.6
Total	300	100.0	58	100.0

Source Computed by authors using CPCB water quality data

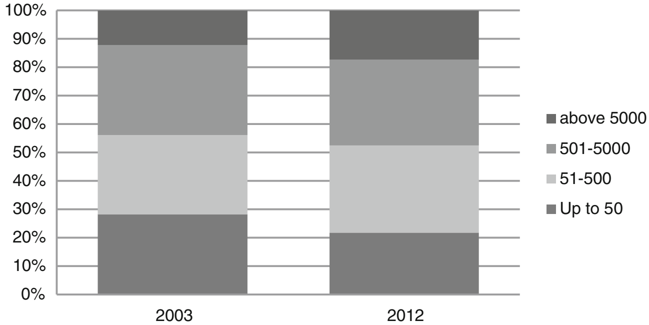

Fig. 5 Distribution of observations according to fecal coliform count (MPN/100 ml)
Source Computed by authors using CPCB water quality data

2012. For the second group (BOD level above 6 mg/l in 2003), the average BOD level increased from 12.9 mg/l in 2003 to 13.9 mg/l in 2012. Evidently, it is a small increase. But, it is an indication of a slight deterioration in water quality.

Having discussed the changes in BOD and DO levels, the change in *F-Coli* count may be taken up next. The distributions of monitoring stations (about 400 in number, common between 2003 and 2012) in regard to different ranges of *F-Coli* count are shown in Fig. 5. The count ranges are in terms Most Probable Number per Hundred milliliter (MPN/100 ml). Four ranges are considered: (i) below 50 (drinking water source standard), (ii) 50 to 500 (outdoor bathing standard), (iii) 500 to 5000, and (iv) above 5000.

Judged in terms of *F-Coli* count, there is an indication of deterioration in water quality. In 2003, about 28% of monitoring stations recorded *F-Coli* count of less than 50 MPN/100 ml. The corresponding figure in 2012 was about 22%. In other words, some 6% of monitoring stations had recorded *F-Coli* count of less than 50 MPN/100 ml in 2003 but did not maintain this standard in 2012. At the other end, in 2003, 13% of the monitoring station had recorded *F-Coli* count of more than 5000 MPN/100 ml. The corresponding figure for 2012 was about 17%.[7]

The overall conclusion that may be drawn on the basis of the data presented above is that during 2003–2012 there has been a slight deterioration in water quality in Indian rivers. This must, however, be juxtaposed to the rapid growth in Indian manufacturing that took place during this period, coupled with increases in the level of urbanization, leading to greater volume of industrial and urban wastewater. In other words, one may draw some comfort from the fact that despite the increases in wastewater from industries and cities/towns during 2003 to 2012, the quality of water in Indian rivers did not suffer any serious deterioration.

Before concluding this section, a brief discussion on the finding of a study undertaken by Greenstone and Hanna (2014) would be useful. The Greenstone–Hanna study is quite relevant to the analysis of trends in water quality in Indian rivers presented above. Greenstone and Hanna have examined air pollution and water pollution in India. For studying water pollution, they have taken a city-level panel data set for the period 1986–2007. The water pollution data cover 424 cities (162 rivers). They have examined the impact of the National River Conservation Plan (NRCP). Under this plan, efforts were made by the government to reduce industrial pollution and create sewage treatment facilities. The technique of econometric analysis applied by Greenstone and Hanna required pollution data on cities before and after the policy (i.e., NRCP) was in place in each particular city. A city was included in the analysis if it had at least one data point three or more years before the policy uptake and four years or more after the policy uptake.[8]

The results of the econometric analysis undertaken by Greenstone and Hanna (2014) indicate that the NRCP did not have a significant positive impact on the three measures of water quality that were considered for the study, namely BOD, DO, and *F-Coli* (this finding of Greenstone and Hanna is consistent with the trends in water quality in Indian rivers observed in this analysis presented above). By contrast, they have found that air pollution regulations did have a beneficial effect in reducing the level of pollution.

[7]Figure 5 indicates that the proportion of observations with *F-Coli* count below 500 MPN/100 ml declined between 2003 and 2012. This does not tally with Fig. 2 which shows that the relevant proportion increased between 2003 and 2012 (which would make one infer that there was some improvement in water quality). This discrepancy seems to be attributable to the fact that Fig. 5 is based on a common set of water quality monitoring points for 2003 and 2012, whereas the proportion for 2012 shown in Fig. 2 is based on a much larger number of monitoring points (many new monitoring pointes added over time) than that for 2003.

[8]The summary statistics of the sample data in Greenstone-Hanna study show an increase in BOD level over time. The mean in the period 1987–1990 was 3.5 mg/l and that during 2004–2007 was higher at 4.1 mg/l. But, one has to be cautious in interpreting these numbers because there are problems of data comparability (as noted earlier) arising from the fact that the number of monitoring points has increased over time.

5 Influence of Urbanization and Industrialization: A Preliminary Analysis

Urbanization and industrialization are expected to be major factors influencing and being the cause of river water pollution. A preliminary analysis is therefore undertaken to find out whether this is borne out by the water quality data along with data on urbanization and industrialization.

In Figs. 6, 7, and 8, the recorded BOD level, DO level, and *F-Coli* count in various water quality monitoring stations are plotted against the level of urbanization in the districts where the monitoring station is located (urbanization is measured by the share of urban population in total population of the district).

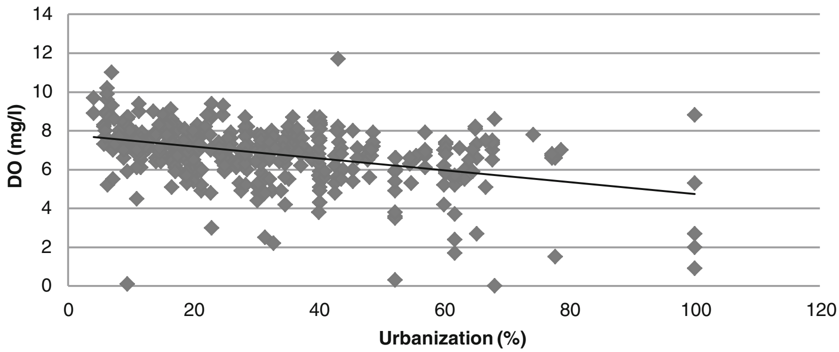

Fig. 6 Urbanization and level of DO (mg/l) in river water, 2012
Source Authors' computations using data as explained in the text

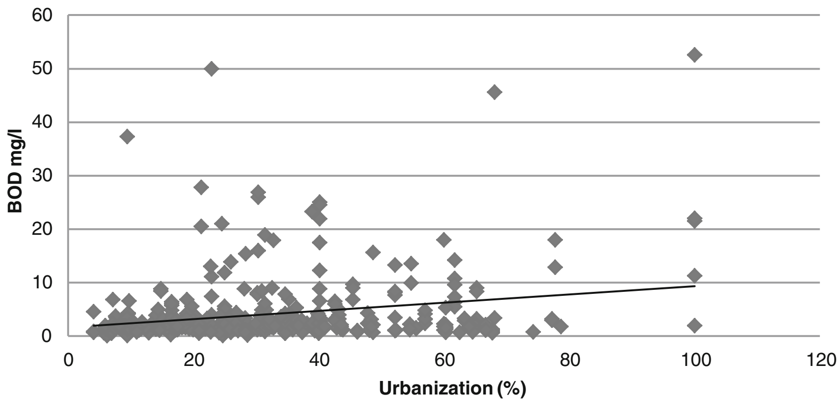

Fig. 7 Urbanization and level of BOD (mg/l) in river water, 2012
Source Authors' computations using data as explained in the text

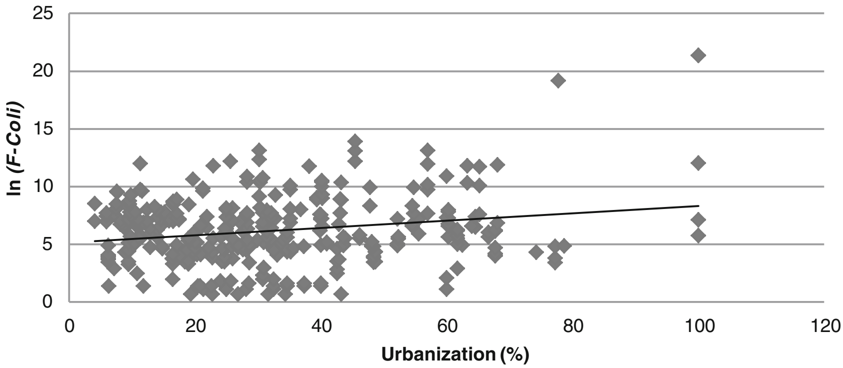

Fig. 8 Urbanization and fecal coliform count (MPN/100 ml) in river water, 2012
Source Authors' computations using data as explained in the text

The aim of this analysis is to utilize regional variations in river water quality and level of urbanization to examine empirically if these two are related. The data on water quality are for 2012, whereas the level of urbanization (which is based on Population Census data) is for the year 2011. The analysis is confined to water quality data for rivers. For BOD and DO, there are 411 and 417 observations, respectively.[9] In the case of count, there are 355 observations.

The plots of river water quality against urbanization indicate that a higher level of urbanization is associated with a lower quality of water in rivers. Such a relationship is obviously expected. The correlation coefficient between DO level and urbanization is found to (−)0.39, and that between BOD level and urbanization is found to be 0.24.

The *F-Coli* count varies widely across monitoring stations. While the 10th percentile is 4 MPN/100 ml, the 90th percentile is about 20,000 MPN/100 ml. The median is 316 MPN/100 ml. In view of the wide variation in *F-Coli* count, the logarithm of *F-Coli* count has been taken to prepare Fig. 8. The correlation coefficient between urbanization and *F-Coli* count (in logarithm) is found to be 0.21.

Figure 9 shows a plot between the level of industrialization in different districts and the DO level in river water recorded in monitoring stations located in the districts. To measure the level of industrialization in a district, the number of workers engaged in manufacturing has been divided by district population. Data on district population are obtained from Population Census 2011. District-level estimate of the number of workers engaged in manufacturing has been made by using the unit-level data of the Employment-Unemployment Survey (EUS) of NSSO (National Sample Survey Office) for 2011–12.

[9]The observations considered for the analysis presented here are those cases where water quality data could be matched with Census data, i.e. mapping the water quality monitoring stations into districts for which Census population data are obtained. There were other considerations too in deciding on water qualty monitoring stations to be covered for data collection for 2012, including availability of such data for 2003.

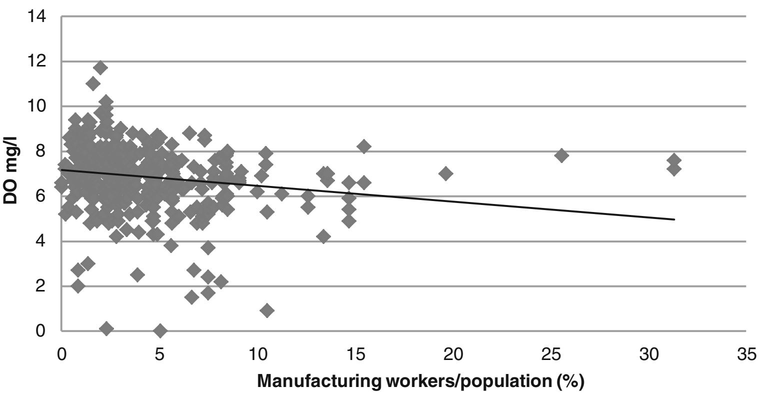

Fig. 9 Industrialization and level of DO (mg/l) in river water, 2012
Source Authors' computations using data as explained in the text

From Fig. 9, a negative relationship is evident between the level of industrialization in a district and the level of DO in river water as recorded in the water quality monitoring station located in the district. Such a relationship is obviously expected. The correlation coefficient is found to be (−)0.18. It would be noticed from Fig. 9 that there are some observations in which the level of industrialization is much above sample average but the level of DO in river water is almost at the sample average. If only observations with industrialization level below 15% are considered for the analysis which covers most the sample, the correlation coefficient is found to be (−)0.27.[10] This suggests that as industrialization progresses in a district, it tends to cause deterioration in river water quality in the district.

6 Determinants of River Water Pollution

6.1 Factors Influencing Water Pollution: Informal Regulation and Income Inequality

Urbanization and industrialization are two important factors influencing river water quality in India as noted in the literature[11] and as borne out by the analysis presented in Sect. 5 above. The explanation lies in the discharge of wastewater from

[10]Between industrialization and BOD level in river water, a positive correlation is found, again as expected. The plot is not presented in the paper.

[11]To give one example, Goldar and Banerjee (2004) have found a significant negative effect of urbanization and industrialization on water quality in Indian rivers based on the econometric analysis undertaken by them.

industries and cities/towns into rivers. It is known that many cities/towns do not have adequate wastewater treatment facility. Two other factors considered for the analysis in this paper are informal regulation and income inequality.

Informal Regulation

The importance of informal regulation in containing pollution has been noted in the literature.[12] It is believed that when formal regulation is nonexistent or weak, informal regulation through community participation can force the polluter(s) to undertake corrective action. Informal regulation may take many forms (Pargal et al. 1997a, b). These include community groups making demands for compensation or the community groups monitoring and publicizing firms' emissions. Other possibilities are the community groups reporting to regulatory institutions violation of legal standards on emissions by firms (where such standards and institutions exist) and putting pressure on the regulatory bodies to tighten their monitoring and enforcement.

It is generally held that important determinants of the strength of informal regulation are education, degree of political organization, and environmental awareness of communities, which interact with information availability, the presence of active media, the presence of non-governmental organizations (NGOs), and the efficiency of the formal system of regulation. These factors are important in determining the effectiveness of informal regulation. Since these are expected to vary directly with community income level, in several studies, the mean income of communities has been taken as a proxy to capture the effect of informal regulation.

To the knowledge of the authors, there have been so far four studies on informal regulation of pollution in India (Pargal et al. 1997b; Murty and Prashad 1999; Goldar and Banerjee 2004; Kathuria 2004). These studies have presented empirical evidence on the effectiveness of informal regulation. Considering the empirical evidence presented in these studies, it seems that there is sufficient empirical basis to infer that informal regulation does exert a significant influence on pollution in India, contributing to the containment of pollution. The findings of the above-mentioned four studies are briefly discussed below.

Pargal et al. (1997b) have stated in their paper that in a survey of industrial plants undertaken by them (covering 250 plants), 51 plants reported that they had adopted measures for pollution abatement because of NGO pressure and another 102 had said that they had done so because of complaints from neighboring communities. Clearly, this signifies the role of informal regulation in containing pollution.

Murty and Prashad (1999) have undertaken an econometric analysis for which they have taken district development index and the rate of participation in the previous parliamentary elections as variables representing informal regulation. They have estimated an econometric model using data for 100 factories in which they have attempted to explain the ratio of effluent BOD to influent BOD, i.e., the extent to

[12]For a discussion on informal regulation, in the general context and in the context of India, see Pargal and Wheeler (1996), Afsah et al. (1996), Pargal et al. (1997a, b), World Bank (1999), Murty and Prashad (1999), Kathuria (2004), Goldar and Banerjee (2004), Blackman (2009) and Murty and Kumar (2011).

which the factories reduce the BOD level in their final discharge of wastewater. From their analysis, they have found that pollution is significantly negatively related to the district development index and political participation by local communities. These results indicate that informal regulation exerts a significant effect on pollution, inducing factories to undertaken greater pollution abatement.

Goldar and Banerjee (2004) have used the literacy rate and participation in parliamentary elections among the explanatory variables in an econometric model estimated by them, aimed at explaining inter-regional variation in water quality in Indian rivers. Their results indicate that both literacy and participation in parliamentary elections (the latter showing if the communities are active politically) have a positive effect on water quality in rivers. This reflects the influence of informal regulation.

Kathuria (2004) has taken news in local press as a form of informal regulation. He has used monthly water pollution data from four hot spots of Gujarat for the period January 1996 to December 2000. He has found that sustained publicity of polluting activities of industrial units does have an impact, leading to a curtailment of the extent of pollution. The effect of media pressure on pollution has been found to be relatively stronger in the case of industrial estates with a mix of small, medium, and large units.

In short, there is empirical evidence indicating a significant role being played by informal regulation in containing pollution. Such evidence exists for India, as also for other countries.

Income inequality among communities

A key element of informal regulation is collective action on the part of the communities. There is some literature which suggests that inequality among individuals in a community may reduce the scope/possibility for collective action as it affects the group's decision-making power (Durlauf 1996; Benabou 1996; Alesina et al. 1999).

Zwickl and Moser (2014) have provided empirical content to the above argument in the context of action against air pollution exposure in different localities in the USA. Their analysis brings out how informal regulation gets conditioned by neighborhood income inequality. Zwickl and Moser have studied air pollution exposure in the USA by using a spatial lag model applied to detailed location-specific data on air pollution, income, and other demographic variables. In the model, they have controlled for formal regulation. After controlling for formal regulation, they have found that, in their estimated model, neighborhood income inequality measured by the ratio between the fourth and second income quartiles or the neighborhood Gini coefficient has a positive effect on local air pollution exposure. They have also found that a concentration of top incomes reduces local air pollution exposure. The explanation given by Zwickl and Moser for their empirical findings is that income inequality hinders collective action and thus reduces organizing capacities for environmental improvements. On the other hand, concentration of the income at the top level leads to concentration of political power which enables the rich residents to negotiate with the regulators or polluting plants in their vicinity.

6.2 *Regression Analysis: Influence of Informal Regulation and Income Inequality*

To study the influence of informal regulation and income inequality on river water quality in India, a multiple regression analysis has been undertaken. To measure water quality in rivers, three parameters of quality are considered, namely dissolved oxygen (DO, in mg/l), biochemical oxygen demand (BOD, in mg/l), and fecal coliform count (*F-Coli*, in MPN/100 ml). These are taken as dependent variables in the econometric models estimated. In the case of *F-Coli*, the count is not taken directly; the logarithm of *F-Coli* has been taken (because of wide variation in the recorded *F-Coli* count).

The econometric models are estimated by using water quality data for river water in 2012. The data source is the CPCB. The monitoring stations which provided data on river water quality for 2012 are chosen for the analysis.[13] Corresponding district-level data have been taken on the explanatory variables. Thus, a mapping of water quality monitoring station to districts has been done (as done earlier in Goldar and Banerjee 2004). The explanatory variables considered are urbanization, industrialization, literacy, and income inequality. The measures of urbanization and industrialization variables have been described above in Sect. 5 and therefore do not require further explanation. These variables relate to 2011. The literacy rate variable which is taken as a measure of informal regulation, as done in Goldar and Banerjee (2004), has been constructed from Population Census data at district level. These data also relate to 2011, as in the cases of urbanization and industrialization.

The income inequality data at district level are not readily available. This study therefore makes use of the estimates of poverty, consumption inequality, etc., for 2004–05 available in a paper by Chaudhuri and Gupta (2009) who have used unit-level data of the Consumption Expenditure Survey of the NSSO for 2004–05. The paper by Chaudhuri and Gupta provides district-level estimates of poverty headcount ratio (i.e., percent of people below poverty line) and the Lorenz ratio (i.e., the Gini Coefficient) for consumption expenditure for both urban and rural areas.[14]

The results of regression analysis are presented in Tables 2 and 3. The estimation of the model parameters has been done by the ordinary least squares (OLS) method. The results in Table 2 are for DO and BOD. In some of the regressions, urbanization has been taken as an explanatory variable, and in others, industrialization has been taken as an explanatory variable. Due to the presence of inter-correlation between these two explanatory variables, both could not be included in any of the equations. The results in Table 3 are for *F-Coli*. In this case, industrialization is not considered as an explanatory variable.

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[13]The analysis is confined to those monitoring points for which water quality data could be obtained also for 2003, since one component of the analysis (presented in Sect. 6.3) deal with direction of change in water quality.

[14]Note that the ratios being discussed are based on expenditure, not income. Such measures based on income are not available. Therefore, for this study, measures of inequality based on data on consumption expenditure are used.

Table 2 Determinants of water quality in Indian rivers, DO and BOD: regression results

Explanatory variables	Dependent variable: DO mg/l			Dependent variable: BOD mg/l		
	(1)	(2)	(3)	(4)	(5)	(6)
Urbanization	−3.08 (5.11)***	−3.59 (−6.19)***		5.36 (2.22)**	8.85 (2.70)***	
Industrialization			−6.33 (−2.99)***			14.24 (1.74)*
Literacy rate	2.05 (2.74)***	1.82 (2.44)**	1.47 (2.06)**	−13.58 (−4.56)***	−13.16 (−4.59)***	−9.55 (−3.75)***
Lorenz ratio (Gini coefficient), rural and urban areas combined	−0.87 (−0.62)		−4.21 (−3.10)***	11.60 (1.84)*		
Lorenz ratio (Gini coefficient) for urban areas		1.65 (1.40)			7.98 (1.29)	14.52 (2.34)**
Constant	6.69 (14.31)***	6.24 (12.61)***	7.33 (18.51)***	8.20 (4.64)***	7.65 (3.36)***	5.30 (2.39)**
R-squared	0.139	0.166	0.063	0.056	0.080	0.036
F-ratio and probability > *F*	13.29 (0.000)	13.27 (0.000)	7.81 (0.000)	8.53 (0.000)	7.65 (0.000)	5.63 (0.001)
No. of observations	379	381	379	373	375	375

Note Urbanization = urban population/total population of the district; industrialization = manufacturing employment/total population of the district; literacy rate = proportion of population who are literate; Lorenz ratio (Gini coefficient), rural and urban areas combined = a weighted average of Lorenz ratio computed by Chaudhuri and Gupta (2009) separately for rural and urban areas of each district, using the urban are rural population as weights. The Lorenz ratios are for 2004–05. Other explanatory variables are for 2001–12. The water quality data are for 2012

The figures in parentheses are *t*-statistics based on heteroscedasticity corrected standard error

*, **, and *** statistically significant at ten, five, and one percent level of significance, respectively

Source Authors' computations

Table 3 Determinants of water quality in Indian rivers, fecal coliform: regression results

Explanatory variables	Dependent variable: log (*F-Coli*, MSN/100 ml)					
	(1)	(2)	(3)	(4)	(5)	(6)
Urbanization	3.41 (2.58)**	3.78 (2.91)***	0.66 (0.55)	1.66 (1.54)	0.91 (0.77)	0.42 (0.34)
Literacy rate	0.72 (0.42)			31.76 (2.14)***		
Literacy rate squared				−21.35 (−2.00)**		
Literacy rate above 80% (dummy)		−0.64 (−1.50)	−0.99 (−2.71)**		−0.61 (−1.78)*	−1.15 (−2.97)***
Lorenz ratio (Gini coefficient), rural and urban areas combined			8.47 (2.49)**			11.22 (3.24)***
Lorenz ratio (Gini coefficient) for urban areas					8.52 (2.68)***	
Poverty headcount ratio, rural areas				0.032 (3.49)***	0.033 (3.88)***	
Poverty headcount ratio, difference between rural and urban areas			0.035 (4.20)***			
Constant	4.47 (3.99)***	4.90 (13.02)***	3.71 (4.57)***	−6.84 (−1.33)	3.28 (3.79)***	2.83 (3.36)***
R-squared	0.050	0.053	0.099	0.059	0.110	0.046
F-ratio and probability > *F*	4.77 (0.009)	4.50 (0.012)	7.66 (0.000)	4.52 (0.001)	9.16 (0.000)	5.07 (0.002)
No. of observations	359	359	338	338	338	338

Note Urbanization = urban population/total population of the district; industrialization = manufacturing employment/total population of the district; literacy rate = proportion of population who are literate; Lorenz ratio (Gini coefficient), rural and urban areas combined = a weighted average of Lorenz ratio computed by Chaudhuri and Gupta (2009) separately for rural and urban areas of each district, using the urban are rural population as weights. The Lorenz ratios are for 2004–05. Other explanatory variables are for 2001–12. The water quality data are for 2012

The figures in parentheses are *t*-statistics based on heteroscedasticity corrected standard error

*, **, and *** statistically significant at ten, five, and one percent level of significance, respectively

Source Authors' computations

It is evident from the regression results reported in Table 2 that urbanization and industrialization tend to affect water quality in rivers adversely. The coefficient of urbanization in the model for DO is negative and statistically significant (i.e., higher urbanization reduces the level of DO in river water), and the coefficient of this variable in the model for BOD is positive and statistically significant (i.e., higher urbanization raises the level of BOD in river water). For the industrialization variable also, the same pattern is seen. The coefficient of the industrialization variable is negative (and statistically significant) in the model for DO, and positive (and statistically significant) in the model for BOD.

The coefficient of the literacy variable is positive and statistically significant in the model for DO, and it is negative and statistically significant in the model for BOD. These results may be interpreted as showing that informal regulation (as proxied by literacy rate) tends to reduce pollution, and this leads to better quality of water in the rivers.

To measure income (expenditure) inequality, two variables have been used: Gini coefficient in urban areas and a weighted average of Gini coefficients of urban and rural areas (population weighted). The results for the income inequality variables are not as strong as those for the literacy variable or the urbanization variable. Nonetheless, there is clear indication from the results that increased inequality is associated with greater pollution. It should be noted that in regressions (3) and (6) the coefficient of the income inequality variable is negative and statistically significant at one percent level in the model for DO and it is positive and statistically significant at one percent level in the model for BOD. These results are in line with the findings of the study of Zwickl and Moser (2014) for air pollution exposure in the USA mentioned earlier. Thus, following Zwickl and Moser (2014), it may be argued that greater inequality in income (expenditure taken as proxy) comes in the way of collective action on the part of community groups and this prevents informal regulation from effectively containing pollution of river water.

The regression results for *F-Coli*, presented in Table 3, are by and large similar to the results for DO and BOD. A positive effect of urbanization on *F-Coli* count is indicated by the regression results. The coefficient is consistently positive, and it is statistically significant in some of the regression equations estimated.

A negative and statistically significant coefficient is not found for the literacy variable in regression (1). On further probing, it was found that the expected negative effect on literacy on *F-Coli* count in river water occurs beyond a threshold. Thus, a dummy variable is used which takes value one if literacy rate (for the district, rural and urban combined) is more than 80% and zero otherwise. The coefficient of this variable is found to be negative and statistically significant in several regression equations. These results may be interpreted as reflecting the role played by informal regulation in containing *F-Coli* pollution in river water.

As an alternative, both literacy rate and the square of the literacy rate are included in the regression equation (regression 4 in the table). This allows the literacy rate to have a nonlinear effect. The coefficient of literacy rate is found to be positive, and that of the squared term is found to be negative. Both coefficients are statistically significant. It may accordingly be inferred that the literacy rate in a district has a negative effect on *F-Coli* count in river water in the district only beyond a threshold (in respect of literacy). This is consistent with results obtained by using the dummy variable based on high literacy rate.

In the regression analysis for *F-Coli*, four variables have been used to capture the impact of income inequality. The Lorenz ratio or Gini coefficient for urban area is found to have a significant positive effect, which holds true also for the weighted average of Gini coefficients for rural and urban areas. Also, the coefficient for the variable formed by taking the gap in poverty headcount ratio between rural and urban areas (reflecting rural–urban income disparity) is found to be positive and statistically significant at one percent level. Further, when rural poverty headcount ratio is included in the model and other measures of income (expenditure) inequality are dropped, the coefficient of rural poverty is found to be positive and statistically significant at one percent level. The result does not change when rural poverty variable and Gini coefficient for the urban areas are both present in the regression equation. It appears from the regression results that other things remaining the same, a greater incidence of poverty in rural areas is associated with higher degree of *F-Coli* pollution in river water.

The results presented in Table 3 indicate that a high degree of income inequality in urban area or high income disparity between urban and rural areas of a district tends to be associated with higher pollution of river water with *F-Coli*. This empirical finding, along with a similar finding emerging from Table 2 regarding BOD and DO, shows that higher income inequality is associated with greater pollution of rivers. A key question is how this empirical finding is to be interpreted. It seems reasonable to argue that the empirical finding basically means that greater income inequality reduces the scope for collective action directed at environmental improvement and thus gets in the way informal regulation, as is argued in Zwickl and Moser (2014). But, there may be other possible interpretations of the empirical finding.

6.3 Additional Analysis

The analysis presented in Sects. 5 and 6.2 above brought out that urbanization and industrialization have adversely affected river water quality in India. This observed relationship is investigated further in this section with additional econometric analysis done.

Two exercises have been carried out. The first exercise is based on data on BOD level and *F-Coli* count in river water at various monitoring points in 2003 and 2012. In this exercise, a common set of monitoring points have been considered for the two years, 2003 and 2012, and a Probit model has been estimated to explain the direction of change in BOD and *F-Coli* levels; i.e., the model estimated for BOD provides for each monitoring point the probability of an increase taking place in the level of BOD between 2003 and 2012 and the model for *F-Coli* provides the probability of an increase in *F-Coli* count.

The second exercise has been undertaken using data on BOD level in river water at various monitoring points in 2012. The analysis is similar to that in Table 2 except that a dummy variable connected with million-plus cities (i.e., cities with population over a million in 2011) has been introduced. For the million-plus cities, a monitoring point close to the city and located downstream has been identified, and a dummy variable for such monitoring points has been included in the estimated regression equation. It is reasonable to assume that for a million-plus city, the water pollution level for a monitoring point downstream would be higher than that for a monitoring point upstream. Hence, if a district has a million-plus city and the level of urbanization is therefore high in the district, the adverse effect urbanization on river water quality is likely to be greater at monitoring points which are located downstream from the million-plus city than those located upstream. This aspect has been incorporated in the multiple regression equation, thereby improving the model specification.

The results of the first exercise are presented in Table 4. The dependent variable is dichotomous; it takes value one if there was an increase in the BOD level at the monitoring point between 2003 and 2012, and zero otherwise (defined similarly for *F-Coli* count). The explanatory variables considered for the analysis, as before, are urbanization, industrialization, literacy, and some measures of income inequality.

The model estimates in Table 4 indicate that the tendency for the water quality (in terms of BOD level and *F-Coli* count) to deteriorate between 2003 and 2012 was greater in a district which had a relatively high level of urbanization or industrialization or both. The basis for this inference is the positive and statistically significant coefficients of urbanization and industrialization variables in the estimates of the Probit model.

The coefficient of the literacy variable in the model for BOD is found to be negative and statistically significant. The same holds true for the model estimated for *F-Coli*. This is in line with the results reported in Tables 2 and 3. Based on the regression results presented in Tables 2 and 3, it was inferred that informal regulation tends to curb pollution of river water. This inference finds corroboration in the results reported in Table 4.

As regards the variables representing income inequality, the coefficients are found to be positive as hypothesized. The coefficients are not statistically significant in the model estimates for BOD. However, in the model estimate for *F-Coli*, the coefficient of the income inequality variable has the right sign and is statistically significant. This supports the inference drawn earlier that income inequality has an adverse effect on river water quality.

Let us now turn to the results of the second exercise. These are given in Table 5. The results in respect of the urbanization, literacy, and income inequality variables are similar to those in Table 2 and are therefore not discussed any further, except to note that there are indications from the results that urbanization tends to lower river water quality, informal regulation (proxied by literacy) tends to curb pollution, and income inequality has an adverse effect on water quality in rivers (probably because it comes in the way of effective collective action for pollution control).

Table 4 Direction of change in water quality (BOD and *F-Coli*) in Indian rivers, between 2003 and 2012: Probit model estimates

Explanatory variables	Dependent variable: Direction of change in BOD level (mg/l) (= 1 if increase in BOD level, 0 otherwise)			Dependent variable: Direction of change in *F-Coli* count (MPN/100 ml) (= 1 if increase in *F-Coli* count, 0 otherwise)
	(1)	(2)	(3)	(4)
Urbanization	0.915 (2.06)**	0.973 (2.43)**		0.799 (1.66)*
Industrialization			3.030 (1.70)**	
Literacy rate	−2.378 (−2.76)***	−2.011 (−2.38)**	−1.607 (−1.99)**	
Literacy rate above 80% (dummy)				−0.613 (−2.07)**
Lorenz ratio (Gini coefficient), rural and urban areas combined	0.498 (0.35)			3.094 (2.01)**
Poverty headcount ratio, rural areas		0.005 (1.28)	0.006 (1.43)	
Constant	1.19 (2.19)**	0.95 (1.65)*	0.83 (1.47)	−0.75 (−2.03)**
Pseudo-R-squared	0.021	0.024	0.018	0.032
LR square and probability > Chi-sqr	10.51 (0.015)	12.02 (0.007)	9.07 (0.028)	13.62 (0.004)
No. of observations	367	367	367	318

Note For each monitoring point, the direction of change in BOD level between 2003 and 2012 is considered which is then coded, one and zero (corresponding to increase and no increase), and taken as the dependent variable. This holds for regressions (1) to (3). In a similar manner, direction of change in *F-Coli* count is considered and taken as the dependent variable for regression (4). Explanatory variables are as explained in the notes in Tables 2 and 3

The figures in parentheses are t-statistics

*, **, and *** statistically significant at ten, five, and one percent level of significance, respectively

Source Authors' computations

The coefficient of dummy variable associated with the million-plus cities (for monitoring points which are located downstream of the city) is found to be positive. In three equations out of four presented in Table 5, the coefficient is statistically significant. It should be noted further the coefficient of urbanization goes down in numerical value when the dummy variable for million-plus cities is introduced. Yet, the coefficient of urbanization remains positive and statistically significant, as in Table 2, indicating adverse effect of urbanization on the quality of water in rivers.

How is the finding of a significant positive coefficient of the dummy variable associated with water quality monitoring points located downstream of the million-plus cities to be interpreted? One interpretation is that big cities not only

Table 5 Determinants of water quality in Indian rivers, BOD: regression results

Explanatory variables	Dependent variable: BOD mg/l (2012)			
	(1)	(2)	(3)	(4)
Urbanization	4.90 (3.17)***	4.11 (2.21)**	8.21 (3.90)***	7.15 (2.92)***
Dummy variable for monitoring points close to million-plus cities and located downstream	3.20 (1.72)*	3.03 (1.60)	4.70 (2.09)**	4.24 (1.81)*
Literacy rate	−13.24 (4.31)***	−13.15 (4.42)***	−12.26 (4.58)***	−12.45 (−4.53)***
Lorenz ratio (Gini coefficient), rural and urban areas combined		11.35 (1.82)*		
Lorenz ratio (Gini coefficient) for rural areas	9.63 (2.55)***			
Lorenz ratio (Gini coefficient) for urban areas				6.51 (1.03)
Constant	8.64 (5.23)***	8.18 (4.70)***	9.48 (5.55)***	7.91 (3.52)***
R-squared	0.070	0.070	0.112	0.102
F-ratio and probability > F	5.54 (0.000)	6.71 (0.000)	8.27 (0.000)	5.98 (0.000)
No. of observations	373	373	407	375

Note Explanatory variables are as explained in the notes in Table 2
The figures in parentheses are t-statistics based on heteroscedasticity corrected standard error
*, **, and *** statistically significant at ten, five, and one percent level of significance, respectively
Source Authors' computations

pollute river water in their vicinity, but also adversely impact the quality of river water at nearby downstream locations.

7 Conclusion

Water quality data of the CPCB for the period 1995—2012 given in their recent reports show that there has been a slow/modest improvement in water quality in Indian rivers between 1995 and the mid-2000s, and a gradual deterioration thereafter. However, an analysis of trends in river water quality based on data for common monitoring points undertaken in the paper reveals that there was a slight deterioration in water quality in Indian rivers between 2003 and 2012. In view of the harmful effects of water pollution on human health, agricultural yield, and aquatic ecology, this trend is particularly worrisome.

In this paper, we looked at the causes of water pollution in rivers in India and particularly focused on the role played by informal regulation in containing pollution of Indian rivers. We also examined the impact of income inequality on water pollution in rivers. For our analysis, each of the CPCB monitoring stations located along river stretches was spatially identified and assigned to a district. Economic and social characteristics of the district were then matched with the quality of surface water prevailing at a particular district for the econometric exercise.

From our analysis, we find that urbanization and industrialization are two important factors influencing river water quality. In view of the large volumes of wastewater discharge from industries and cities/towns into rivers, this is not very surprising. While efforts are being made to curtail the effluent discharge and untreated sewage discharge into surface water sources, the fact remains that large increases in urbanization and manufacturing are proving to be a largely unsustainable burden on these resources.

We believe that in such a scenario the role of informal regulation becomes crucial. The literature tells us that when formal regulation is nonexistent or weak, informal regulation through community participation can force the polluter(s) to corrective action. However, there are grounds to believe that high inequality among individuals in a community may reduce the scope for collective action as it affects the group's decision-making power. There are probably only a few studies on the impact of income inequality on pollution. The present study is perhaps the first one for India.

In our analysis, we find that urbanization and industrialization tend to affect water quality in rivers adversely. In most model variants, a significant and positive relation was found between level of pollution and these variables. The analysis also revealed that the tendency for the level of pollution of river water to rise over time (between 2003 and 2012) was more pronounced among districts with high level of urbanization and industrialization than among districts with low levels of urbanization and industrialization. Another interesting finding of our analysis is that big cities not only pollute river water in their vicinity, but also adversely impact the quality of river water at nearby downstream locations.

The econometric results obtained in this study point toward a negative effect of literacy on pollution. We found the coefficient of the literacy variable to be positive and statistically significant in the model for DO and negative and statistically significant in the model for BOD. As for *F-Coli*, the results indicated that literacy has a negative effect on *F-Coli* count in river water, but only beyond a threshold (say, literacy rate beyond 80%). These results could be interpreted as showing that informal regulation is effective in reducing pollution and thus leading to better quality of water in the rivers in India.

We however did not find a similarly strong relationship between income inequality and the level of BOD and DO in river water. On the other hand, a significant positive relationship of income inequality (say, income inequality between rural and urban areas) with *F-Coli* pollution in river water was found. These results, in our opinion, bring out the adverse effect that inequality has on effectiveness of informal regulation and lend support to the hypothesis that an equal society helps in attaining a better environment quality.

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Transaction Costs in Irrigation Management in Kathmandu Valley, Nepal

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1 Introduction

Agriculture remains an important livelihood option in developing countries like Nepal, where it not only contributes about 32% of the GDP but also provides employment for more than two thirds of the population (NPC 2007). Agricultural incomes crucially depend on productivity-enhancing infrastructure, irrigation being one of them. About 1.8 million hectares of land in Nepal is irrigable. However, currently, only 1.2 million ha of this area is under irrigation although the facility is not available even for this land throughout the year. The total irrigated area, as a percentage of the total cultivable area in Nepal, is only 28% (NPC 2007). In Nepal, both the state and the farmers play a role in creating and maintaining irrigation infrastructure (Regmi 2007). In areas where irrigation is by surface water through gravity flow, it needs either community or state involvement for both proper maintenance and for efficient water distribution.

The small-scale canal irrigation systems of the Kathmandu Valley typically represent common pool resource features of non-excludability and rivalry (see an early discussion of these issues by Coman (1911) in the American context).[1] It is

[1]In other contexts the excludability problem can be resolved (see, Araral 2009).

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difficult to exclude any farmer in the command area from utilizing irrigation water, but its use upstream will indubitably reduce its availability to those living downstream of the canal. Thus, water allocation and provisioning are two potential problems associated with the management of irrigation systems (Ostrom 1990). The operation and maintenance of an irrigation system require coordination among many farmers. Unfortunately, resource management is riddled with conflicts and free-rider problems which often result in poor maintenance (Tang 1992). Numerous solutions for creating a strong institutional mechanism have been suggested to solve such problems which include re-alignment of property rights, state action, as well as collective action at the community level (Baland and Platteau 1996).

Transaction costs are in the nature of investment in institutions for collective action in order to improve the productivity of irrigation systems through better coordination. In this paper, like much of this literature, the term "institutions" represent "rules of the game" (for a nuanced discussion, see North (1991)). Production is not just a technical relation between inputs and output but is located in a system of governance (Williamson 1998). Productivity differences between firms, and nations, could well be attributed significantly to differences in institutions (Acemoglu et al. 2014; North 1990). Received theory associates "efficiency" with lower transaction costs (Ostrom 2005). As Tadelis and Williamson (2013) point out, the central problem of economic organisation is adaptation to reduce transaction costs.

In agrarian systems, transaction costs have been found to have an inverse relationship with productivity (Stifel and Minten 2008). However, there is no uniformity in the empirical literature on what items are considered to be transaction cost. For example, Stifel and Minten (2008) measure transaction cost as the gap between farm gate prices and market prices which includes transportation costs. Toufique (2012) has included the cost of searching and monitoring agricultural labor as transaction costs. These inclusions lead to difficulty in separating out production costs from transaction costs.

Our study systematically estimates the quantum of transaction costs and analyzes the impact of transaction costs on agricultural productivity in Nepal's Farmer Managed Irrigation System (FMIS), which to the best of our knowledge has not been attempted by any prior study.

1.1 Transaction Costs: A Brief Discussion

Transaction costs are said to arise when an individual or a group of individuals exchange ownership rights over economic assets and enforce their exclusive rights. It includes the costs of (a) information search; (b) bargaining and negotiation; (c) ensuring the fulfillment of contract; (d) compensation valuation; and (e) legal expenses to gather evidence, present a case, challenge opponents, award and collect damages (Field and Olewiler 1995; Holloway et al. 2000). Some authors have also included the cost of isolation (or transportation from producer to market) as a transaction cost (Stifel and Minten 2008).

The total cost of bringing a commodity (or service) to the market comprises both transformation costs, which include the cost of inputs of land, labor, and capital involved in transforming the physical attributes of a good, and transaction costs, which include the cost of defining, protecting, and enforcing the property rights to goods (North 1990). Institutions, which are the key to achieving economic efficiency, must therefore minimise transaction costs by generating both trust as well as social norms for mutual benefit (North 1990; Ostrom 1994; Fukuyama 1995; Uphoff and Wijayaratna 2000).

1.2 Transaction Costs and Resource Management

Traditionally four key factors in natural resource management have been thought to have influenced transaction costs: uncertainty, asset specificity, frequency of decision-making, and care or effort intensity (Williamson 1985). Recently, adaptation costs for farmers facing climate change are also being considered (Araral 2013). Uncertainty about a resource, which could be due to natural factors (such as natural disasters, timing of monsoons) or man-made factors (such as security of property rights), can result in high levels of transaction costs. Similarly, the frequency of decision-making could raise transaction costs since transaction requires time, ranging from daily to seasonal, and resource commitment from involved agents (Birner and Wittmer 2004; Williamson 1991). Asset specificity describes the condition where an asset is essential in a particular transaction and its absence would adversely affect productivity. The asset could take any form—physical or otherwise and as Tadelis and Williamson (2013) emphasize the identity of transactors makes a difference to efficiency. In the case of effort- and care-intensive transactions, the former describes production activity while the latter describes protection activity (Fenoaltea 1984). If the existing institutional structure changes, the transaction cost structure may also change. Co-management has the potential to increase the ex-ante transaction costs although it may also result in a reduction in ex-post transaction costs (Kuperan et al. 1998).

Transaction costs exist at several resource management stages: description of the resource use context, regulatory design, and implementation of agreed rules (Hanna 1995). Previous studies have shown that transaction costs can vary across regions and sectors. In Kenya, transaction costs of landowners arising from collaborative wildlife management were relatively low (Mburu et al. 2003) but in the Philippines, monitoring alone accounted for more than 50% of the total costs of co-management in the fisheries (Kuperan et al. 1998). The transaction costs accounted for 37% of the total costs in another study from the Philippines of a community-based coastal management program where the share of the transaction cost was as high as 74% of the total cost in the implementation phase (Sumalde and Pedroso 2001).

In Nepal, Adhikari and Lovett (2006) found transaction costs to be a major component of resource management costs in the community forestry sector ranging between 9 and 14% of the total cost. Another study based on two irrigation systems located within the Kathmandu Valley distinguished between the conveyance and congestion costs for canal maintenance. When the conveyance cost of water was high, all farmers paid the maintenance fee regularly, but when upstream farmers showed reluctance to cooperate with downstream farmers, congestion costs became important and farmers paid more for waiting, watching, and negotiating (Osanami and Joshi 2005). These studies do not however systematically either estimate or analyze the nature of the transaction costs or their impacts on productivity in the irrigations systems of Nepal even though irrigation in Nepal has been widely studied.

1.3 Farmer Managed Irrigation Systems: A Short Review

In the 1960s and 70s, the Government of Nepal committed significant expenditure (approximately Nepali Rs. 17 billion according to various NPC documents) toward the development of irrigation canals with support from various external agencies. However, despite sophisticated engineering infrastructure and highly trained staff, the performance of these government-managed irrigation systems was not satisfactory (APROSC 1978; Singh 2010), leading both to low productivity and severe deprivation of tail-enders (WECS 1982). This received further attention with the commencement of its basic needs fulfillment program in the 1980s.

Recognizing its inability to develop and manage large numbers of irrigation infrastructure by itself, the Government started providing assistance to FMIS in different parts of the country in the 1980s with support from donor-driven programs (such as Irrigation Line of Credit (ILC), and Irrigation Sector Program (ISP)). However, while this helped to increase the irrigated area, it also placed many of the FMIS under the Irrigation Department for a short period of time (Pradhan 2002).

The need to devolve responsibility for irrigation systems management to local user organizations gained momentum in Nepal only after 1990. The Government of Nepal not only transferred irrigation systems to farmers but also provided strong institutional support to farmers for the management of irrigation water under the new policy (NPC 2007). However, various pieces of legislation, like the Water Resource Act of 1992, Water Resource Regulation of 1993, and Irrigation Regulation of 1999, vested the ownership of water with the state. These laws made it mandatory to register canals with the state even if they had been traditionally managed by farmers. Evidence suggests that the registration of irrigation systems has not fared well. Even in the Kathmandu Valley, which houses the capital of the country, registration of irrigation institutions had not reached the 50% mark despite the legal requirement to do so (Dulal and Pradhan 2002).

Since irrigation development has been a community-level concern given the nature of the terrain in the hill tracts, it is important to understand how transaction costs influence agricultural productivity. With this objective in mind, we examine the relation between transaction costs and productivity (measured as the total value of output per hectare).

2 Methods

Administratively, Nepal is divided into 75 districts which are further divided into Village Development Committees (VDCs) and Municipalities for purposes of governance. There are 3914 VDCs and 58 Municipalities including one metropolitan and four sub-metropolitan cities. The VDCs and municipalities are further subdivided into smaller units called the wards. There are 9 wards in each VDC while the number of wards in a municipality ranges from 10 to 35. Nepal has approximately 16,000 FMISs which irrigate approximately 714,000 hectare (i.e., 67% of the total irrigable area) of the country (Lam 1998; Pradhan 2002; Shivakoti 2007). The average farm size per household is 0.8 hectare (CBS 2001).

We chose three districts (Kathmandu, Lalitpur, and Bhaktapur) located in the Kathmandu Valley, which is reputed for its agricultural production.[2] The valley is home to about 1.7 million people 60% of whom reside in the urban centers while the remaining 40% reside in the countryside (CBS 2001). The total cultivable area in the three districts is approximately 12,800, 11,069, and 7097 hectare, respectively. The major cereal crops cultivated in the valley are paddy, wheat, maize, and millet while the major cash crops are potato, oilseed, and vegetable. Irrigation water is necessary for wheat, winter potato, and early paddy (planted before the onset of the monsoons in May). In the case of the paddy plant, the normal rainfall is sufficient once planted. The summer potato crop which is cultivated just after the harvesting of paddy does not need much water since the land is wet during this period. Only the winter crop is crucially dependent on irrigation, and potato and wheat are the typical winter crops although some farmers may get a second crop of paddy in this season. In some parts of Kathmandu, however, farmers plant paddy in May, in order to cultivate two crops of potato after the paddy harvest.

2.1 Data Collection Strategy

As a first step, we listed and categorized the 415 irrigation systems within the three districts according to the number of VDCs they cover. This classification yielded 51 large (comprising 3 VDCs and above), 122 medium (comprising 2 VDCs), and 242 small (comprising just 1 VDC) irrigation systems. We selected twenty systems from each category randomly. We collected both system-level data and household-level data. Selection of canals and households was done using the stratified random sampling technique.

We divided the farmers in the large systems into three groups as head-, middle-, and tail-enders while grouping farmers in the medium-sized systems into two as head- and tail-enders. On the other hand, we considered all farmers in the small

[2]At the time of the survey, Nepal was under political turmoil and it was difficult to undertake data collection in other parts of Nepal.

Table 1 Classification and selection strategy of FMIS irrigation systems

Systems	Systems covering village	Total systems within Kathmandu Valley	No. of systems selected randomly	Households selected randomly and surveyed	No. of households finally used in analysis
Small	1	242	20	60 (3 from each system)	55
Medium	2	122	20	120 (3 from head and 3 from tail of each system)	100
Large	3 and above	51	20	180 (3 from head, 3 from middle and 3 from tail-end users)	145
Total		415	60	360	300

Source Fieldwork by authors

system as head-end users. Since our sample included twenty canals from each category of irrigation systems, the number of households surveyed was 180, 120, and 60 for the large, medium, and small systems, respectively (see Table 1). We collected the data during the winter of 2007.

The survey instruments included two separate questionnaires that were administered at the system and household levels. The system-level questionnaire recorded the characteristics of the Water User Associations (WUA) and the canal system while the household-level questionnaire included questions about the respondent's and household's demographic and socioeconomic characteristics and their agricultural practices. It also recorded the time spent on different components of transaction during the two seasons, winter and summer, of the previous year, which was the year 2006. While the survey collected socioeconomic and institutional data, its main focus was on capturing transaction costs information.

2.2 Monetary Estimation of Transaction Costs

Transaction costs estimation involved both a direct monetary measurement as well as an imputed measurement. The direct measure included payments to hired labor while the imputed measure involved the opportunity cost of time that individuals expended on organizational work. Households in the Kathmandu Valley can opt for non-farm employment throughout the year. Thus, we use the normal daily wage labor rate in Kathmandu as the opportunity cost of time, which was arrived at by averaging the wage rates for the peak and slack seasons.

In the case of community-based resource management of irrigation water, farmers incur costs in the form of negotiation, in monitoring activities related to the institutional design, in maintenance of the organization, and enforcement of rights over the water. We therefore classify the transaction costs into two broad categories,

Table 2 Individual household annual transaction cost for different activities (N = 300) (in NRs)

Sl. No.	Item (Major components)	Mean	Std. Dev.	Min	Max
1	Formation	3.1	4.8	0	24.9
2	Communication	1.3	1.8	0	10.1
3	**Ex-ante (sum 1 + 2)**	6.6	8.6	0	33.9
4	Meeting	21	41.4	0	212.5
5	WWN	265.2	250.4	0	1400
6	**Ex-post (sum 4 + 5)**	291.7	258.8	0	1515.9
7	**Total (sum 3 + 6) (Household + System)**	298.3	259.3	**0**	**1518.3**

Source Fieldwork by authors

ex-ante and ex-post costs,[3] which we in turn divide into five broad activities: (i) meeting, (ii) formation costs, (iii) waiting, watching, and negotiating (WWN), (iv) conflict resolution, and (v) communication (see Table 2).

Operation and maintenance of canals cost money and some of the resources are generated internally by WUA members and these form part of the production costs. The delivery of water to the farm could however involve additional expenses (like supervision) in the nature of transaction costs which are over and above the maintenance costs. Efficient institutions are synonymous with lower transaction costs (ex-post), as a lower transaction cost implies more labor time being available for directly productive purposes. Institutional efficiency therefore is expected to have a direct and positive impact on agricultural productivity.

The *formation cost* is a one-time fixed cost which we calculated on the basis of the time and resources devoted by farmers at the time of WUA formation. Water allocation among other things is decided at WUA meetings. The time taken at such *meetings* constitutes a part of transaction cost.

Once there is an informal agreement, a larger group is invited which takes the shape of a general body which formalizes the formation of the WUA and selects the members of the Ad Hoc Executive Committee. They normally accept the format commonly used by other WUAs with minor alterations. Sometimes, a representative of Nepal Irrigation Water Users Association motivates the formation of a WUA and also participates in the initial general meeting. The next step is to register the association and it starts with an application to the Water Resource Committee. The cost of registration is very small (about NRs 50) but there are other associated costs which are larger like travel and time costs, typing and printing costs. After registration, the WUA gets a certificate of registration, and subsequently, a general body meeting of all the user farmers is convened. This meeting elects an executive

[3]The separation of ex-post and ex-ante costs is also sighted as a difference between the Property Rights Theory (PRT) and the Transaction Costs Economics theories. While PRT has stressed on reduction of ex-ante costs the latter have emphasised on reduction of ex-post costs (see Tadelis and Williamson 2013).

committee of up to 11 members. The committee must have at least 33% women and two should be from among the minority or deprived group of people.

Even after such allocation has been decided and agreed upon, given the weakness of such institutions in ensuring the contractual decisions, individual farmers end up *waiting* at the canal head and along the irrigation channel for their turn so that they receive their winter allocation. They also have to *watch* so that no one interferes with the supply to their fields and to ensure that their allocation is not taken by someone else. Sometimes, they also have to spend time *negotiating* since contracts in the WUA between participating farmers may be incomplete or need re-enforcing routinely. We also recorded the instances when a negotiation resolved a dispute. Our survey recorded the time spent on each of these activities by households and is labeled waiting, watching, and negotiating (WWN).

As far as water distribution is concerned, the upstream farmers usually have the right of prior appropriation. However, in some cases we found that downstream farmers were also able to negotiate water allocations. In Siddhipur Raj Kulo, for example, (located in the northeast of Lalitpur municipality) an institutional arrangement has evolved where the lower riparian farmers get the water before the upper riparian. One reason for this arrangement could be well-established social networks—almost all the farmers here are of the same caste (a social category, *Newar*). The chairman of the WUA is a widely respected civil servant who also worked within the royal palace and so all the farmers accepted his decisions.

On the other hand, in Sankhu (located in the northeast of Kathmandu District and one of the oldest towns of the Kathmandu Valley) where there is considerable social heterogeneity (different castes), there were reports of conflict. The people of Salambutar (lower riparian) were mostly Bahun Kshetry and the upper riparian were Newari, and there was lack of cooperation among them. There were reports of water diversion to the downstream farms at night for the plantation of paddy. This led to efforts by upper riparian to spend more time on supervision (WWN).

When participating farmers are unable to resolve an issue bilaterally regarding water distribution, then we term it as a situation of *conflict*. In this study, a conflict specifically meant dispute regarding water diversion in the last two cropping seasons which was not resolved mutually but required a mediator. Information was sought from the respondent if any member of the household was involved either as a conflicting party or mediator in any such dispute. If yes, we recorded the time and money spent in resolving the conflict and is a component of transaction costs.

While WWN and "conflict resolution" are ex-post transaction costs, "communication" and "formation" are ex-ante transaction costs. Meeting costs, depending on the nature of the meeting, could be either ex-ante or ex-post.

The formation cost is a one-time fixed cost which we calculated on the basis of the time and resources devoted by farmers during WUA formation. We therefore used the lowest bank interest rate in Nepal for lending during the period of the study (9%) to estimate the annual transaction costs of formation. To arrive at the annual formation cost, we took the annual interest on the original sum spent irrespective of which year the initial payment was made. Suppose a WUA was formed in 2004 and the formation cost was Rs. 1000 at that time, the annual formation cost was considered to be Rs. 90 for that WUA in our study.

We estimated the total annual transaction time by adding the expenses incurred by households at the system level as well as at the household level. In our study, the system-level transaction costs are communication cost, conflict resolution cost, general meeting time cost, preliminary meeting cost, and formation cost. The household-level costs are meeting costs and waiting, watching, and negotiating costs. In order to make these compatible and allow an analysis at the level of household, we divided the system-level total annual transaction time by the total number of households within the system and added it to the household-level transaction time. The general meeting time at the system level was included in the household's transaction cost estimate through the system-level costs in order to avoid the problem of double counting. We valued the imputed time cost by converting every 7 hours into one working day. We found that the system-level expenses attributable to the households are about 9% of the total transaction costs.

3 Results

Survey results show that the major part of the transaction costs are under the category of waiting, watching, and negotiating (about 81%) and ex-post transaction costs are about 90% of the total transaction costs per hectare (see Table 2).

The average ex-post transaction costs per hectare in smaller systems was the lowest and not unexpectedly, large systems had the highest ex-post transaction cost per hectare (see Table 3). Agriculture was the dominant occupation for at least one member of every household interviewed. The average family size was 6 while about half the household heads were illiterate. Most irrigation systems in the area were the work of the ancestors of the present users. Only 4 had been constructed using direct bilateral assistance during the present users' lifetime. Rivers and streams were the sources of water for most of the canals. The average irrigated area varied between 0.14 hectare (for small systems) and 0.20 hectare (for large systems) per household. The average length of the canal varied between 1.8 km in the case of small and medium canals to 2.8 km in the case of large systems (see Table 3).

All the 300 farmers in our sample were cultivating paddy which is the main summer crop. In winter, 269 farmers were undertaking cultivation of which 209 cultivated wheat and only 74 cultivated potato. Evidently, potato is the most remunerative crop. Potato cultivators reported the highest average value (gross returns) per hectare about NR 147,052 and wheat was much lower at NR 26,911. All farmers cultivated paddy in summer and the average return per hectare from paddy was reported to be NR 119,082 (see Table 4).

The winter crop is crucially dependent on irrigation as rain-fed agriculture in this season is not viable. Therefore, the reliability of irrigation will play a crucial role in crop choice and therefore farm profitability. The net scarcity of water after crop

Table 3 Summary table by type of canal system

		Large	Medium	Small	Total
Transaction cost (in NRs.)	Mean	2,249.90	2,536.60	1,306.70	2,172.50
	Confidence interval	[1,951.3; 2,548.4]	[2,041.4; 3,031.9]	[1,069.0; 1,544.3]	[1,949.0; 2,396.1]
Type of organisation (Registered = 1, Not registered = 0)	Mean	0.5	0.3	0.3	0.4
	Confidence interval	[0.4; 0.5]	[0.2; 0.4]	[0.2; 0.5]	[0.3; 0.4]
Canal quality (Good = 1, Poor = 0)	Mean	0.5	0.4	0.1	0.4
	Confidence interval	[0.4; 0.6]	[0.3; 0.5]	[−0.0; 0.1]	[0.3; 0.4]
Irrigation reliability (Reliable = 1, Not reliable = 0)	Mean	0.6	0.7	0.6	0.6
	Confidence interval	[0.5; 0.7]	[0.6; 0.8]	[0.5; 0.8]	[0.6; 0.7]
Total value of output/hectare (in NRs.)	Mean	179,916.4	164,243.2	147,125.9	168,680.4
	Confidence interval	[164,513.9; 195,318.9]	[146,766.2; 181,720.2]	[122,346.2; 171,905.6]	[158,192.4; 179,168.4]
Winter output/hectare (in NRs.)	Mean	58,636.70	56,983.30	49,234.60	56,284.40
	Confidence interval	[44,118.7; 73,154.6]	[42,910.3; 71,056.3]	[33,388.3; 65,080.9]	[47,378.0; 65,190.9]
Length (in kms)	Mean	2.8	1.8	1.9	2.3
	Confidence interval	[2.4; 3.2]	[1.5; 2.0]	[1.7; 2.1]	[2.1; 2.5]
Canal quality by type of system	Poor	24.33	20.67	17.33	62.33
(each cell represents % of all	Good	24	12.67	1	37.67
systems)	All	48.33	33.33	18.33	100
Type of organisation	Not registered	42.86	37.36	19.78	100
	Registered organization	56.78	27.12	16.1	100
Reliability of irrigation	Reliable	52.53	29.29	18.18	100
	Not reliable	46.39	33.73	19.88	100

Source Fieldwork by authors

Table 4 Value of Output per hectare and farmer's perception of reliability of irrigation water (for different crops)

Variable	Obs	Mean	Std. Dev.	Min	Max
Value of output per hectare (in NRs)					
Summer (Paddy)	300	119,082.5	46,917.3	19,200	230,400
Wheat	209	26,911.1	16,967.5	720	79,200
Potato	74	147,052.3	102,337.8	25,500	533,333.3
Winter Crops (Wheat + Potato)	269	56,284.4	74,039.6	720	533,333.3
Farmer's perception of reliability of Irrigation water					
Summer (Paddy)	300	0.7	0.4	0	1
Wheat	206	0.55	0.5	0	1
Potato	74	0.88	0.3	0	1
Winter Crops (Wheat + Potato)	269	0.63	0.5	0	1

Source Fieldwork by authors

choice has been adjusted to water availability will determine the likelihood of conflicts over water allocation, and, therefore, the size of transaction costs needed to resolve such conflicts. The perceived reliability of irrigation was 88% for potato growers, whereas it was only 55% for wheat growers in the previous agricultural year.

We examined the quality of canals because it crucially determines quantity of water flow in an irrigation system. When the flow is adequate, the transaction costs will be lower since conflicts are less likely to arise. We divided the infrastructure quality of canals, using parameters such as the use of concrete in the canal, the quality of lining of the canal, leakage in the canal, into two categories: good and poor (see Table 3). Canals were categorized as "good" infrastructure if it had more than 25% lining, and headworks with or without concrete. The rest were classified as "poor." On the basis of this classification, we determined most of the canals to be in "poor" condition either due to leakages arising from improper lining or due to lack of a proper dam structure at the intake point of the canal which made it difficult to consolidate water from the source.

We determined that approximately 62% of the households were using canals with "poor" infrastructure. Interestingly, most of the canals in good condition belonged to the large systems—probably because the water travels a longer distance in these canals and therefore requires better quality canals. Almost, all the small canals were in the category of "poor".

During our surveys, we learned that half the surveyed irrigation systems had undergone rehabilitation during the last 3 decades. Approximately 2/3 of the systems had received partial support from the government for this purpose. Only in the case of 10% of the systems were the user farmers themselves responsible for repairs. The users had received partial support from non-government donors to repair the remaining systems.

Some of the irrigation systems, formed after 1990, had formal registration. In most cases, the motivating factor in organizing and registering the institution had been the possibility of receiving external assistance to repair the canal. The large systems' category had the highest number of households with membership in registered WUAs compared to the medium and small systems (see Table 3).

A majority of the systems (60%) had not registered their WUA (see Table 5). According to our survey data, approximately 87% of the unregistered WUAs did not receive any support. In contrast, only 12.6% of the registered WUAs failed to receive any support and about 85% of them did receive support from the government. WUAs registered with government agencies had a higher likelihood of receiving financial assistance for maintenance purposes (the correlation between support and registered WUAs was 0.7, which was significant at 1%) (see Table 6).

Those who received external support also had high probability of having good infrastructure (correlation coefficient = 0.29, significant at 5%, see Table 6). Downstream and ex-post transaction costs are also positively correlated and significant even though the association is weak (0.18). One possible explanation for this is that those who are located downstream are likely to spend more time and effort to ensure that irrigation water reaches their fields. Thus, systems with registered WUAs had good infrastructure and more reliable irrigation. Where the ex-post transaction cost was low (i.e., where farmers exerted themselves less in ensuring the flow of water), or where the farmers were located downstream, they had less reliable irrigation. We also note that there is a negative relationship but insignificant association between ex-post transaction costs and total value of output per hectare (−0.08).

Overall, about 79% of the non-registered WUAs reported poor infrastructure quality while 70% of the registered WUAs reported good infrastructure quality (see Table 5). Our data suggest that large systems performed better in terms of infrastructure quality which declines as the size of the system decreases. Also, the proportion of WUAs which received government or external support is lowest among the smaller systems and highest among the large systems. It is possible that the

Table 5 Summary table by type of organisation and irrigation reliability

	Type of organisation			Irrigation reliability		
	Not registered	Registered	Total	Not reliable irrigation	Reliable irrigation	Total
Canal quality						
Poor	79.14	20.86	100	42.77	57.23	100
Good	30.09	69.91	100	29.25	70.75	100
Support from government						
No support	87.37	12.63	100	39.88	60.12	100
Received Support	14.55	85.45	100	33.33	66.67	100
Total	60.67	39.33	100	37.36	62.64	100

Source Fieldwork by authors

Table 6 Correlation matrix of select variables ($N = 300$)

	Support	Downstream	Total value per hectare	Type of organisation	Ex-ante TC per hectare	Ex-post TC per hectare	Canal quality
Support	1						
Downstream	0.0618	1					
Total value of output per hectare	0.0824	0.0262	1				
Type of organisation	0.7184***	0.0624	0.1600***	1			
Ex-ante TC per hectare	0.4241***	−0.0237	0.1147**	0.3541***	1		
Ex-post TC per hectare	0.1037*	0.1809***	−0.018	0.0333	0.2118***	1	
Canal quality	0.4506***	0.1653***	0.2279***	0.4866***	0.2233***	0.0189	1

Significance level $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$
Source Authors

larger strength in membership of the large systems enables them to lobby for external support much more than smaller groups.

The difference in the ex-post transaction costs between those who received support (higher costs) and those who did not (lower costs), irrespective of the type of system, was significant (see Table 7). There was no significant difference reported in total output per hectare but the downstream farmers incurred a significantly higher transaction costs than upstream ones (see Table 7). This is an expected outcome since problems of ensuring water supply to tail-enders in irrigation systems are well recorded in the literature (Ostrom 1990; Shivakoti 2007).

There was no significant difference reported in total output per hectare by upstream and downstream farmers which was not unexpected as farmers in order to achieve similar output spend time ensuring water flows and their WWN costs are higher as seen earlier (see Table 7).

We also examined the output and ex-post transaction cost differences between those who received support and those who did not in our sample (see Table 7). It turns out that farmers who belonged to a WUA which received support had higher ex-post transaction costs and also higher output per hectare.

Farmers during the interview were asked whether they received reliable irrigation water. On average, farmers who had reliable irrigation had a significantly higher productivity (see Table 7). The reliability of a system as expected would depend on the existence of good infrastructure: well-maintained canals in good working condition. Seventy-one percent of the farmers who had good infrastructure reported reliable irrigation and those with poor infrastructure reported only 57% reliability (see Table 5). So, the key to reliability is the presence of good irrigation infrastructure.

It is common for farmers in this area to have informal meetings before any organization is given shape. It is recognized in prior studies that if there is any prior social link or cooperative link, forming new groups becomes easier, less costly, and time-consuming (Putnam 1993). For groups that have never worked together before, consensus building could take considerable time and effort (Seabright 2000).

Although we did not collect data on other components of production costs during our survey, for purposes of comparison, we used the estimates of the Government of Nepal on the total annual human labor requirements for the cultivation of paddy, wheat, and potato, which was 181, 141, and 235 days, respectively. This dataset had a separate line item for cost of marketing which was used for calculation of profit by the agricultural department. We, however, only used the production cost data and not the marketing data.

Table 7 Summary table of two-sample *t*-tests (with unequal variances)

	Ex-post transaction costs per hectare (in NRs) by irrigation reliability (N = 265)			Ex-post transaction costs per hectare (in NRs) by location (N = 300)			Ex-post transaction costs (in NRs) by support (N = 300)		
	Not reliable	*Reliable*	*Combined*	*Upstream*	*Downstream*	*Combined*	*No support*	*Support*	*Combined*
Observation	99	166	265	154	146	300	190	110	300
Mean	2583.48	1907.84	2160.25	1819.42	2544.99	2172.53	2014.35	2445.75	2172.53
Standard error	198.82	155.76	124.04	151.83	171.60	115.95	129.79	221.47	115.95
Standard deviation	1978.28	2006.76	2019.14	1884.12	2073.51	2008.36	1789.07	2322.81	2008.36
Lower confidence limit	2188.92	1600.31	1916.03	1519.48	2205.82	1944.34	1758.33	2006.80	1944.34
Upper confidence limit	2978.04	2215.37	2404.47	2119.37	2884.16	2400.72	2270.38	2884.70	2400.72
T-value of diff = mean(0) − mean(1)		2.68			−3.17			−1.68	
Pr(|T| > |t|)		0.0081			0.0017			0.0946	
	Total value of output per hectare (in NRs) by irrigation reliability (N = 265)			Total value of output per hectare (in NRs) by location (N = 300)			Total value of output per hectare (in NRs) by support (N = 300)		
	Not reliable	*Reliable*	*Combined*	*Upstream*	*Downstream*	*Combined*	*No support*	*Support*	*Combined*
Mean	151,621.6	187,936.5	174,369.8	166,312.3	171,178.3	168,680.4	162,873.2	178,711.2	168,680.4
Standard error	8460.42	7539.60	5775.04	7581.15	7592.93	5359.41	6922.25	8361.53	5359.41
Standard deviation	84,180.11	97,140.99	94,010.84	94,079.63	91,745.71	92,827.72	95,416.67	87,696.45	92,827.72
Lower confidence limit	134,832.1	173,050	162,998.8	151,335.1	156,171.2	158,133.5	149,218.4	162,138.9	158,133.5
Upper confidence limit	168,411	202,823	185,740.8	181,289.6	186,185.4	179,227.4	176,528	195,283.5	179,227.4
T-value of diff = mean(0) − mean(1)		−3.21			−0.45			−1.46	
Pr(|T| > |t|)		0.0015			0.65			0.15	

Source Authors

4 Discussion and Conclusion

The share of transaction time as a percentage of the total human labor required for the production of crops on average was 5% when all households were considered—it was 4.5% for upstream and 6.5% for downstream households. Moreover, the transaction time for winter crops was four times that for summer crops. This is mainly because the summer crop has the benefit of the monsoon rains and is thus less dependent on canal water. Farmers rely on canal water to irrigate the winter crop and thus have to devote more time for WWN. Transaction cost per hectare, however, is only about 1.7% of the total value of output per hectare. Our understanding from field surveys is that if the farmers did not spend this time (primarily WWN) the resulting loss in productivity could be very large. Therefore, this is a cost-minimizing strategy for farmers.

We are not able to gauge whether our estimates of transaction costs are high or low because there are no other studies to date on transaction costs in Nepal's FMIS. Our findings are, however, consistent with those of Mburu et al. (2003) although our estimates are lower than those of Adhikari and Lovett (2006) as we have discussed earlier.

Our study confirms some of the received knowledge on institutions and FMIS but also provides new insights. We find that for smaller systems, formalization is associated with higher productivity. While transaction costs and productivity are weakly inversely related for households in large irrigation systems, and in small systems, transaction costs and productivity are positively correlated in unregistered WUAs (see Fig. 1) which nuances on Stifel and Minten's (2008) findings of an inverse relation. Farmers incur transaction costs at two stages: during registration of a WUA, which is an ex-ante cost, and after formation, which includes time for meetings, dispute resolution, and WWN, which are ex-post costs. WWN is the bulk and constitutes 81% of the total transaction cost. Transaction time was about 5% of the total human labor required for agricultural production. However, as a proportion of total value of output, transaction costs are only about 1.7%. Even though the transaction cost as a proportion of total output is small, transaction activities are clearly important to the farmers because they enable efficient water allocation. The absence of the transaction activity could cause a large drop in productivity due to dysfunctional water sharing arrangements resulting in unavailability of water (Alchian and Demsetz 1973). Our survey revealed that farmers with reliable irrigation reported higher productivity as anticipated. It is therefore rational for farmers to invest in ensuring reliable irrigation. This may also be driving the association between formalization and productivity in smaller WUAs as registered associations have greater access to external funds for maintenance of canals.

Our study confirms that farmers who are more in need of reliable irrigation undertake greater transaction activity. We find transaction costs are higher for households cultivating downstream in a canal system than those for households cultivating upstream. This is in conformity with much of the literature on FMIS (e.g., Ostrom 1990). Similarly, seasonal differences arise in transaction activity too. Transaction costs are four times higher for winter crops (when there is little rain) than for summer crops when the area receives monsoon rains.

While this study is able to compute the transaction costs incurred by farmers in FMIS, the expenses incurred by government agencies were not included and future studies could consider them for a more holistic evaluation of the WUA and FMIS. Further, the cost of cultivation information could be used to examine the efficiency of WUA at the farmer level and its causal impact on farm-level profits. Importantly, given the impacts on agriculture due to climate change that are increasingly evident, future studies could look at farmer adaptation costs in Nepal in the context of Transaction costs analysis.

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Part III
Environment and Human Well-being

Ecological Distribution Conflicts and the Vocabulary of Environmental Justice

Joan Martinez-Alier

1 Introduction

The increasing number of ecological distribution conflicts around the world is ultimately caused by the changing metabolism of the economy in terms of growing flows of energy and materials. "Ecological distribution conflicts" (Martinez-Alier 1995a, b; Martinez-Alier and O'Connor 1996) is a term for environmental injustices that comes from ecological economics. For instance, a factory may be polluting the river (which belongs to nobody or belongs to a community that manages the river—as studied by Ostrom (1990) and her school). This is not a damage valued in the market. The same happens with climate change, causing perhaps sea level rise in some Pacific islands or in Kuna islands in Panama or in the Sunderbans. More than market failures (a terminology that implies that such externalities could be valued in money terms and internalized into the price system), these are "cost-shifting successes" (Kapp 1950; Gerber 2016) which oftentimes lead to complaints from those bearing them. If such complaints were effective (which is not the rule), some activities could be banned, or if we accept economic commensuration and reject incommensurability of values (Martinez-Alier et al. 1998), "equivalent" eco-compensation mechanisms could be introduced. The economy would change accordingly.

The term "ecological distribution conflicts" has been used since 1995 to describe social conflicts born from the unfair access to natural resources and the unjust burdens of pollution. Environmental gains and losses are distributed in a way that causes such conflicts. While the term "economic distribution conflicts" in political economy describes conflicts between capital and labor (profits versus salaries), or conflicts on prices between sellers and buyers of commodities, or conflicts on the interest rate to be paid by debtors to creditors, the term "ecological distribution

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conflicts" in political ecology stresses the idea that the unequal or unfair distribution of environmental goods and bads is not always coterminous with economic distribution.

Such ecological distribution conflicts were perceived in terms of persistent injustices toward "people of color" in the USA giving rise to a social movement in the 1980s when the words "environmental justice" (EJ) began to be used in struggles against the disproportionate dumping of toxic waste in urban or periurban African-American areas. EJ offers a powerful lens to make sense of many struggles over the negative impacts that the changing metabolism imposes on human livelihoods and nature conservation worldwide (Gottlieb 2005). As early as in 1991, at the "People of Color Environmental Leadership Summit" in Washington DC, ties were forged so as "to begin to build a national and international movement of all peoples of color to fight the destruction and taking of our lands and communities" as the declaration states. The principles developed at this Summit spoke to the world and not to a minority. Participants wanted to establish humans' spiritual interdependence with the sacredness of our Mother Earth; to respect and celebrate each of our cultures, languages, and beliefs about the natural world and our roles in healing ourselves; to ensure EJ and promote economic alternatives which would contribute to the development of environmentally safe livelihoods; and to secure political, economic, and cultural liberation denied for five centuries of colonization and oppression, resulting in the poisoning of communities and land and the genocide of peoples.

Conceptually "environmentalism of the poor" is related to the EJ movement applied to rural and indigenous populations in India and Latin America. It was introduced by academics and also by activists like Anil Agarwal and Sunita Narain of the Centre for Science and Environment (CSE) in India in the late 1980s and Hugo Blanco in Peru and the early 1990s, respectively. Since the mid-1990s, the explicit connection between the two movements—EJ in the USA and the environmentalism of the poor in Latin America, Africa, and Asia—was established both in theory and practice (Martinez-Alier 1997; Guha and Martinez-Alier 1997, 1999). In the mid-1990s, classical books analyzing movements against dams (McCully 1996) and tree plantations (Carrere and Lohman 1996) were published by activists while Leonardo Boff's Cry of the Earth and Cry of the Poor (1995) established the connections between poverty and environmental complaints. Boff is a Brazilian "liberation theologist" whose work has been fully vindicated in Pope Francis' encyclical Laudato si' of 2015. The deaths of Chico Mendes (1988) fighting deforestation in Brazil, Ken Saro-Wiwa and his Ogoni comrades in the Niger Delta (1995) fighting oil extraction and gas flaring by Shell, and hundreds of others down to Berta Cáceres in Honduras (2016) fighting the Agua Zarca hydroelectric dam and grandmother Gloria Capitan (2016) in the Philippines struggling against coal stockpiling in Mariveles, plus many other deaths of environmental defenders (as listed by Global Witness, and also in the EJAtlas), have cemented the links between EJ and the environmentalism of the poor.

2 The Vocabulary of Environmental Justice

Since the 1980s and 1990s, the global EJ movement developed a set of concepts and campaign slogans to describe and intervene in ecological distribution conflicts. The conceptual language that has arisen from particular conflicts such as those collected in the EJAtlas has been critical to the development of global EJ networks and activist movements (www.ejatlas.org). We present here a set of concepts with origins outside academia, which are used by the global EJ movement (Martinez-Alier et al. 2014a, b; Sikor and Newell 2014). Many of them come from Latin America and India. Environmental Justice Organizations (EJOs) have produced not only a series of powerful concepts, but they also link them to practice through what Charles Tilly called "repertoires of collective action" in his study of other social movements (Martinez-Alier et al. 2014a, b; Tilly and Tilly 1981). Short definitions and the dates of origin of such concepts are provided in Table 1. This does not come only from the knowledge acquired through the EJOLT project (2011–15) and the compilation of the

Table 1 Vocabulary of the global environmental justice movement

Concept	EJOs ar other organizations promoting it	Short description
Environmental justice (EJ)	US Civil Rights Movement, North Carolina, 1982, against environmental injustices (Bullard 1990)	"People of color" and low-income populations suffer disproportionate harm from waste sites, refineries and incinerators, transport infrastructures
Environmental racism	Rev. Benjamin Chavis, 1982	The fight for EJ, against pollution in Black, Hispanic, Indigenous areas, was seen as a fight against environmental racism
Ecological debt	Instituto Ecología Política, Chile, 1992, Acción Ecológica 1997	Rich countries' liability for resource plunder and disproportionate use of space for waste dumping (e.g., GHG)
Popular epidemiology	Brown (1992, 1997)	"Lay" local knowledge of illnesses from pollution may be more valid than official knowledge (sometimes absent)
Environmentalism of the poor	A. Agarwal/S. Narain (CSE, Delhi) c. 1989	Struggles by poor/indigenous peoples against deforestation, dams, mining…; proactive collective projects for water harvesting, and forest conservation
Food sovereignty	Via Campesina, c. 1993	People's right to healthy, culturally appropriate, sustainably produced food. Right to define own food and agriculture systems

(continued)

Table 1 (continued)

Concept	EJOs ar other organizations promoting it	Short description
Biopiracy	RAFI (Pat Mooney) 1993, popularized by Vandana Shiva	Appropriation of genetic resources (in medicinal or agricultural plants) without recognition of knowledge and property rights of indigenous peoples
Climate justice	CES (Delhi), 1991, Durban Alliance, CorpWatch 1999–2002	Radically reduce excessive per capita emissions of carbon dioxide and other GHG. "Subsistence emissions versus luxury emissions"
Water justice, hydric justice	Rutgerd Boelens, EJOs in Latin America (e.g., CENSAT). 2011	Water should not run toward money or toward power. It should go to those needing it for livelihood
Water as human right	Pablo Solon (Bolivian envoy to UN), Maud Barlow (Council of Canadians), 2001	Human right to water recognized at UN level in 2011, as an independent human right
Green deserts	Brazil, network against eucalyptus plantations, Rede Alerta contra o Deserto Verde, 1999	Brazilian local term for eucalyptus plantations, used by networked CSO and communities, also by researchers and activists for any tree plantation
Tree plantations are not forests	Pulping the South, 1996 by R. Carrere, L. Lohman, World Rainforest Movement	The WRM collects and spreads information on tree plantation conflicts. It proposes a change in the FAO definition of forest, to exclude tree monocultures
Land grabbing	GRAIN (small pro-peasant EJO), 2008	The wave of land acquisitions in southern countries for plantations for exports, leading to first statistics on land grabbing
Resource caps	Resource Cap Coalition, RCC Europe, c. 2010	It advocates reduction in global resource use and in poverty. It calls for a European energy quota scheme and the ratification of the Rimini Protocol
To Ogonize/ Yasunize	ERA Nigeria, Acción Ecológica, Oilwatch, 1997–2007	Leave oil in the soil to prevent damage to human rights and biodiversity, and against climate change. Adopted by anti-shale gas fracking, tar sands, and open cast coal mining movements
Rights of nature	Ecuador, Constitutional Assembly, 2008	In Constitution of Ecuador 2008, art 71, pushed by Acción Ecológica and Alberto Acosta. Actionable in court
Corporate accountability	Friends of the Earth International, 1992–2002	At UN Johannesburg summit, FoE proposed the adoption of a

(continued)

Table 1 (continued)

Concept	EJOs ar other organizations promoting it	Short description
		Corporate Accountability Convention, against lukewarm CSR principles
Critical mass, cyclists rights	San Francisco 1992 (Chris Carlsson)	International movement reclaiming the streets, cyclists marching to impose cyclists rights
Urban waste recyclers movements	c. 2005, GAIA against incineration and "energy valorization" of urban waste	Unions or cooperatives of urban waste gatherers, with their positive environmental impact, including climate change (movements in Delhi, Pune, Bogota)
Urban "guerrilla food gardening"	c. 2000, started by "food justice" networks	Vacant lot food growing, permaculture, community gardening movements in cities around the world
Toxic colonialism, toxic imperialism	BAN, Basel Action Network, c. 2000	Fighting the long-distance export of waste from rich to poor countries, forbidden by the Basel Treaty, e.g., ship-breaking in South Asia, chemical residues or nuclear waste, e-waste
Post-extractivism	Latin America, 2007, E. Gudynas (CLAES), A. Acosta, Maristella Svampa	Against the reprimarization of LA economies. Transition to a sustainable economy based on solar energy and renewable materials. Impose quotas and taxes on raw materials exports
Buen vivir, sumak kawsay	Ecuador and Bolivia 2008	Adopted in Constitutions of both countries, inspired by indigenous traditions and by the "post-development" approach
Indigenous territorial rights and prior consultations	Convention 169 of ILO, 1989; Adivasi forest rights in India…	In conflicts on mining, oil exploitation, dams… communities ask for applying legislation defending indigenous rights
Sand mafias	Name given c. 2005 by environmental movement, journalists	The illegal "mining" of sand and gravel in India in many rivers, driven by the growing building and public works industry
Cancer villages	In China, popular name adopted by academics, officials (Lora-Wainright 2013)	Rural villages where industry has caused pollution (e.g., heavy metals), where lay knowledge of illness is relevant, and subdued protests take place

EJAtlas but also from previous research together with activists over many years (Martinez-Alier 2002; Healy et al. 2012).

There are concepts of academic origin (such as "working class environmentalism" (Barca 2012), "ecologically unequal trade," (Hornborg 1998) or "ecological footprint") that are also used or could be used by the global EJ movement. Here, we focus on concepts of non-academic origin. The first concept in the list is "environmental justice," born in the USA in struggles against waste dumping in North Carolina in 1982, as mentioned above. Activist authors such as sociologist Robert Bullard but also civil rights activists with no academic affiliation and members of Christian churches saw themselves as militants of EJ (Bryant and Mohai 1992; Agyeman et al. 2003; Pellow and Brulle 2005; Pellow 2007). The fight against the disproportionate incidence of pollution in areas predominantly black, Hispanic, or indigenous was also seen as a fight against "environmental racism," a concept that in the EJOs' language means to treat badly other people in pollution or resource extraction injustices on grounds of membership of particular ethnic groups, social class, or caste.

In EJ conflicts, the disproportionate incidence of morbidity or mortality sometimes cannot be proved from official statistics because of the lack of doctors or hospitals in the areas concerned. Consider the emergence of so-called "popular epidemiology" (Brown 1992, 1997), a concept of relevance in many struggles inside and outside the United States. A pertinent example would be the attempts by the plaintiffs in the Chevron-Texaco case in Ecuador to gather information in the 2000s related to the incidence of cancer in the Sucumbios region of the Amazon in the 1970s and 1980s. For this, memories of the local populations was resorted to, proving that such memories concentrated around areas with wells and pools for the disposal of extraction water (Martin Beristain et al. 2009). Think of the long battle to have valid figures on the victims of the Bhopal accident. Popular epidemiology implies that "lay" knowledge of pollution illnesses is not less valid than official knowledge. It is a concept that fits into the "post-normal science" theory (Funtowicz and Ravetz 1993), "street science" (Corburn 2005), and the notion of "activists mobilizing science" (Conde 2014).

Reflecting the specific environmental challenges and distributional inequities of the global South, some EJOs adopted the term "environmentalism of the poor" which as explained above is very close to the notion of EJ born in the USA but applies less to urban than to rural peoples in the global South, like the Navajo in New Mexico who suffered from uranium mining. Academics started to use this term in 1988–89 (drawing on research on India and Latin America). Similar words had been used by Anil Agarwal, the founder of the CSE in Delhi and editor of the First Citizens' Report on the State of India's Environment. His successor, Sunita Narain, often uses this term to refer to the struggles in India against dams, deforestation, mining projects, and nuclear power stations (Narain 2008). Recently, Shrivastava and Kothari (2012) have compiled many socio-environmental struggles and successes while putting forward a proposal for a radical ecology democracy.

The "environmentalism of the poor" (and of the indigenous) is a concept opposed to the influential "post-materialist" interpretation of environmentalism (and other new social movements) by Ronald Inglehart (Inglehart 1995). It does not envision environmental preservation as a luxury good, contrary to what Inglehart did. It is also contrary to Ulrich Beck's view of environmental risks as being impartial to social class (as might have been the case for a nuclear accident such as Chernobyl but which is not true in general) (Beck 1992). The "environmentalism of the poor" is expressed by the poor and indigenous in place-based struggles for their own material livelihoods. In most ecological distribution conflicts, the poor are more often than not on the side of preservation of nature against business firms and the State. This behavior is consistent with their interests and their values, including the defense of indigenous territorial rights and claims regarding the sacredness of particular elements of nature (a mountain, a forest, a river or lake, or even a tree). It follows that those affected will be motivated to act, provided that there is a sufficient degree of democracy and they are not suffocated by fear or are not violently repressed. In the EJAtlas, we have collected about 2100 cases of socio-environmental conflict by May 2017. In about 12%, one of the outcomes is (one or more) "deaths" of environmental defenders.

One of the primary environmental challenges faced by populations of the global South stems from an economic system that produces "ecologically unequal trade," an academic concept (Bunker 1985; Hornborg 1998, 2005; Hornborg et al. 2007) mentioned earlier. One form of such unequal trade has been called biopiracy by Pat Mooney of RAFI in 1993 and Shiva (1997). Biopiracy denotes the appropriation of genetic resources (in medicinal or agricultural plants) without any recognition of the original knowledge and "property rights" of indigenous peoples. The word "biopiracy" has been used in many complaints by EJOs. Even State authorities in Brazil and India have started to use this term. Many academics writers and doctoral students also use it (Robinson 2010).

There are a number of other EJO concepts and policies that stem from the conflicts over biomass. The many complaints against tree plantations grown for wood or paper pulp, depriving local people of land and water, led to the slogan and movement "plantations are not forests" twenty years ago. In Brazil, "green deserts" was the spontaneous, bottom-up name for eucalyptus plantations in some regions, which were opposed by local peasants and indigenous peoples. This was certainly a form of enclosure of commons. The driving force was the export of paper pulp and cellulose.

The related concept "food sovereignty" was introduced in the early 1990s by Via Campesina, an international movement of farmers, peasants, and landless workers. Food sovereignty means the right of rural people (including women in particular) to grow their own food for themselves and for local markets, against corporate agriculture, particularly against agrofuel monocultures and tree plantations (Schutter 2012; GRAIN 2005). A small organization called GRAIN introduced in 2008 the term "land grabbing" to showcase the new wave of land acquisitions—often by force—in southern countries, for new plantations for exports. The term was then taken up by the Journal of Peasant Studies in special issues, including a Forum on Global Land Grabbing (2011; vol. 38 issue 2).

A term originating from the EJOs that has been very successful in the fights against ecologically unequal trade and for identifying those responsible for climate change is that of the "ecological debt" (Robleto and Marcelo 1992; Borrero 1994). There was an alternative treaty in Rio de Janeiro in 1992 (in contrast to United Nations Conference on Environment and Development (UNCED), popularly known as Earth Summit), on the ecological debt from North to South. Acción Ecológica of Ecuador took the term and the struggled up in 1997, with several publications which included a definition and many examples. The ecological debt arises from the plundering away of resources and also from the occupation of disproportionate environmental space by the rich countries (to deposit an excessive amount of carbon dioxide in the oceans and the atmosphere, which belong to all humans equally). Some governments from countries of the South have deployed the concept of "ecological debt" (or one part of it, the "climate debt") in international negotiations on climate change (Bond 2010). In the 2009, Copenhagen Conference of the Parties (COP), perhaps over 30 heads of government or ministers, talked about the ecological debt awakening the fury of the US Ambassador, Todd Stern (Reuters 2009). The origin of the concept and many of the theoretical developments are mainly due to Latin American EJOs (Martinez-Alier 2002) and to some extent also to the international Friends of the Earth (FoE) and Jubilee South. Academics joined in later doing some calculations (Paredis et al. 2008; Srinivasan et al. 2008; Roberts and Parks 2009; Warlenius et al. 2015). Pope Francis' encyclical Laudato si' of June 2015 devotes paragraphs 51 and 52 to the ecological debt from North to South and to the environmental liabilities of transnational companies.

The position of the rich countries, in contrast, denies liability for climate change. Todd Stern, the US climate envoy, repeated in Paris in 2015 what he had said in Copenhagen in 2009: The USA had long acknowledged there was a need to support countries acutely vulnerable to climate change impacts, but there was "one thing that we do not accept and will not accept in this agreement and that is the notion that there should be liability and compensation for loss and damage. That is a line that we can't cross." He was supported by Miguel Arias Cañete, EU climate commissioner, who said there was now a "growing understanding" that loss and damage provisions would be included in the Paris agreement, as long as they did not expose wealthy countries to new claims for compensation. Therefore, the Paris agreement denies liability and offers no recognition of an ecological debt (Financial Times, December 6, 2015).

Unsurprisingly, it was also EJOs that had introduced and developed the related concept of "climate justice." An influential role in its introduction and dissemination was played by the CSE (Delhi) booklet of 1991, Global Warming in an unequal world: A Case of Environmental Colonialism, authored by Anil Agarwal and Sunita Narain pointing out that there were subsistence carbon dioxide emissions vs. luxury carbon dioxide emissions and it is important to differentiate the two (Shue 1994, 1999). Subsequently, in the late 1990s came the Jubilee campaign against northern financial bullying of the South, comparing the large ecological debt from North to South to the financial debt from South to North (Simms et al. 1999; Simms 2005).

The concept of climate debt was supported by the World Council of Churches, the Third World Network, Action Aid, and Christian Aid.

A 2000 event in The Hague sponsored by the New York group CorpWatch was the first known conference based on this term (Bond 2011, 2013). CorpWatch in a document in November 1999 stated that

> Climate Justice means, first of all, removing the causes of global warming and allowing the Earth to continue to nourish our lives and those of all living beings. This entails radically reducing emissions of carbon dioxide and other greenhouse gases. Climate Justice means opposing destruction wreaked by the Greenhouse Gangsters at every step of the production and distribution process—from a moratorium on new oil exploration, to stopping the poisoning of communities by refinery emissions—from drastic domestic reductions in auto emissions, to the promotion of efficient and effective public transportation. (Bruno et al. 1999)

Four years later, the Durban Group for Climate Justice was launched. It made itself well-known by its campaigns against fake Clean Development Mechanism projects.

The concept of water justice is associated with a university professor, Rutgerd Boelens (Wageningen University; Boelens et al. 2011), but he has been working so closely with activists for many years that he himself would no doubt like to see water justice or hydric justice as concept of the EJOs themselves. Their favorite slogans are "water runs towards power" and "water runs towards money" unless stopped by civil society movements. The World Commission on Dams (WCD) was a civil society initiative that reported its conclusions in 2000 (WCD 2000). Among its members were representatives of business and of the World Bank, and also of conservationist organizations. It arose because of the strength of resistance movements against dams, the most visible at the time being the Narmada Bachao Andolan in India where Medha Patkar's campaigns had been most influential (McCully 1996). The WCD's conclusions went directly against the unidimensional cost-benefit analysis procedures for deciding on dam building. The WCD report recommendations have not been implemented. Anti-dam movements continue to denounce water enclosures along with forced acquisition of land, diversion of rivers, and dispossession and displacement of rural and indigenous communities inhabiting territories rich in biodiversity and water sources (Rodriguez-Labajos and Martinez-Alier 2015). They include the Brazilian MAB (Movement of People Affected by Dams) and the MAPDER network in Mexico. The EJAtlas provides many cases on conflicts on water where several valuation languages are deployed.

Meanwhile, another new term has been appearing with greater regularity in recent years in EJ struggles: "the commons movement." This looks at the commons as a crucial sector of the economy which must be defended to preserve decommodified access to food, water, forests, and clean air (Di Chiro 1998). Influenced by Karl Polanyi, the movement fights against old and new enclosures. Since the late 1980s, as a reaction against Garrett Hardin's misnamed "tragedy of the commons," authors like John Kurien defended in India and elsewhere small-scale fisheries against large-scale industry, using the term "modern enclosures" or "the tragedy of enclosures" (Martinez-Alier 1991). In municipal water management, paradigmatic movements against privatization of urban water services as in Cochabamba, Bolivia, are sources of inspiration for the defense of the commons in general (including access to information) and also for the defense of the human right to water.

Proposals to "leave oil in the soil," also in defense of the commons, were first put forward in 1997. We now call them Yasunizing or Ogonizing, and they come from Acción Ecológica, Ecuador, ERA of Nigeria, and the Oilwatch network founded in 1995. Such proposals apply also to tar sands, to coal ("leave coal in the hole"), and to shale gas. In the form of moratoria to extraction projects, they are applicable in particular for areas of great biodiversity value and where human rights are threatened. To such local reasons, climate change reasons are added, based on the thesis that there are "unburnable fuels" if we want to stop increasing the concentration of carbon dioxide in the atmosphere (Temper et al. 2013). A new major figure in the climate justice movement, Naomi Klein (2014), became acutely aware of Ogonization and Yasunization movements—she calls them Blockadia, a name used by activists in Canada and the USA (sometimes indigenous) stopping the construction of oil and gas pipelines. One case in Sompeta (Andhra Pradesh) became well known because of the connection between local complaints and climate change (https://ejatlas.org/conflict/sompeta-power-plant). Community members, especially fishermen and farmers, were opposed to the construction of a coal-fired power plant since it would destroy their entire livelihoods. The proposed construction site was on an expanse of wetlands, and the villagers of Sompeta used this land to sustain their fisheries and farmlands.

Also in the field of energy policy, the civil society movements against nuclear energy since the 1970s gave rise to their own concepts. One of them, in Germany, was Energiewende (born in Wyhl, https://ejatlas.org/conflict/whyl-in-germany) which is now used in official public policy. Germans use sometimes a parallel term, Wachstumwende (growth turnaround), to translate the French décroissance or English "degrowth," a movement in some northern countries born in alternative urban or rural movements (Chatterton and Pickerell 2010) that disengage mentally and practically from the growth economy. In Germany, post-Wachstum is also used. The degrowth movement might support EJ (Healy et al. 2012), for instance by asking for resource caps, meaning a policy to reduce extraction of materials. Resource caps have been discussed since the 1990s (Spangenberg 1995) in terms of calculations of "fair shares" in the use of limited resources and limited environmental space. Degrowth is also very sympathetic to claims of an ecological debt from the South. This "degrowth movement has different sources (Martinez-Alier et al. 2010; Demaria et al. 2013; D'Alisa et al. 2014) including the proto-ecological economist Georgescu-Roegen (1971) but also the "post-development" movement of the 1980s of Ashish Nandy, Shiv Visvanathan, Gustavo Esteva, Arturo Escobar, Wolfgang Sachs, Serge Latouche, and Vandana Shiva (Sachs 1992). An alliance between the degrowth (or steady-state economy or post-Wachstum) movements in the North and the global EJ movement was proposed by Martinez-Alier (2012), while in South America there are calls for a "post-extractivist" economy (by Eduardo Gudynas, Alberto Acosta, Maristella Svampa) leading to buen vivir instead of economic growth.

Other new concepts that are growing among the EJOs are "energy sovereignty," "sacrifice zones" (Lerner 2010), "ecocide" (Zierler 2011), and the call for an international environmental crimes tribunal (complementary to demands for civil liabilities). Refusing to participate in the game of corporate social responsibility, the EJOs have asked for corporate accountability (Broad and Cavanagh 1999). The new provision on the "rights of nature" (introduced in Ecuador's Constitution 2008, article 71, after an original idea from Accion Ecologica) is also popular among the EJOs that see themselves as fighting against crimes against humanity and crimes against nature.

The movement in southern Italy denounces the eco-mafia and campaigns against waste dumping, complaining about "biocide" (Armiero and D'Alisa 2012). There must be many other national or regional terms of EJ that we could discover through the EJAtlas. For instance, in India conflicts on sand and gravel mining from rivers or beaches are particularly acute (with people getting killed in different states), and the new label "sand mafias" was given to this phenomenon. Similarly in China, in the complaints against pollution not only in urban areas but also in rural areas, the term "cancer villages" began to be used in the last ten years or so (Lora-Wainright 2013). Researchers registering such complaints in China appeal to the notion of "popular epidemiology" born in the 1980s in the USA. According to Lora-Wainright (2017), there is feeling of powerlessness among protestors against pollution in the Chinese villages she studied. In Argentina, there is a long-delayed but growing movement against glyphosate (used for transgenic soy cultivation introduced by Monsanto), under the name paremos de fumigar ("stop fumigating"). Laudato si' (para. 135) mentions the danger to people living near fumigated fields. In Brazil, one term from local transport conflicts is justiça nos trilhos, "justice in the railways" against the loss of life in accidents caused by massive iron ore transport to the export harbors (Porto de Souza et al. 2013).

For the EJ movement of the 1980s, with urban roots, a good environment as defined by the 1991 People of Color Environmental Leadership Conference in Washington DC was a safe, non-polluted place for living and making a living—environment is where we "live, work, and play." Most of the world population is now urban. Inside cities, there are interconnected movements introducing new concepts for a less unsustainable economy, such as "food justice," "transit justice," cyclist and pedestrian rights (cyclists' "critical mass" movements in many cities) (Carlsson 2008), and fights against gentrification. Such urban movements give a political meaning to squatting (Cattaneo 2011), and they remake places for groups in danger of being "displaced," re-assert traditional or new practices of land use, urban food production, and water harvesting, and try to protect territory from contamination, land grabbing, and real estate speculation (Gottlieb 2009; Gottlieb and Joshi 2010; Anguelovski 2014).

New terms and new cultural manifestations of the global environmental justice movement appear from time to time. Thus, in parallel to "land grabbing," the movement in defense of fisherfolk has proposed the slogan "ocean grabbing," to cast new light on processes of enclosures negatively affecting communities whose cultural identity and livelihoods depend on their involvement in small-scale fishing.

Ocean grabbing thus means the capturing of control by powerful economic actors of crucial decision-making around fisheries, their main concern being making profits by gaining control of both the fisheries' resources and the benefits of their use. https://www.tni.org/en/collection/ocean-grabbing.

In India in 2017, the Carnatic song by T. K. Krishna complaining about the destruction of Ennore Creek, North of Chennai, by coal-fired power plants and other polluting industries became a hit. The song condenses into a few phrases a research paper by environmentalist Nityanand Jayaraman, insisting that the meaning of the word Poromboke in Tamil is "the commons." Mangroves and beaches are commons and are being destroyed: Poromboke ennaku illai, poromboke unnaku illai (Poromboke is not for me, it is not for you). Poromboke ooruike, poromboke bhoomikku (Poromboke is for the city, it is for the Earth).

3 Conclusion

A well-known expert in agrarian studies who reviewed my boon The Environmentalism of the Poor (Bernstein 2005) wrote that it merely provided a series of "vignettes" of environmental conflicts, not weighty enough to support the thesis that there is a rural and urban global movement for environmental justice. Now, we have the EJAtlas and more evidence also from other sources to show that such a global movement exists although it (fortunately?) lacks a "central committee" or "politbureau." EJ networks spread out across borders (Keck and Sikkin 1998; Bandy and Smith 2005).

Environmental conflicts are related to the changing and growing social metabolism of industrial economies (Fischer-Kowalski and Haberl 1997, 2007, 2015; Steinberger et al. 2010; Martinez-Alier et al. 2014). Energy cannot be recycled. Therefore, the energy from the fossil fuels can be used only once, and new supplies of coal, oil, and gas must be obtained from the "commodity extraction frontiers" (Moore 2000). Similarly, materials can be recycled only in part, and therefore, even an economy that would not grow would need fresh supplies of iron ore, bauxite, copper, and paper pulp. The economy is not circular; it is entropic (Haas et al. 2015). Meanwhile, renewable resources such as aquifers, timber, and fisheries are overexploited, the fertility of the soil is jeopardized, and biodiversity is depleted. Thus, the changing social metabolism of industrial economies (including the excessive production of carbon dioxide) gives rise to conflicts on resource extraction, transport, and waste disposal. Such ecological distribution conflicts sometimes overlap with other social conflicts on class, ethnicity or indigenous identity, gender, caste, or territorial rights. The gains and losses of the use of the environment are often unjustly distributed not only with regard to other species or future generations of humans but also among humans living today. There are many local movements expressing their grievances over such environmental injustices. Sometimes, there are complaints against international ecological and economic unequal exchange. Sometimes, in large countries such as India, there are complaints against internal colonialism.

Several groups have been producing inventories of ecological distribution conflicts (by country, continent, or theme), such as OCMAL in Latin America on mining conflicts or Fiocruz in Brazil on all kinds of environmental conflicts (Porto de Souza et al. 2013). Our own contribution has been to build up the EJAtlas at ICTA-UAB (Temper et al. 2015, Martinez-Alier et al 2016) with many outside collaborators.

Social mobilizations over resource extraction, environmental degradation, or waste disposal are not only about the distribution of environmental benefits and costs (expressed in monetary or non-monetary valuation languages); they are also about participation in decision-making and recognition of group identities. All such issues appear very regularly in the cases collected in the EJAtlas (Schlosberg 2007; Walker 2012; Sikor and Newell 2014). EJ research encompasses issues of exclusion (Agarwal 2001) but also of the potential new leadership of environmental movements by different social actors; e.g., in the environmentalism of the poor as in EJ movements in general, it is crucial to recognize the contribution women make in poor communities both rural and urban (Agarwal 1992). Since the 1980s, EJOs and their networks have provided definitions and analyses of a wide array of concepts and slogans related to environmental inequities and explored the connections and articulations between them. The protests against the World Trade Organization in Seattle in 1999 and at the World Social Forums of the 2000s certainly pushed forward the globalization of EJ (for instance, the Ecological Debt was featured in the alternative meetings to the WB and IMF assembly in Prague in 2000). There were earlier underpinnings in the alternative "treaties" signed at Rio de Janeiro in 1992 and in the 1991 People of Color Environmental Justice Leadership Summit. EJ spread through organizations like Friend of the Earth, which, while born in California as a "white" conservationist movement, brought in EJOs which existed since the 1980s like CENSAT in Colombia and WALHI in Indonesia. Other environmental organizations such as the CSE in Delhi and Acción Ecológica in Ecuador linked the idea of environmentalism of the poor with wider notions of EJ and climate justice (FOEI 2005).

With these activist and social movement roots, the concepts of EJ were then taken up in academic research in political ecology studying southern countries. Going beyond case studies, researchers now generate statistics on ecological distribution conflicts (Özkaynak et al. 2012; Latorre et al 2015; Martinez-Alier et al. 2016) made possible by the EJAtlas and similar inventories. The social sustainability sciences (human ecology, ecological economics, political ecology, environmental law, environmental sociology, ecological anthropology and ethno-ecology, environmental history, environmental politics, urban ecology, agroecology, industrial ecology) have an academic origin, with international societies, academic journals and handbooks, and professorships that go under such names. Many concepts and theories have been produced in these booming fields of science in the last 30 years. There are also grassroots concepts for sustainability introduced by EJOs which have been discussed here and which are also objects of academic research. Such concepts support the global EJ movement, and at the same time they also support local rural and urban movements protecting territory and defending place-based interests and values (Escobar 2008; Anguelovski and Martinez-Alier 2014).

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Forest Dependence and Poverty in the Himalayas—Differences Between India and Nepal

Priya Shyamsundar, Saudamini Das and Mani Nepal

1 Introduction

There are over 1 billion people around the world who are dependent on forests for a variety of goods and services (World Bank 2016). For such forest-dependent people, forests act as both a constraint to movements out of poverty and a source of economic well-being. Thus, strategies to conserve forests and reduce rural poverty, often, revolve around a legitimate enquiry about how poor households, whose livelihoods depend on forests, can be supported alongside forests.

Poverty reduction in most rural areas is a result of improvements in agricultural productivity, income diversification, or migration (World Bank 2008, ILO 2014). The remote locations where forests are found make it difficult for households to access public infrastructure, services, and markets. This in turn constrains their ability to diversify income sources or build the required human or economic capital. In fact, it is possible that such households are in geographic poverty traps that keep them tied to subsistence activities and relatively unproductive lands (Jalan and Ravillion 2002; Kray and McKensie 2014; Barbier and Hochard 2016).

Forests are also a source of "environmental income" to many households. Families depend on timber and non-timber forest products to meet multiple

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economic needs. Thus, for many rural households, forests act as a means of diversification. Environmental income can act as a buffer during times of economic downturn, allowing households to smooth consumption over time and use forests as a safety net (Pattanayak and Sills 2001; Wunder et al. 2014). There is a large literature that documents the value of nature's rent, i.e., the goods and services freely provided by nature (Cavendish 2000; Sunderlin et al. 2005; Vedeld et al. 2007; Angelsen et al. 2014). An earlier meta-analysis estimated environmental income to be as high as 22% of income, for households who lived in and around forests (Vedeld et al. 2007). More recent analysis suggests that environmental income makes up some 28% of total household income in certain areas. This income is somewhat equivalent to what households obtain from agriculture (Angelsen et al. 2014). Naturally, environmental income varies across geographies and forest condition and depends on whether households use forests for subsistence purposes such as energy and food or whether they use it to market timber and non-timber forest products.

In addition to providing timber and non-timber forest products, forests also provide ecosystem services that make households more resilient to shocks. Forests provide hydrological services, for instance, that serve many needs (MEA 2005). In some cases, the presence of forests can improve water supply, in other cases, sediment filtration results in cleaner water, and, in still other cases, forests can provide storm protection, reducing the impacts of floods (Daily et al. 1997; Das and Vincent 2009; Das and Crepin 2013). Such ecosystem services are increasingly important as households cope with climatic changes.

The complex interconnections between people and forests make deforestation and forest degradation difficult to address without taking care of people's economic needs and vice versa (World Bank Group 2016; Colfer et al. 2015). Reducing poverty in remote rural areas may require targeted geographic investments (Barbier and Hochard 2016; Shyamsundar et al. 2017). It may also need investments that strengthen people's rights over forests, improve the productivity of forests, support the creation of forests and ecosystems-based markets, and build public infrastructure and services that can help households add value to forest products or take advantage of labor markets in distant areas (Shyamsundar et al. 2017).

Globally, an important transformation has occurred in the forests sector over the last few decades that has implications for rural poverty. The rights of local communities over natural resources have slowly been strengthened through power-sharing agreements with the state, increased legal access to natural resources and decentralization within national agencies (World Resources Institute 2005; Shyamsundar and Ghate 2014). Community ownership and management over forests increased from 21% in 2002 to 30% in 2013, even though this trend is largely restricted to Latin America and China (Rights and Resources Initiative 2014). Nepal is a prime example of strengthened local management of forests (Kanel 2008). While evidence of the implications of community forestry on poverty reduction is not very clear, providing rights to communities may be foundational for enabling better use and management of forests (FAO 2011; Shyamsundar and Ghate 2014).

In South Asia, as elsewhere, the rural poor are dependent on forests both for economic goods and for services associated with agricultural productivity, water availability, soil erosion, and flood protection. (Gundimeda and Shyamsundar 2012;

Mukhopadhyay and Shyamsundar 2012; Baland et al. 2010). Some 50% of Indian households use local commons, whether they are pastures or degraded forests (Chopra and Dasgupta 2008). In Nepal, rural property value differs based not only on distance from the forest but also on the types of forest management regimes from where households gather firewood (Nepal et al. 2017a). Evidence suggests a complementarity between community forest management and planting trees in private lands (Nepal et al. 2007). Thus, forests are an important source of rural wealth and well-being, and degradation will have both short-term and long-term impacts on the rural poor (Gundimeda and Shyamsundar 2012).

In the lower Himalayan region, India and Nepal share geographic conditions that are very like each other. However, the two countries have vastly different policies and regulations. India is a much more developed country with a higher per capita income and a relatively large network of roads and markets. On the other hand, in the mid-hills of Nepal, community rights over forests are well developed and rules to manage forests are better established at the local level (Shyamsundar and Ghate 2014). Thus, forest policies and rural development policies differ. But does this matter for how households survive and thrive in and around forests?

In this paper, we examine forest-dependent households along the Indian and Nepal Himalayas and ask how they differ in the two countries. We seek to understand what affects these differences. In the sections below, we first undertake a brief and broad scan of forests, forest use, and laws that govern use in India and Nepal. We then focus on a group of rural Nepali and Indian households in the Himalayan region who live across the border from each other. We examine their use of forest resources to assess how poor households who start with the same natural endowments may exploit resources differently. We examine dissimilarities in socioeconomic characteristics of Indian and Nepali households and correlates of poverty. We use data from a survey of 652 households (301 in India and 351 in Nepal)[1] to address poverty and forest linkages among households who are just separated by a river and face rules and regulations of two different countries.

2 Forest Use in India and Nepal

A little less than a quarter of the land area in both India and Nepal is designated as forests (see Table 1).[2] Forest use in both countries is closely tied to energy needs. In India, while modern energy sources dominate, fuelwood is regularly used in rural

[1]These households were surveyed for the project “Valuation of Ecosystem Services of Kailash Sacred Landscape” undertaken jointly by the South Asian Network for Development and Environmental Economics (SANDEE) and the International Center for Integrated Mountain Development (ICIMOD) under the Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI).

[2]This is contested data as latest Nepal forest inventory data indicate that 40% of Nepal’s land area is in forests and 4% in shrub (DFRS 2015).

Table 1 Economic and forest indicators in South Asia

Attributes	India	Nepal	South Asia
GNI per capita ($)	1570	730	1496
Population per square km	436	197	360
Under five mortality rate (per 1000 live births)	48	36	53
Agriculture land (% land area)	61	29	57
Electric power consumption per capita (kWh)	765	128	673
Energy from biomass products and waste (% of total)	24.3	80.6	26.3
Forest area (% land area)	23.8	25.4	17.5
Annual deforestation rate (average annual %, 1990–2010)	−0.5	0.5	−0.4
Protected areas (% land area)	5.4	22.9	6.6

Source https://openknowledge.worldbank.org/bitstream/handle/10986/24543/9781464809286.pdf. Accessed 31st March 2017

areas. In Nepal, nearly 90% of energy used comes from biomass products and waste. In both countries, forests provide fodder and bedding for livestock and timber for housing and agricultural implements. There is also a growing literature that points to the ecosystem services provided by forests.

Given dense populations and large-scale economic development, both India and Nepal confront deforestation and degradation. Nepal's estimated annual rate of deforestation is higher than India, with degradation and deforestation being attributable to forests use for fuelwood, fodder, illegal logging, and forest conversion for agricultural use, roads, and other development activities (Acharya and Dangi 2009; Table 6). In India, positive changes in forest cover are attributable to growth in plantations and community forestry, while negative changes are likely to be a result of shifting cultivation, submergence from dams, etc. (FSI 2011; Table 2.8.1).

The history of forest laws across South Asia reflects a tension between forces for conservation and those for strengthening community user rights over forests. In Nepal, forest nationalization in the 1960s is acknowledged as having triggered deforestation. This caused significant alarm, and, in 1974, a new policy discussion emerged on the role of local communities in forest management. Some 25 years later, in 1986–88, a master plan for the forestry sector was prepared and large areas of forests in the middle-Himalayas were handed over to traditional users (Kanel 2008). Community Forestry User Groups (CFUGs) were established to manage and sustainably use forests. These organizations became independent, self-governing entities with forest access, utilization, and management rights (Kanel 2008). Currently, there are over 14,000 CFUGs scattered across Nepal. Community forestry is viewed as a successful test of decentralized forest management, and improvements in forest cover, in many parts of Nepal, are attributed to community management (Shyamsundar and Ghate 2014).

Forest policy in India has also changed significantly over the past 100 years or so. In British India, forests were mainly a source of commerce, given huge demand for building railways (Guha 1983). However, prior to independence (in 1931), widespread protests over laws that reduced local control over forests led to the creation of Van Panchayats (forest committees), which were given some autonomy over forest patches. This historic experiment in decentralized forest management was given a boost in the 1980s, when the National Forest Policy of 1988 launched Joint Forest Management (JFM). JFM builds village-level institutions, called Forest Protection Committees (FPCs), which are expected to participate in forest management. By 2009, there were at least 84,000 FPCs in twenty-seven states managing in some way about 17 million ha (approximately 25%) of India's forests (Balooni and Inoue 2009). The Forest Rights Act of 2006 further empowered tribal communities to use forest resources. Thus, India has seen a variety of laws that have both favored stronger conservation and community use of forests over the years.

3 Study Area and Data

Our study is based on data collected from two watersheds, one from India and one from Nepal. The data for this study come from a survey undertaken for a larger study organized jointly by the South Asian Network for Development and Environmental Economics (SANDEE) and the International Center for Integrated Mountain Development (ICIMOD) (Nepal et al. 2017b).

The watersheds we study are the Gwalek Kedar watershed of Baitadi District in Nepal and the Chandak-Aunla Ghat watershed of the Pithoragarh District in India. Figure 1 indicates the location of these two watersheds along the Nepal—India border. The Gwalek Kedar watershed covers an area of more than 5,700 ha. The forest area in the watershed is surrounded by 23 villages under 8 village development committees, with a population of 28,400 and 5,393 households. The Chandak-Aunla Ghat watershed covers a 2323 ha area with 12 Gram Panchayats and 28 Revenue Villages, with 1,774 households. In Gwalek watershed, about 84% of the forest is broad leaf oak and chir pine, while in Chandak-Aunla Ghat watershed, about 79% of the forest area is covered by bush, and above 10% of the forest area is broad leaf oak and chir pine.

We study 301 households from Chandak-Aunla Ghat watershed in Pithoragarh District in India and 351 households from Gwalek watershed of Baitadi District in Nepal. These watersheds are on either side of Mahakali River that forms the international boundary between India and Nepal and thus are similar in terms of altitude, climatic and historical natural endowments. However, the anthropogenic pressures and administrative differences have resulted in different socioeconomic and occupational features of these households (Nepal et al. 2017b).

The data collection was undertaken in the summer of 2016 and followed a structured approach: stakeholder consultation, questionnaire development, training and pretesting of questionnaire, and household survey. A series of focus group discussions and consultations were carried out with local villagers; officials of government, local bodies, and non-government organizations, which helped in

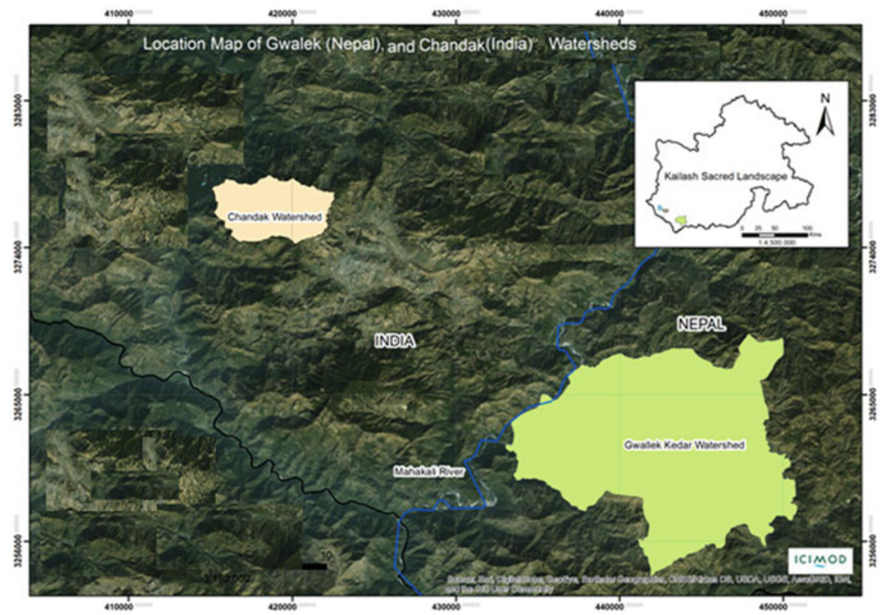

Fig. 1 Study area in Kailash Sacred Landscape region in India and Nepal. *Source* Nepal et al 2017b

developing the survey questionnaire. Households were selected following systematic random sampling. Household heads of either gender of the approached households were interviewed.

4 The Characteristics of the Forest-Dependent Poor

Tables 2 and 3 describe the socioeconomics of the households in the two watersheds on either side of the Mahakali River. Table 2 shows households in Nepal to have larger family sizes, more landholding as well as larger livestock holding. Thus, both in terms of labor and land, Nepali households seem to be better-off relative to their Indian counterparts. Interestingly, more Indian households have concrete (*pucca*) houses, while Nepal has more advanced sanitation facilities; nearly 80% of Nepali household has a *pucca* toilet. On the other hand, 17% of households India are without toilets. Thus, open defecation is likely to be higher on the Indian side of the border.

Households in Nepal have better access to tap water relative to Indian households (Table 3). In dry months, when most households face water stress, nearly half the water (44%) used by the surveyed households in India come from public wells, while less than one-third of water (30%) consumed by Nepali households come

Table 2 Socioeconomic differences between India and Nepal

Features	Chandak-Aunla Ghat, India (N = 301)	Gwalek, Nepal (N = 351)
Family size	4.7	7
Share of females	0.50	0.51
Age of the respondent (60% were household head)	42 years	47 years
Average education of respondent	Up to 10th standard	Up to class 5
Share of Dalit caste	41	14
Share of general caste	52	86
Share of HHs having concrete houses	71.4	50.1
Share of HHs having pucca toilet	78.9	93.4
Share of HHs having no toilet	17.3	0.6
Share of HHs throwing waste water in open (no sewer connection)	94.9	97.4
Total average agricultural area (in Ropani)	1.63	5.66
Average livestock unit[a]	3.6	6.5
Annual average expenditure in livestock	4709 INR (US$73)	6650 NPR (US $64)
Median household annual income (67% of households)	Less than US$770	US$481–2888

[a]Livestock = (1.1 * no of cattle) + (0.6 * no of buffaloes) + (0.9 * no of goat)

from a well. This appears to have two impacts. Households in India spend a lot more on water treatment (INR 80) relative to households in Nepal (INR 12). Furthermore, since, as shown in Table 3, women are the ones who undertake most of the water collection, Indian women spend much more time than women in Nepal on collecting water. Wells are further away from private or public taps; hence, it takes longer in India to obtain water.

While water is more easily accessible in Nepal, the opposite is true for access to markets and community forests. Nepali households live in very remote areas as indicated in Table 3. The average Nepali household in our survey lives a good one hour walk away from a motorable road. This distance is three times more in Nepal relative to India.

5 Forest Use in Nepal and India

This region has historically been dominated by broadleaf forests, with chir pine seen mainly in steep slopes (Opinion in Focus Group Discussions, see Nepal et al. 2017a for detail). However, over the years, chir pine and scraggy bush have increased. Figure 2 points to some interesting differences in these forests between the two countries.

Table 3 Water deficiency in dry season and access to water and other infrastructure

Type of infrastructure and access		Chandak-Aunla Ghat, India (*N* = 301)	Gwalek, Nepal (*N* = 351)
Water deficiency in dry season per day per household		20.9 l	13.3 l
Water sources			
Private tap	Share of total requirement collected	0.29	0.17
	Average walking time[a]	7.4	1.4
Public tap	Share of total requirement collected	0.26	0.53
	Average walking time[a]	16.0	4.3
Public well	Share of total requirement collected	0.44	0.30
	Average walking time[a]	25.1	17.3
Share of households where women collect water		88.7	86.7
Average expenditure on water treatment in a year		80 INR (US$1.23)	12 NPR (US $0.11)
Other public and natural infrastructure	Average walking time to motor able road (min)	14.5	56.9
	Average walking time to community forest (min)	39.5	55
	Share of HHs with broadleaf forests in community forests	40.2	39.3
	Share of HHs with broadleaf forests surrounding villages	9.6	29.3

Note All average differences are significant at 1% level
[a]One-way walking time to source

Approximately 40% of households in both countries indicate that their community forests are mainly broadleaf forests, while 30% of Nepali and 10% of Indian households indicate that forests surrounding their village are broadleaf. As Fig. 2 shows community forests, in both India and Nepal, are largely either pine mixed broadleaf (mixed forest) or broadleaf. However, forests near villages are predominantly bush in India, while mixed forests dominate areas close to Nepali villages. Field observations as well as this data suggest that community forests are less disturbed and are more likely to reflect the historically dominant type of forests in the region, relative to forests that are close to the villages. Forests neighboring villages in India seem to be the most disturbed, most likely through regular unsustainable use. Nepali households, on average, walk 55 min one-way to get to community forests, while their Indian counterparts have a slightly shorter or possibly less steep walk (40 min).

In the hills around the Mahakali River, households are highly dependent on fuelwood for both heating and cooking. Table 4 indicates that Nepali households, on average, burn approximately half as much fuelwood as Indian households.

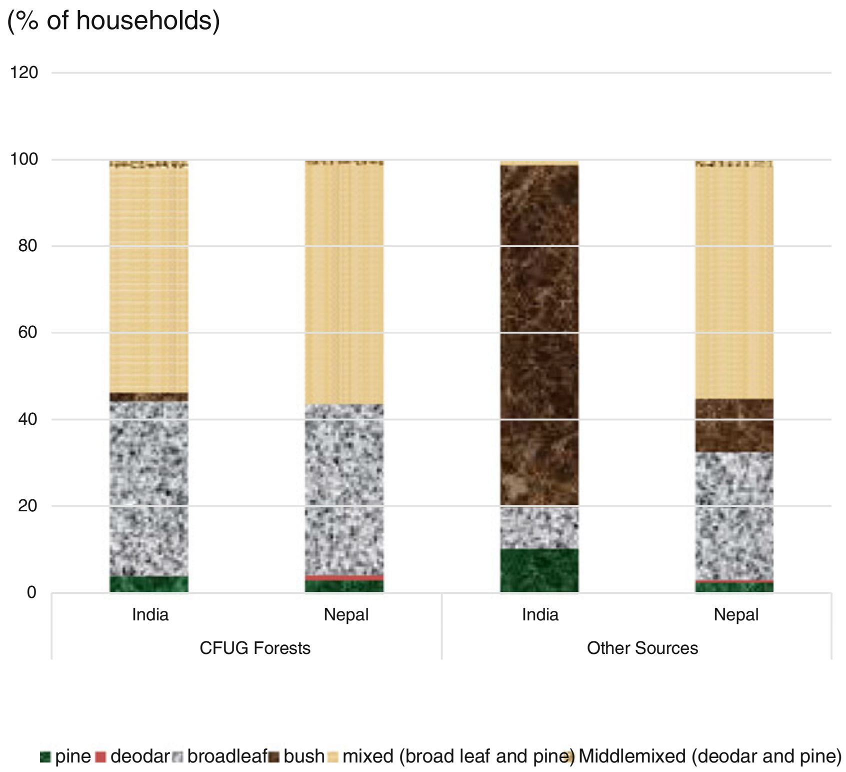

Fig. 2 Dominant forest types found in community and forests surrounding villages in India and Nepal

Table 4 Average forest product collection in India and Nepal

Total collection from all sources (in Bhari)	India	Nepal	Difference
Firewood collection	157.98	74.17	112.87*** (t = 11.77)
Fodder collection	315.7	349.8	−33.8** (t = 2.02)
Leaf litter	28.18	44.16	−15.97*** (t = 3.98)

***, **Imply 1 and 5% level of significance

We do not have data on energy choices and cook stoves, so we cannot say whether this is because Nepali households are using technologies that make them more efficient. Since forests are more abundant in Nepal and roads are further away, it is unlikely that they are using other sources of energy.

Households in the region also collect fodder for livestock and leaf litter, which is mixed with manure and used as a fertilizer in agricultural fields. Nepali households, who have more livestock relative to their Indian counterparts, collect more fodder and leaf litter. Leaf litter appears to be a less important forest product relative to the fodder and fuelwood.

Table 5 Two paired t test of collection from different sources

Forest products	Source of collection	India	Nepal
Firewood collection	Community forest	46.496	52.83
	Other sources	116.40	21.76
	Difference of means	−69.94***	31.07***
Fodder collection	Community forest	75.46	70.94
	Other sources	240.19	278.53
	Difference of means	−164.72****	−207.58***
Leaf litter collection	Community forest	9.58	38.94
	Other sources	18.6	5.22
	Difference of means	−9.01***	33.72***

***Imply 1% level of significance

Table 5 shows that Indian households collect more fuelwood, fodder as well as leaf litter from outside sources rather than community forests. The average Indian household collects a little less than 30% of its annual fuelwood from community forests, while the average Nepali households collect 70% of its annual intake from community forests. Fodder for livestock is predominantly obtained from areas close by in both countries. Thus, community forests are key resource for fuelwood and leaf litter in Nepal. However, in India, forests surrounding the villages are the dominant source for all forest products.

To better understand the correlates of forest products in the two different countries, we ran least squared regressions of total fuelwood and fodder collected on household characteristics, natural features of the region, public services available, and household assets (see Table 6).

In both India and Nepal, fuelwood and fodder increase with household size. Thus, with growth in population, we can expect more use of commonly available forest resources. There is some indication that in India, increases in wealth and road access may reduce fuelwood use. However, these effects are not strong for India and do not appear to matter in Nepal. These effects are reinforced in Fig. 3, which we discuss below. In general, socioeconomic factors are not particularly strongly correlated with forest use. This suggests widespread use of forests among rural households who do not have many other options for making a livelihood and in terms of energy choices.

The strongest influencers of fuelwood and fodder collection are physical attributes. Aspect (direction faced by the trees) is very important as is the type of forests. Households appear to prefer to collect fuelwood, particularly, from pine forests relative to other forest types, including the traditional broadleaf forests. An interesting and important indicator is the presence of deities and sacred forests in India. This contributes to a decline in forest use.

A surprising result is that distance to community forests does not have a negative effect, particularly, on fuelwood collection, as expected. To tease out this result some more, we graph forest product collection in community forests relative to time

Table 6 Factors associated with collection of firewood and fodder in India and Nepal

Independent variables	Estimated OLS coefficients for total collection from community forests and other sources			
	Y = Log (firewood)_IN	*Y* = Log (firewood)_NP	*Y* = Log (fodder)_IN	*Y* = Log (fodder)_NP
Family size	0.086*** (0.032)	0.031* (0.016)	0.047** (0.021)	0.017 (0.0164)
Education above 10 years (1/0)	−0.136 (0.127)	−0.096 (0.113)	0.009 (0.103)	−0.117 (0.127)
Agriculture as main occupation (1/0)	−0.057 (0.313)	−0.081 (0.110)	−0.108 (0.095)	0.005 (0.118)
Dalit caste (1/0)	0.071 (0.148)	0.199 (0.189)	−0.198* (0.102)	0.095 (0.142)
Concrete house (1/0)	0.000 (0.144)	0.164 (0.109)	−0.124 (0.106)	0.301** (0.134)
Permanent toilet (1/0)	0.119 (0.143)	−0.069 (0.206)	0.168 (0.126)	0.369 (0.343)
Aspect: West (1/0)	0.253* (0.140)	0.223 (0.236)	0.314*** (0.113)	−0.016 (0.178)
Aspect: South East (1/0)	−0.035 (0243)	−0.082 (0.196)	0.131 (0.221)	−0.213 (0.162)
Aspect: South West	0.152 (00168)	0.021 (0.223)	0.096 (0.153)	−0.722*** (0.190)
Forest type: broadleaf (1/0)	−0.523*** (0.174)	0.161 (0.193)	−0.211* (0.126)	1.049*** (0.195)
Forest type: bush (1/0)	−0.975*** (0231)	0.001 (0.183)	−0.156 (0.236)	0.782*** (0.188)
Forest type: pine mix	−1.939* (1.153)	−0.379** (0.180)	−0.997** (0.456)	0.735*** (0.181)
Forest offered to deity (1/0)	−0.877*** (0.205)	–	−0.143 (0.172)	–
Travel time between house and community forest (min)	0.006 (0.004)	0.003* (0.001)	0.001 (0.002)	−0.003 (0.002)
No of livestock	0.038* (0.022)	0.015 (0.020)	0.028 (0.017)	0.023 (0.022)
Walking distance between house and motorable road (min)	−0.008 * (0.005)	0.001 (0.001)	−0.002 (0.004)	0.001 (0.001)
Total area (ha)	−0.044* (0.026)	0.029** (0.014)	−0.001 (0.014)	−0.011 (0.0122)
Constant	5.210*** (0.355)	3.635*** (0.323)	5.33*** (0.207)	4.390*** (0.388)
Number of observations	301	351	271	341
F statistic	F (17. 283) = 15.93, *P* = 0.00	F (16, 334) = 4.25, *P* = 0.00	F (17, 253) = 2.78, *P* = 0.00	F (16, 324) = 5.63, *P* = 0.00
R-squared	0.29	0.13	0.15	0.11

Notes Robust standard errors are in parenthesis
***, **, *Imply level of significance at 1, 5, and 10%, respectively

taken to walk to community forests in Fig. 3. In India, we see a downward trend for fodder but not for the other two forests products. The same pattern is observed in Nepal, where a larger percentage of households source their products from community forests. This information seems to suggest that because of the lack of

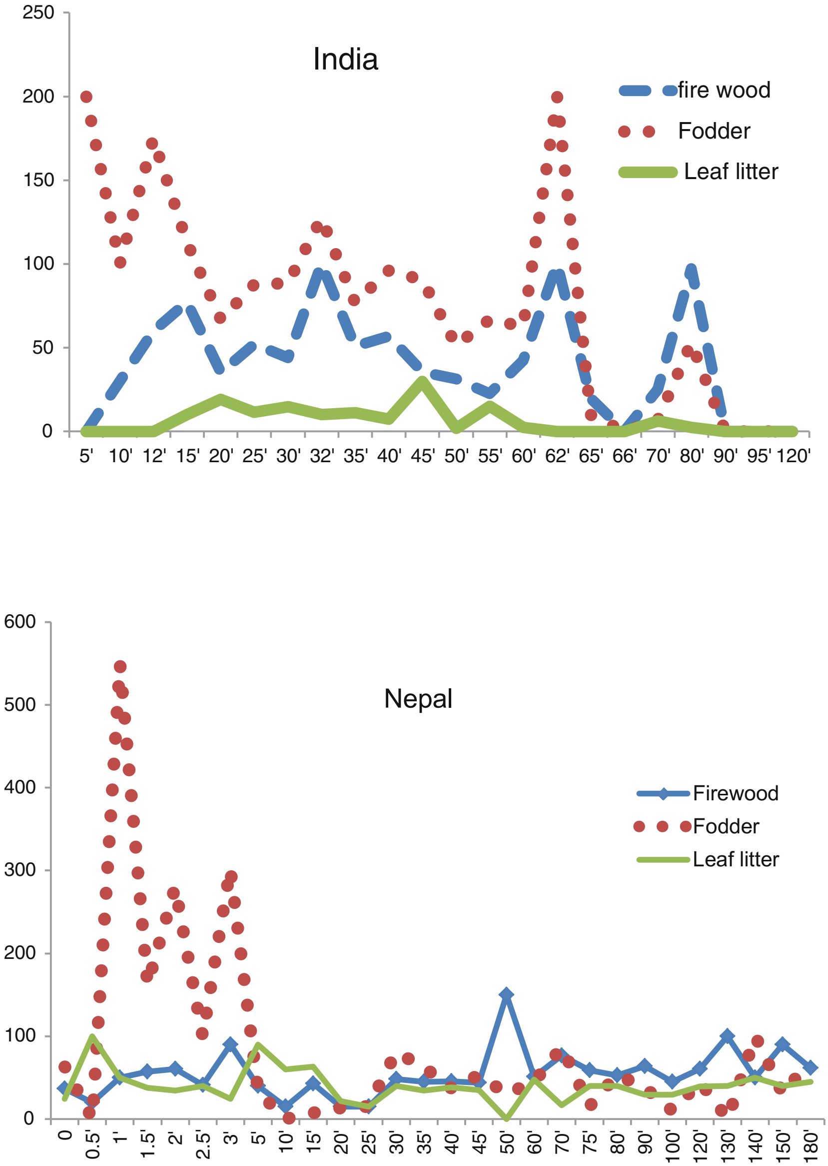

Fig. 3 Collection from community forests relative to distance to community forest, India and Nepal. Except fodder, there seems to be no pattern

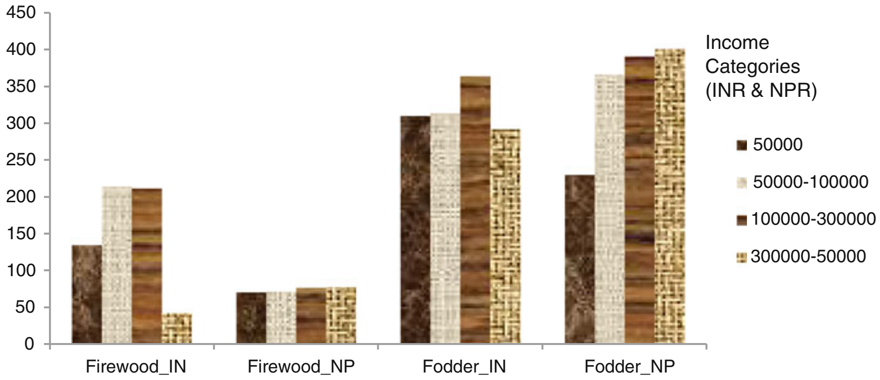

Fig. 4 Total collection of firewood and fodder by different income groups. There seem to be an inverted U-shape in India, but not in Nepal

alternatives, distances walked do not matter to remote rural households in India and Nepal. However, this does not mean that walking these long distances is not a costly endeavor.

Figure 4 looks at how forest product use varies with income. The expectation is that forest use is income elastic and as households become wealthier they may reduce their use of forests. It is interesting to note that an inverted U shaped relationship is prevalent to some extent in India. However, in Nepal, forest products are so fundamental that increases in income do not change their consumption. The lack of substitutes is probably the main reason for this pattern.

6 Correlates of Poverty

One of the questions we are interested in is how households in India and Nepal differ in terms poverty. Our data suggest that in terms of assets and income, households in Nepal are comparatively better off than their Indian counterparts (see Table 2). Table 7 presents a more disaggregate picture of occupational dependence and sources of household income.

Table 7 shows that agricultural households dominate in both countries, with 91% of households in India and 67% in Nepal depending on agriculture. Interestingly, nearly 70% of Indian households' state that their main source of income is agriculture, while only 56% in Nepal consider agriculture to be their main source of income. Remittances, which constitute the second major source of income in Nepal, do not play a major role in India. While it is not clear from our data if households have diverse sources of income, at least at the aggregate level, there is much more income diversification in Nepal versus India.

Table 7 Primary occupation and main source of income (share of households)

	Chandak-Aunla Ghat, India (N = 301)	Gwalek, Nepal (N = 351)
Primary occupation		
Agriculture	91.0	67.2
Traditional work	1.0	7.7
Government job	2.3	10.5
Others (wage labor + business + NGO or private job)	5.6	14.5
Main source of Income		
Agriculture	69.8	55.6
Pension	16.0	9.4
Remittances	14.0	30.8
Other sources	0.3	4.3

To understand better what may be contributing to transitions out of poverty, we examine the correlates of poverty. We use household income as a measure of household welfare. In rural agrarian settings, measuring household income with any given level of precision is a challenging task. Therefore, we collected data on an indicator of household income instead of the actual amount. Households were asked to indicate their monthly income-bracket from a list of less than Rs. 50,000; between Rs. 50,000 and Rs. 100,000; between Rs. 100,000 and 200,000, and above Rs. 200,000 per month. Their responses were coded as 1, 2, 3, and 4, where 1 being the lowest and 4 being the highest income brackets.

For understanding the correlates of poverty, we regress the household income indicator on socioeconomic status, demographic characteristics, household assets, different features of forests that the households have access to for collecting firewood, from where they get their water supply, distance between forest and house, and access to motorable roads, measured by the travel time between nearest motorable road and the house.

As a starting point, we first estimate the income equation using the ordinary least squared (OLS) method. Since our income measure is reported as an indicator variable, we also estimate the same model using an ordered logit regression. Table 8 presents both the OLS coefficients and the marginal effects as measured from the ordered logit coefficients of the covariates of household income. These coefficients indicate the degree and direction of the association between household income and other household, public and geographic characteristics.

Table 8 indicates that the determinants of household income vary between two countries. In India, household income is positively associated with the household head's education level, presence of permanent (concrete) toilet, and size of landholdings; while in Nepal, household size and concrete house structure have positive association with household income. In Nepal, households have more land and more households get remittances. Thus, larger household sizes in Nepal may be

Table 8 Determinants of household income

Variables	India		Nepal	
	OLS	Ordered logit[a]	OLS	Ordered logit[a]
Total number of people in family	0.026	0.131	0.034	0.091
	(−1.24)	(−1.51)	(2.46)*	(2.65)**
Education above 10 years (1/0)	0.241	0.917	0.098	0.263
	(3.03)**	(2.33)*	(−1.03)	(−1.14)
Agriculture as main occupation (1/0)	−0.531	−1.359	−0.496	−1.166
	(2.79)**	(2.72)**	(4.79)**	(4.63)**
Dalit (1/0)	−0.081	−0.523	−0.234	−0.647
	(−0.95)	(−1.26)	(−1.55)	(−1.83)
Concrete house (1/0)	−0.084	−0.384	0.362	0.857
	(−1.25)	(1.27)	(3.81)**	(3.78)**
Permanent toilet (1/0)	0.305	1.513	0.307	0.737
	(4.68)**	(3.68)**	(−1.66)	(−1.57)
Aspect: West (1/0)	−0.261	−1.217	−0.241	−0.43
	(2.50)*	(2.68)**	(−1)	(−0.72)
Aspect: South_East (1/0)	−0.81	−3.708	−0.093	−0.131
	(5.38)**	(5.07)**	(−0.52)	(−0.34)
Aspect: South_West (1/0)	−0.063	−0.332	−0.599	−1.348
	(−0.55)	(−0.68)	(2.69)**	(2.69)**
Forest type: broadleaf (1/0)	−0.069	−0.363	0.841	2.212
	(−0.4)	(−0.67)	(3.44)**	(2.60)**
Forest type: bush (1/0)	0.157	0.444	1.012	2.648
	(−0.91)	(−0.78)	(3.77)**	(2.91)**
Forest type: pine_mix (1/0)	0.806	1.67	0.993	2.56
	(2.57)*	(2.69)**	(4.19)**	(3.02)**
Forest offered to deity (1/0)	−0.472	−1.805	–	–
	(3.39)**	(3.52)**	–	–
Travel time between house and community forest (min)	0.004	0.017	−0.004	−0.009
	(−1.85)	(−1.81)	(3.07)**	(2.94)**
No. of livestock units	−0.023	−0.085	−0.009	−0.026
	(2.06)*	(−1.45)	(−0.68)	(−0.78)

(continued)

Table 8 (continued)

Variables	India		Nepal	
	OLS	Ordered logit[a]	OLS	Ordered logit[a]
Travel time between house and motorable road (min)	0.002	0.005	−0.002	−0.004
	(0.62)	(0.44)	(1.94)	(2.14)*
Land area (ha)	0.039	0.077	0.013	0.03
	(2.38)*	(1.88)	(1.24)	(1.09)
Constant	1.653	–	1.495	–
	(6.28) **		(3.89) **	
Observations	301	301	349	349
R-squared	0.35		0.27	

Notes Robust *z* statistics in parentheses
*Significant at 5%; **significant at 1%
[a]The estimates are marginal effects of ordered logit regressions

contributing to income through both agriculture and remittances. In India, where there appears to be less diversification in income, sources and households are largely dependent on agriculture, area of land matters. In both countries, the variable households with agriculture as the main occupation are negatively associated with household income. This seems to suggest, as would be expected, that agriculture alone is not a pathway out of poverty.

In India, communities sometimes offer their forests to deities for a fixed term (usually 5–10 years) when forest degradation becomes a major issue. As expected, such an arrangement tends to lower household income since households may not be able to fulfill their need for forest products. In Nepal, access to forests other than pine forest is positively associated with household income, while this is not the case in India.

7 Discussion and Conclusion

Our analyses of communities on either side of the Mahakali River in India and Nepal suggest that households from Nepal have more land and livestock, yet are not entirely dependent on agriculture for their livelihood. Indicators related to income and assets suggest that Nepali households are better off than their Indian counterparts.

India is a richer country with a per capita income that is twice that of Nepal and a larger road network. However, this does not translate to better indicators of well-being in this remote pocket of rural India. We are not fully able to explain why the Nepali households are better off than their Indian counterparts, even though they live in more remote areas with even less access to markets and transportation than the Indians. However, our data suggest that remittances may play an important role as nearly 30% of the households in Nepal receive money from outside. Diversification is an important pathway out of poverty, and these remittances may be allowing Nepali households to further diversify or recover faster from any economic or health shocks. Our statistical analysis also shows a strong correlation between agricultural households and poverty. Solely relying on agriculture, without some diversification in income, is unlikely to be a pathway out of poverty. Another socioeconomic difference that may affect Indian households is caste structure. Some 41% of the households on the Indian side are Dalits and this may influence how well they are able to use social networks to seize new opportunities.

Do natural resources matter for poverty reduction? The Nepali watershed seems better endowed with both water and forest resources. Nepali women spend less time collecting and managing water. The average walking time a household spends to collect water in Nepal is 56 percent less than India. Nepal also has better sanitation infrastructure, while nearly 20% of Indian households do not have a toilet in their home. This may translate health disparities between these countries.

Nepal's forests are in better health than Indian forests. Forests in India, particularly those surrounding villages, are degraded. This is likely because Indian households collect a large share of fuelwood from nearby areas and not from community forests. The average Indian household collects less than 30% of its annual fuelwood from community forests, while Nepali households collect 70% of their annual intake from community forests. Forests are further away, and roads are further away in Nepal. Yet, because of the lack of alternatives, distances walked do not seem to reduce how much wood is collected. Furthermore, while there is some limited evidence of income elasticity in fuelwood use in India, like distances walked, income growth does not seem to reduce fuelwood consumption in Nepal. Given the degraded bush forests that dominate areas around villages in India, it is a good sign that fuelwood use seems to be a bit responsive to income changes.

In per capita term, Indians use and collect more than twice as much fuelwood as do Nepalese. This may be because they get most of their fuelwood from around their villages. It is also possible that Indians sell some fuelwood because they are relatively close to motorable roads. Another possible reason could be that Nepalese households use other household energy sources. This may have led to lower collection of firewood by these households. In summary, our analyses suggests that there are key differences between Nepali and Indian forest dependent households. It is likely that a combination of norms, technology and institutional differences make fuelwood use and where resources are sourced from very different across India and Nepal.

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Household Microenvironment and Its Impact on Infectious Diseases in India—Evidence from the National Sample Surveys

Indrani Gupta and Samik Chowdhury

1 Introduction

Household microenvironment consisting of drinking water, sanitation, hygiene, drainage, housing, indoor air quality, etc., are some of the key determinants of communicable and infectious diseases like diarrhea, cholera, typhoid, tuberculosis, malaria, dengue. There have been numerous studies exemplifying the disease burden from inadequate and improper access to these basic amenities (Murray and Lopez 1996; WHO 2002, 2004, 2009; Cairncross and Valdmanis 2006; Prüss-Ustün et al. 2008; Lim et al. 2012; Wolf et al. 2014; Prüss-Ustün et al. 2016). Diarrheal diseases cause 20% deaths in children under five years (WHO 2015a), and 58% of all cases of diarrhea in low- and middle-income countries could be attributed to inadequate drinking water, sanitation, and hygiene (Prüss-Ustün et al. 2014).

In 2013, malaria caused over half a million deaths—mainly of children—particularly from Africa. Female Anopheles mosquito, the vector in this case, prefers clean and stagnant water (Muir 1988). A study on interventions to combat malaria showed that environmental management and alterations in human habitation reduced the risk of malaria by 88.0 and 79.5%, respectively, (Keiser et al. 2005a, b). Organically polluted water forms the breeding ground for vectors that transmit the lymphatic filariasis disease which currently affects over 120 million people, mainly in Southeast Asia and Africa, but also in other tropical areas (WHO 2014a). Leishmaniasis, another infectious disease, is caused by a parasite which could be effectively controlled through improved environmental sanitation and housing (Joshi et al. 2009; Warburg and Faiman 2011).

Substantial underreporting and misclassification notwithstanding, dengue happens to be the most rapidly spreading mosquito-borne viral disease in the world. Recent studies indicate that there are 390 million dengue infections per year

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(Bhatt et al. 2013) and almost 3900 million people are exposed to the threat of this disease (Brady et al. 2012). The mosquito vector breeds in clean water accumulations close to human habitation. Therefore, unreliable water supply that leads to storage of potable water (Kumar et al. 2001), accumulated rainwater on discarded containers and car tires (WHO 2015b), and poor drainage especially in urban areas have emerged as the leading causes of dengue.

Another disease that has well-defined links with environment and sanitary conditions is Japanese Encephalitis (JE). A recent literature review estimates nearly 68,000 clinical cases of JE globally each year, with up to 20,400 deaths (Campbell et al. 2011). Pigs are the main host of the JE virus, while mosquitoes that mostly breed in irrigated rice fields are the vector. Appropriate environmental health interventions have been found to reduce JE transmission (Erlanger et al. 2009; Keiser et al. 2005a, b; Rozendaal 1997) significantly.

Tuberculosis, an infectious bacterial disease that killed 1.5 million people in 2013 (WHO 2014b), mostly in low and middle income countries, has often been associated with factors like crowding in households (Baker et al. 2011), malnutrition (Jaganath and Mupere 2012; Schaible and Kaufmann 2007), exposure to indoor smoke (Sumpter and Chandramohan 2013), and passive tobacco smoke (Leung et al. 2010). While there is consistent evidence linking TB with tobacco use, there are studies that indicate that indoor air pollution probably increases the risk of TB as well (Lin et al. 2007).

A number of other communicable diseases disproportionately affects people with compromised immunity, and malnutrition is the leading cause of such immunodeficiency (Keusch 2003; Katona and Katona-Apte 2008). Given the well-established link between malnutrition and diarrhea, household microenvironment turns out to be a key determinant of communicable diseases in general.

The impact of environmental parameters on health has been recognized in international agenda and national policies as well. The Millennium Development Goals (MDGs) called for halving the proportion of the world's population without sustainable access to safe drinking water and basic sanitation by the end of 2015. Global progress toward the MDG's Water, Sanitation and Hygiene (WASH) targets, however, has been mixed. There have been instances where national averages have masked significant disparities within populations. For example, while the global MDG target for drinking water has been met in 2010, 663 million people still (in 2015) lack improved drinking water sources and 80% of them live in rural areas. Although 2.1 billion people have gained access to an improved sanitation facility since 1990, 2.4 billion people still (in 2015) lack improved sanitation facilities. Seven out of ten people without improved sanitation facilities, and nine out of ten people still practicing open defecation, live in rural areas (UNICEF and WHO 2015). The close links with household microenvironment and the social determinants of health or the SDH (Marmot and Wilkinson 1999; WHO 2010) are now well-recognized, and the SDH are very much part of the post-2015 development agenda (UNDP 2015).

India is still home to a vast range of infectious diseases, despite commendable progress made in control and prevention of such diseases. While diseases like smallpox, poliomyelitis, guinea worm, yaws, maternal, and neonatal tetanus have been successfully eradicated, there has been a stubborn prevalence and sometimes re-emergence of some easily preventable diseases like tuberculosis, malaria, dengue, chikungunya, visceral leishmaniasis. The Global Burden of Diseases study shows that in 2015 lower respiratory tract infections, diarrhea, and TB occupied the fourth, fifth, and sixth places, respectively, as causes of mortality in India; diarrheal deaths is the sixth most important cause of premature death. The study also shows that unsafe water, sanitation, and handwashing are the sixth most important factor for deaths and disability. Clearly, there is a need for an integrated approach to disease management and control involving the social determinants of health, particularly household microenvironment which is currently lacking in India (John et al. 2011; Patel et al. 2015).

Most analysis of burden of diseases in India is based on disease surveillance data. Household level data are generally not used because of the possible biases of self-reporting. In this paper, we take another look at the burden of infectious diseases from household level data and attempt to establish the link between selected diseases and household microenvironmental characteristics. Further, we study the treatment-seeking behavior and treatment costs to understand whether these could be a potential source of financial burden for households.

The next section discusses the data and methods, Sect. 3 presents the results, and Sect. 4 concludes with some discussion on policy.

2 Data and Methods

We use two sets of data from the National Sample Survey—(1) 69th round (July 2012–December 2012) and (2) 71st round (January 2014–June 2014). The National Sample Survey Office (NSSO) under the Ministry of Statistics and Programme Implementation (MOSPI) conducts nationwide sample surveys on various socioeconomic subjects, at regular intervals known as “rounds.” The NSS surveys are conducted through household interviews from a scientifically designed random sample of households covering almost the entire country. In the 69th round, the NSS conducted a nationwide survey on “Drinking water, Sanitation, Hygiene and Housing Condition” in India. The sample size was 95,548 households, 56% of which were rural. The objective of the survey was to examine and study different aspects of living conditions necessary for decent and healthy living, e.g., quality of drinking water, condition of dwelling, sanitation, drainage, garbage disposal, cooking arrangement. Responses were also collected on whether any member of the household suffered from selected communicable diseases (malaria, stomach ailments, skin diseases, and fever of unknown origin) during the last 30 days (Government of India 2013). The previous survey on these subjects was undertaken in the 65th round of NSS (July 2008–June 2009).

The NSS 71st round (Social Consumption: Health) generated basic quantitative information on the health sector—prevalence rate of morbidity among various age–sex groups in different regions of the country, extent of use of health services, and the expenditure incurred on treatment received from public and private sectors. The NSS 71st round also asked a truncated set of questions on household microenvironment, viz. type of latrine, drainage, and source of drinking water. It surveyed 65,932 households, 55% of which were rural.

Relative to the 69th round, the 71st round was more comprehensive on disease burden information. On the other hand, aspects of household environment were more exhaustive in the 69th round. Another point of distinction between the two surveys is that the 69th round collected information at the household level while the 71st round provides information both at the household as well as the individual level.

A probit regression model was applied on both sets of data, to estimate the impact of different aspects of the household microenvironment on the probability of selected infectious and communicable diseases. Probit (and logit) models are used when the dependent variable is categorical in nature while the independent variables may be continuous or categorical. Marginal effect of a particular independent variable shows the change in probability of the dependent variable, when the independent variable increases by one unit. For continuous independent variables this represents the instantaneous change, while for binary variables the change is from 0 to 1, indicating presence or absence of that factor.

In case of the 69th round, our definition of infectious and communicable disease comprised malaria, stomach ailments, and skin disease, leaving out fever of unknown origin. The dependent variable for the 69th round, therefore, was the likelihood of a household reporting any of the three infectious diseases. In the 71st round, however, based on the more exhaustive information available on disease burden, the following diseases and conditions were included under infectious and communicable diseases: fever with rash/eruptive lesions, diphtheria/whooping cough, typhoid and other fevers of unknown origin, filariasis, jaundice, diarrhea/dysentery, other stomach ailments, skin infections, undernutrition, and acute upper respiratory infections. The dependent variable for the 71st round was the likelihood of a person reporting any of these infectious diseases and requiring an outpatient (OPD) visit.

The independent variables related to microenvironment were re-coded as binary variables, based on the responses to questions on water, sanitation, drainage, garbage disposal, dwelling condition, ventilation, and existence of separate kitchen (for the 69th round). The other two independent variables were monthly per capita consumption expenditure of the household and rural residence. For the 71st round, however, microenvironment responses were collected only for water, sanitation, and drainage. The other independent variables were log of per capita consumption expenditure, age categories as reported previously with adults (age 15–59) being the reference category and whether the person is a female. A probit model was estimated to understand the impact of household microenvironment on the likelihood of selected ailments, for both the rounds, with the marginal effects being reported in the results section.

3 Results

3.1 NSS 69th Round

Figure 1 presents the status of household environment emerging out of the 69th round data. It clearly shows that India still lacks universal access to any of these basic amenities. In addition, the rural–urban disparities in access are quite stark. Within the selected amenities, households had the least access to formal garbage collection. Self-reported drinking water quality emerges as the best amenity in the household microenvironment. Close to half of the rural households had no access to drainage, while almost 60% had no latrines. Households in rural India were consistently disadvantaged vis-à-vis urban India with respect to access to these basic amenities. The rural–urban gap is the highest in case of access to latrines.

The prevalence of selected diseases in the 69th round is shown in Fig. 2. Twenty percent of all households had at least one episode of gastrointestinal ailment in the last 30 days. Cases of skin disease were reported from 7%, while malaria was prevalent in 5% of Indian households. In case of disease prevalence too, rural households are relatively more disadvantaged compared to their urban counterparts.

3.2 NSS 71st Round

The 71st round which is a health-specific survey shows that of those who had an OPD visit in the last 15 days, 30% reported an infectious disease, indicating the fairly high occurrence of these diseases. Of all the infectious diseases reported, 70%

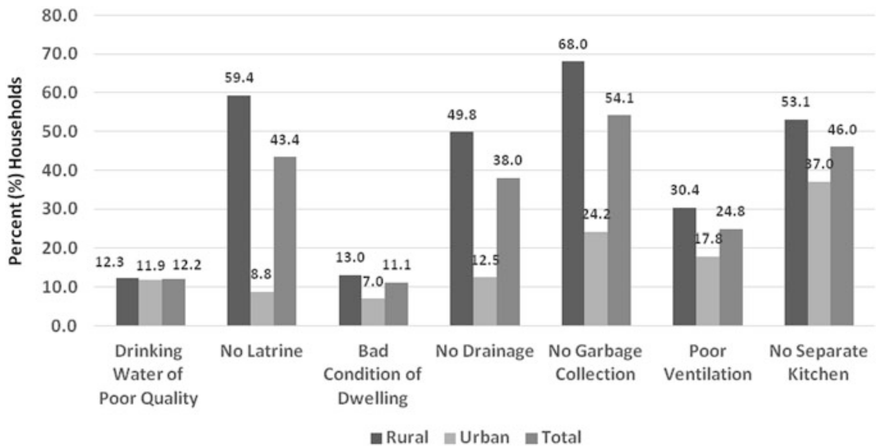

Fig. 1 Status of household environment, NSS 69th round. *Source* Unit level data, NSS 69th round

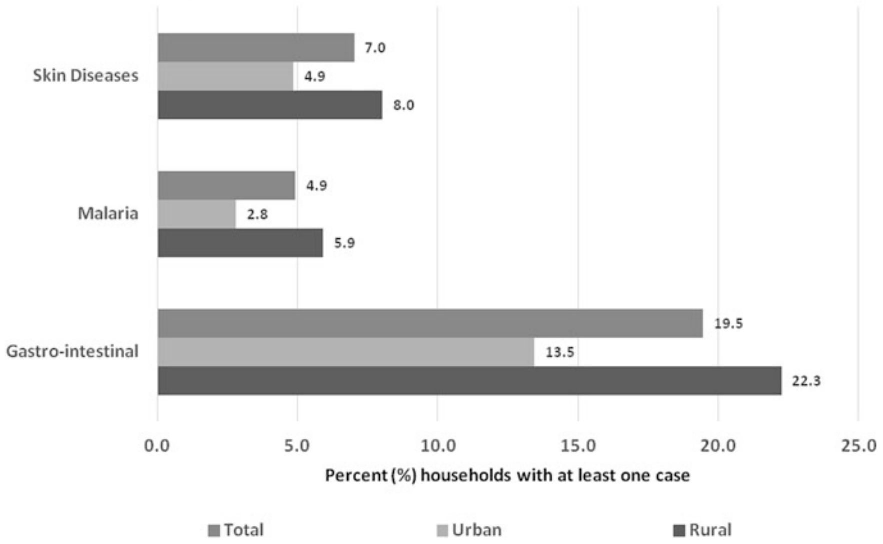

Fig. 2 Prevalence of selected disease, NSS 69th round. *Source* Unit level data, NSS 69th round

occurred in the rural areas. Among children aged less than 5 years in the sample, 67% had reported at least one of these illnesses. The corresponding numbers are 60, 25, and 12%, respectively, for age groups 5–15, 16–59 and 60 and above.

3.2.1 Treatment-Seeking Behavior and Expenditure, NSS 71st Round

Around 16% of those with infectious diseases did not seek care. While the most common cause for this was the perception that the problem was not serious (62%), about 27% stated supply-side constraints—lack of accessible and available facilities or affordability issues. Table 1 presents the source of treatment among those who did avail treatment.

An important result from the table is that a majority of the respondents went to private sources of care (76%). Among the remaining that did go to public sources, almost half went to public sector hospitals, leaving only a small minority seeking

Table 1 Source of OPD treatment of infectious diseases, NSS 71st round

Source of treatment	%
Health workers like ASHA or Anganwadi workers	2.3
PHC/CHC/dispensary	9.8
Public hospital	11.5
Private doctor/clinic	62.4
Private hospital	14.0

Source NSS, 71st round, authors' calculation

Table 2 Expenditure on infectious diseases as share (%) of household consumption expenditure, NSS 71st round

Quintiles	Rural	Urban
1	16.8	13.1
2	11.7	8.4
3	11.8	7.9
4	11.0	8.4
5	8.0	5.7
All	11.9	8.6

Source NSS, 71st round, authors' calculation

care at primary and secondary tiers of the public health care system. When asked why they did not seek care at government facilities, the response mostly centered around quality, availability, and accessibility of such facilities (93%).

While expenditure on NCDs is usually higher due to the higher treatment costs and chronicity, we looked at the economic burden on households from infectious diseases. Overall, rural and urban households with at least one infectious disease visiting an OPD spent 12 and 9% of their per capita monthly consumption expenditure on treatment. Table 2 shows the distribution of this share across quintiles for rural and urban areas separately.

The table shows that the lower quintiles spend proportionately more on treatment of these diseases compared to the upper quintiles; in fact, the lowest quintiles in both rural and urban areas spend a very large share of their total consumption expenditure on treatment. Also, rural residents spend consistently more than their urban counterparts as a share of consumption expenditure. While a part of it could be attributed to relatively lower rural incomes, the possibility of a treatment cost-induced catastrophic burden or even impoverishment is more likely for the rural households.

3.3 Household Microenvironment as Disease Determinants

Table 3 displays the results of the probit model estimated on both sets of data. In the 69th round data, quality of drinking water emerges as the most statistically significant determinant of these diseases. A household with poor quality drinking water has a 12% higher probability of falling ill with infectious disease. The other significant factors are garbage collection, existence of separate kitchen, and access to latrine. Controlling for other variables, rural households demonstrate a higher likelihood while households with higher economic status display a lower likelihood of these diseases.

The regression results from the 71st round indicate that probability of illness is negatively related to household consumption. For all the WASH variables, the effect is significant and as expected—with higher probability of illness resulting from poorer access to these amenities. While the marginal effects are not very high, these are significant. We also find that the strongest effects are on children and

Table 3 Determinants of infectious diseases, NSS 69th round and 71st round

Independent variables	Dependent variable: whether ill with gastrointestinal disease, malaria, or skin disease, NSS 69th round (Yes—1, No—0)	Dependent variable: whether ill with an infectious disease, NSS 71st round (Yes—1, No—0)
	Marginal effects (d*F*/d*x*)	Marginal effects (d*F*/d*x*)
Rural	0.021*** (*0.003*)	–
Log MPCE	−0.098*** (*0.003*)	−0.05*** (*0.004*)
Drinking water—poor quality	0.116*** (*0.005*)	0.02*** (*0.005*)
Housing—poor structure	−0.003 (*0.005*)	–
Housing—poor ventilation	0.005 (*0.004*)	–
No latrine	0.008** (*0.004*)	0.02** (*0.006*)
No separate kitchen	0.012*** (*0.003*)	–
No garbage collection	0.031*** (*0.003*)	–
No drainage	−0.003 (*0.004*)	0.03*** (*0.006*)
Child less than 6 years	–	0.38*** (*0.008*)
Child between 6 and 15 years	–	0.31*** (*0.01*)
Elderly 60 and above	–	−0.15*** (*0.005*)
Female	–	−0.009* (*0.005*)
Obs. *P*	0.261	0.26
Pred. *P*	0.254	0.24
No. of observations	95,546	37,281
Pseudo R2	0.033	0.15
Log likelihood	−53,066.8	−16,638

Note The dependent variable “Infectious Disease” (71st round) includes fever with rash/eruptive lesions, diphtheria/whooping cough, typhoid, and other fevers of unknown origin, filariasis, jaundice, diarrhea/dysentery, other stomach ailments, skin infections, undernutrition, and acute upper respiratory infections
***Significant at 1% level, **significant at 5% level, *significant at 10% level
Italicized figures in parentheses are the standard errors

adolescents, who have a much higher probability of falling ill from infectious diseases than the adults. Females have a lower probability of falling ill compared to males.

4 Discussion

Any communicable disease prevention agenda must take into account cross-sectoral multilevel interventions involving services like safe drinking water and sanitation, housing, drainage (GoI 2014). A sustained focus on these can rein in a lot of avoidable morbidity and mortality. In addition, it also has the potential for direct and indirect cost savings for the individual as well as the state.

The 2015 WHO/UNICEF Joint Monitoring Programme indicates that while India had made some progress on both water and sanitation, the progress is much slower for sanitation, with 44% defecating in the open, with another 6% accessing unimproved sources. Figure 3 from the Ministry of Drinking Water and Sanitation shows that many of that sanitation coverage remains very poor in many of the EAG states.

Waste disposal remains a big challenge in the country, especially in rural areas with liquid waste disposal being almost totally devoid of any planned norms and practices that can reduce the negative impacts of such disposal (Navrekar 2016). Domestic as well as commercial wastewater is disposed off in an ad hoc manner in India, resulting in a poor sanitation situation.

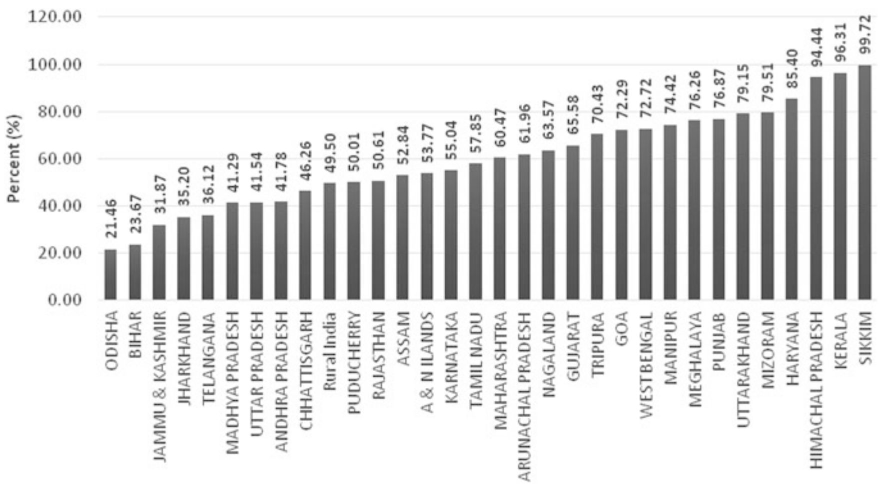

Fig. 3 Sanitation coverage, 2016, Ministry of Drinking Water and Sanitation. *Source* Ministry of Drinking Water and Sanitation Presentations (http://www.mdws.gov.in/documents/presentations)

The progress has been better with respect to water, though the pace has been slow in rural areas, with population having access to safe and adequate drinking water being only about 76%. Overuse and drying up of groundwater, contamination of drinking water sources, and population increase have been stated to be some of the main reasons for underachievement in the rural areas (GoI 2016).

The government has launched the National Rural Drinking Water Programme and the Swachh Bharat Mission (Gramin) in rural areas to tackle the water and sanitation issues. While it may be a bit early to comment on the success of these programs, it has been argued that sanitation practices, in particular, may be deeply entrenched in the social and cultural aspects of a region/state, and, therefore, highly dissimilar across the country. Very often, these aspects prevent people from using services even while available (Gupta et al. 2016).

While the pace of policies and the readiness of states (health as well as water and sanitation are state subjects in India) are areas that can always be improved further, it might be important for greater synergies to take place between the main stakeholders—departments of health, water, and sanitation. A coordinated mapping of infectious disease outbreaks, WASH situation, and treatment responses is required. There have been discussions, for example, on how the health and nutrition database and responses can be improved in India through a more coordinated approach (Kurian 2016). A similar but broader effort needs to be made to explicitly include WASH and infectious disease burden surveillance and responses under a common umbrella so that geographically sensible policies can be implemented. For example, if there are areas that have high disease burden from diarrhea, have poor WASH indicators as well as inadequate public health facilities, policies can be implemented on all fronts in a coordinated manner. There are other models of public health and primary care integration around the world that can be examined to see whether India can replicate any of these models (ASTHO 2012). Such initiatives have to be local with local expertise and local officials included in the coordinated approach.

Also, most of the aspects of household microenvironment are constitutionally mandated functions of local governments, i.e., the Panchayati Raj Institutions (PRI) and Urban Local Bodies (ULB). While the 73rd and 74th Constitutional Amendment Acts (1992) established them as the third tier of government, thereby devolving a host of functions, they have been chronically short of funds and functionaries. This is particularly true of smaller ULBs and PRIs, because the bigger ones are relatively sustainable financially, on account of their larger revenue base.

A potential now exists to improve the coverage and quality of basic services, with the Fourteenth Finance Commission's landmark decision to more than double the grant (Rs. 2,870 billions) for local bodies for the award period 2015–20 and the recommendation that nearly all of this money be spent on improving basic services like water supply, sanitation, solid waste management, sewerage, drainage. Eighty percent (for ULBs) and 90% (for Gram Panchayats) of this grant would be unconditional, while the remaining would be performance-based subject to compliance with certain governance reforms. The possibility of political differences at the state and local levels notwithstanding, this presents an opportunity to strengthen local-level service delivery substantially, which would have a positive impact on household microenvironment. It is crucially important, therefore, to periodically assess service levels and the anticipated impact on avoidable communicable diseases.

This approach will also address the concern with high out-of-pocket expenditures of especially the poor households. India has not made much progress on Universal Health Coverage with most schemes focusing on tertiary care. While offering coverage for tertiary care is one option, it is more important to strengthen the primary and secondary public health facilities so that individuals can avoid going to the more expensive private facilities and travel long distance for care, which can be given fairly easily closer to their homes, in non-tertiary settings. There is also an urgent need for implementing proper treatment guidelines for treating childhood infectious disease so that appropriate care is given (Kotwani et al. 2012).

WASH as well as related health indicators are closely related to other SDH indicators. While it might be too idealistic to hope for coordination with other departments concerned with social and economic well-being of individuals, it should be kept in mind that some parts of WASH can be improved through education and awareness, which improve with overall development of a region.

India spends very little on health and on water and sanitation. The trends over the years have not been encouraging; in this resource-constrained scenario, it is even more important to focus on prevention rather than treatment alone, which would improve the efficiency of public spending, while leaving more resources to address the growing burden of non-communicable diseases, which are relatively more expensive to treat.

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Understanding Quality of Life in an Urban Context: Measurement of Poverty and Vulnerability Using Fuzzy Logic

Preeti Kapuria

1 Introduction

Cities are the drivers of economic and technological advancement of any nation and therefore contribute greatly to improving peoples' lives. By offering excellent opportunities for education, training and skill development, as well as access to quality healthcare, housing, basic infrastructure and entertainment, urban areas have grown rapidly in recent decades. But increasingly the benefits of urban economies are not broadly shared among city residents. Poverty persists despite gains in productivity, and the gap between those with a better or poorer quality of life appears to be widening. Scenes of extreme urban squalor and deprivation are not uncommon in most cities in the developing world, indicating that the benefits of economic development in cities have not been ploughed back adequately to ensure that all citizens have access to basic infrastructure and services to experience an acceptable quality of life. Cities are not homogeneous units and the level of deprivation tends to vary from one location to the other. As a result, greater attention is now being paid to assessments of the quality of life, where the inequalities and disparities in access are properly accounted.

Quality of life is a complex, multifaceted concept that has been defined variously depending on the study context and objectives. The concept lacks a standard definition and is most commonly used to refer to life satisfaction, happiness, well-being, health status, standard of living and living conditions, to cite a few examples. Quality of life can mean 'different things to different people, encompassing such notions as 'well-being' centred on the individual to 'good place' centred on the location' (Dissart and Deller 2000). Pacione (2003) defines quality of life to describe some attribute of people themselves or to the conditions of the environment in which people live. There are models of quality of life even within

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the discipline of human ecology that combine anthropological, biological, epidemiological, psychological and sociological perspectives to provide a holistic view of the concept (van Kamp et al. 2003: 9). Recent conceptual insights to define quality of life have generated a great deal of discussion on the concept and how it relates to notions of development and poverty, particularly for large cities, that show rapid economic growth and population expansion.

Poverty in urban areas is typically manifest in the poor quality of housing, lack of sanitation and availability of clean water, and the limited access to other basic amenities and infrastructure. However, identifying the populations that experience a poor quality of life is a difficult task because of the substantial gap between the official urban poverty figures (largely derived from income or expenditure methods) and the proportion of people actually experiencing poor living conditions. This calls for fresh thinking on the methodologies and criteria that have been derived to measure urban poverty, and many experts hold that current poverty figures are gross underestimates. As long as poverty is considered only in terms of income and not overall living conditions or the provision of basic services and goods, the gap between the real and measured levels of deprivation in cities will remain large.

The paper combines an assessment of the living conditions of the people residing in the National Capital Territory (NCT) of Delhi with my own assessment of their poverty levels to examine the quality of life of Delhi's population. I explain the notions of 'income' and 'human' poverty and develop an analytical framework for capturing 'vagueness' that arises when concepts like poverty, well-being or quality of life are quantified. I present results based on these two measures of poverty to support my argument that poverty is multidimensional and that income alone is a poor proxy. As a result, in the context of the present study, inferences drawn about the quality of life based on *income* poverty alone are far from reality. In addition, any policy measures that aim to improve the quality of life through poverty reduction should address the notion of 'vulnerability'.

Delhi, the capital city of India, represents a heterogeneous mix of communities belonging to different income groups, with diverse social, cultural, ethnic and linguistic backgrounds. The present population of Delhi stands at around 16.7 million and is one of the fastest growing urban centres in India. In 2011, Delhi was the second most populous metropolitan Indian city after Mumbai with the highest density of population in the country around 11,297 persons per km^2 compared to the average all-India density of 382 persons per km^2 (Government of NCT of Delhi 2012). The city also has the highest per capita income in the country. However, equity continues to be a concern with disparities in access to some of the basic services (Government of NCT of Delhi 2013). Rapid urbanization in Delhi has brought about accelerated demand for basic services, infrastructure, jobs, land and affordable housing, particularly for the urban poor.

Using the concept of vulnerability, I examine the quality of life across five dimensions depicting living conditions: availability of drinking water facility in the premises, quality of fuel used for cooking by households, availability and quality of toilet facilities within household premises, access to electricity and the extent of green cover in the district. In addition, I also include one economic indicator, represented by possession of specified assets, in the analysis. Finally, I make an assessment of who the 'definitely poor' are on these dimensions of quality of life and who are 'extremely vulnerable' and thus at the margin of being classified as poor. What percentage of the population is 'definitely poor' and 'extremely vulnerable' as regards access to basic amenities? Which districts have poor access to basic amenities or where the percentage of 'definitely poor' and/or 'extremely vulnerable' households is considerable?

The methodology relies on two particular methods of operationalization: (1) the use of fuzzy set theoretic poverty measures and (2) assigning membership degrees to a given fuzzy set. The notions of 'poverty', 'quality of life', 'well-being' or 'standard of life' could become complex and vague because of the number of interrelated variables, dimensions and spaces these terms include with no clear-cut boundaries between them. The fuzzy sets logic can capture this complexity and vagueness to provide estimates that are close to reality. Studies by Chiappero-Martinetti (2000), Qizilbash (2002) and Qizilbash and Clark (2005) attempt to provide an account of quality of life with an account of the vagueness of poverty using fuzzy sets logic. This study is one such attempt. The notion of 'vagueness' discussed here has to do with the difficulty in defining sharp boundaries and precise distinctions. The fuzzy sets theory explains *uncertainty* (related to the notion of vagueness) that crisp sets are unable to analyse. I use an ordinal aggregator namely the Borda rule to rank districts along the multiple dimensions reflecting living conditions in order to identify districts that need immediate policy intervention.

2 Conceptualizing Quality of Life, Poverty, Vulnerability, Vagueness and Fuzzy Set Theoretic Measures

Quality of life is a vague and a difficult concept to define, with no exact definition. Consequently, many concepts are used for measuring quality of life: the personal well-being approach; the community trends approach; the liveability comparisons approach focusing on comparing different areas according to a number of objective indicators assumed to reflect quality of life (Burnell and Galster 1992).

Quality of life has mostly been assessed using monetary indicators such as GDP, price levels and cost of life. Although high incomes do enable access to a better life, the quality of life is determined by a number of factors not necessarily linked to income. Complex definitions of quality of life have evolved over time that consider income and consumption as only poor measures of the quality of life and include a variety of dimensions such as shelter, health and education. Sen (1999: 80) considers real income as a poor indicator of important components of well-being and quality of life that people have reason to value. Instead Sen suggests that one should be concerned with the capability to fulfil certain 'basic needs' or 'basic values'. Poor people lack access to basic services (for instance, education and health), they lack assets, live in deprivation and are vulnerable to poverty.

Vulnerability to poverty can be studied in two respects: one has to do with the possibility of being classified as poor and the other is vulnerability related to the risk of falling into a lower state of well-being. Former is the result of the vagueness of the terms ‘poor’ and ‘non-poor’ that leads to imprecise estimates of poverty and the latter is mainly due to ‘basic capability failure’. Poverty viewed in relation to lack of ‘basic goods’ or ‘basic capabilities’ is conceptualized as ‘human’ poverty, while poverty defined in financial terms (insufficient income or consumption) is known as ‘income’ poverty (World Bank 1990, 2001; UNDP 1997; Drèze and Sen 1989). Poverty is relative when assessed in terms of income and resources and ‘absolute’ in terms of capability to achieve important functionings (Qizilbash 2002).

Chiappero-Martinetti (2008: 279) explains that the idea of poverty is intrinsically vague in any dimension of human well-being even in terms of income or nutrition, physical health and so on. This is large because the term ‘poor’ may at once be absolute or relative, and lacks a quantitatively precise meaning. As a result, it is difficult to decide whether the term can be precisely applied in particular cases, or at what exact point a person ceases to be poor in an absolute sense based on the given criteria. Qizilbash (2003: 50) argues that there are two aspects to make predicate ‘poor’ more precise: one relates to the dimensions in which someone is poor and another relates to the key cut-off point in any dimension below which someone counts as poor.

Significant attempts have been made to analyse such imprecision using fuzzy sets theory by identifying the cut-off above and below which people are *definitely non-poor* and *definitely poor*. In between the two cut-offs, there is *ambiguity* and people belong to the set of the poor to *some degree* (Qizilbash 2002: 759). Qizilbash and Clark (2005: 109) note that the fuzzy poverty measures address vagueness or imprecision about poverty rather than its depth or intensity. They are measures of *vulnerability,* where vulnerability relates to the possibility of being classified as poor (Qizilbash 2003: 52–53).

3 Materials and Methods

3.1 The Database

District-level information on the availability, quality and access to basic urban amenities, assumed to be dimensions reflecting living conditions, in the NCT of Delhi is collected from Census of India 2001 and 2011 series on houses, household amenities and assets. In addition, the extent of green cover (relative area under green area) in each of the nine districts is also taken as another dimension of living conditions. This data is generated using IRS-1D-LISS-III Image taken in April 2000 with 23.5 m resolution and IRS-P6-LISS-IV image taken in April-2007 with 5.8 m resolution. Among the many dimensions reported in the Census, the dimensions selected for this study are: availability of drinking water facility in the premises, quality of fuel used for cooking by households, availability and quality of toilet facility within premises, access to electricity. Apart from these, income poverty is captured by possession of specified assets as listed in the Census. While these dimensions are important to quality of life, they do not constitute the universal set of indicators that have been used or are available. However, I shortlisted these dimensions because they are relevant and compatible with fuzzy set measures given the way they are documented in the Census.

3.2 Methods

3.2.1 Fuzzy Sets Approach

Fuzzy sets are suitable for modelling preferences and outcomes that are inexact. Unlike crisp sets that assign a membership value of either 0 or 1, in a fuzzy set A the membership function μ_A takes the form

$$\mu_A : X \to [0, 1] \tag{1}$$

where [0,1] is the interval of real numbers from 0 to 1. Hence, $\mu_A(X) = 1$ if x completely belongs to A, $\mu_A(X) = 0$ if x does not belong to A and $0 < \mu_A < 1$ if x partially belongs to A. Membership value of 1 indicates the category definitely poor in a particular dimension and 0 definitely non-poor. The membership values between these two extremes indicate a vulnerable group. However, selecting a suitable membership function depends on the context of study and the way indicators are described. Here, I estimate the membership function using fuzzy approach developed by both Ceroli and Zani (1990) and Cheli and Lemmi (1995).[1]

Further, inter-district comparisons of the living conditions are made based on the rank-order scoring obtained using ordinal aggregator, namely Borda Rule (Tables 1, 2, 3 and 4). The results are explained below.

[1]See Appendix 1 for membership functions proposed by Ceroli and Zani (1990) and Cheli and Lemmi (1995). Fuzzy set theoretic poverty measures are also explained and estimated using Ceroli and Zani (1990) and Cheli and Lemmi(1995) approaches with the help of two dimensions depicting living conditions: availability of drinking water facility in household premises and type of cooking fuel used by households.

Table 1 Definite poverty rankings 2001

District	Water	Fuel	Lighting	Toilet	Green cover	Borda score	Borda rank
North-west	2	3	5	2	3	15	1
North	1	5	1	3	8	18	2
North-east	8	1	3	9	5	26	5
East	6	7	9	7	4	33	8
New Delhi	7	9	2	1	7	26	5
Central	9	8	4	5	9	35	9
West	5	6	6	8	6	31	7
South-west	3	2	6	6	1	18	2
South	4	4	8	4	2	22	4

Table 2 Definite poverty rankings 2011

District	Water	Fuel	Lighting	Toilet	Green cover	Borda score	Borda rank
North-west	2	1	1	1	3	8	1
North	1	7	2	4	8	22	4
North-east	7	6	3	8	5	29	7
East	8	8	8	7	4	35	8
New Delhi	4	3	6	6	7	26	5
Central	9	9	9	8	9	44	9
West	6	5	6	5	6	28	6
South-west	3	2	3	3	1	12	2
South	5	4	3	2	2	16	3

Table 3 Extreme vulnerability rankings 2001

District	Water	Fuel	Lighting	Toilet	Green cover	Borda score	Borda rank
North-west	1	1	3	9	3	17	3
North	3	9	6	4	5	27	5
North-east	6	1	2	1	4	14	1
East	6	6	7	3	6	28	8
New Delhi	6	7	8	5	8	34	9
Central	2	5	9	2	9	27	5
West	6	4	4	6	7	27	5
South-west	4	7	5	8	1	25	4
South	5	1	1	7	2	16	2

Table 4 Extreme vulnerability rankings 2011

District	Water	Fuel	Lighting	Toilet	Green cover	Borda score	Borda rank
North-west	2	4	1	2	2	11	1
North	1	8	3	6	6	24	5
North-east	7	3	1	9	4	24	5
East	9	9	8	7	7	40	9
New Delhi	6	6	3	1	5	21	3
Central	5	5	8	3	9	30	8
West	8	1	3	4	8	24	5
South-west	4	6	3	8	1	22	4
South	3	2	3	5	3	16	2

4 Results

Delhi has performed well in providing tap water facility to its residents from 75% of households having access to tap water in 2001 to 85% in 2011. As regards use of cooking fuel, provision of LPG has improved from 68% per 2001 Census to nearly 90% according to 2011 estimates. The other commonly used fuel is kerosene, though its use has declined between the two Census periods. Cow-dung, crop-residue, firewood are also in use with a declining percentage.

Considering the source of lighting, anyone who has no source of lighting at home is considered most deprived, while those using any kind of oil (with no specifics) are *extremely vulnerable* according to V_{cz}. Electricity has nearly universal coverage in Delhi. However, a small percentage of population, even after improvements from 2001 situation, does not have any lighting provision at home. Kerosene is no more considered as another key source of lighting; from close to 6.2% of households using kerosene per 2001 Census, the percentage has fallen to less than 1 according to 2011 Census.

Next to reflect on the living conditions of the residents of Delhi is the availability and type of toilet facilities within premises. Nearly 22% of Delhi's population did not have this facility within household premises and close to 3.3% still defecate in open. The importance of public toilets is apparent from Census figures. Open defecation is the highest in the North-west district (5.3%) followed by South district (4.6%) by 2011 estimates. Comparative figures for these districts per 2001 Census are around 32 and 21%, respectively.

The extent of green cover in the immediate vicinity is considered as another important dimension influencing living conditions. Tree cover is assumed to be an integral part of an urban unit. The aim of urban planners is to make the city green by planting trees, keep the boulevards intact and ensure that the tree cover is not reduced. On the contrary, dense bushes which are mostly found on barren, vacant or fallow lands do not represent green cover. Dense bushes/scrubs represent worst category in terms of green cover in urban areas. Tree cover in Delhi appears to be declining, while dense bushes have marginally increased and so have scattered trees. Tree cover as a percentage of total green cover appears to be reduced in all the districts of Delhi except for South, North-west and West. New Delhi district has experienced a distinct decline from nearly 9% in 2000 to 2.3% in 2007, while area under sparse bushes has increased from around 2 to 10%. Dense bushes can be mostly found in the South-west district.

Considering the possession of assets as specified in the Census 2001 and 2011, households that possess none of the assets listed in the Census are identified as *definitely poor*, while households possessing subsets of such assets are higher in rank. Ascertaining *extremely vulnerable* households is difficult because of the way in which the asset ownership information is presented in the two Census documents.

The inter-district rankings for these dimensions are presented in Tables 1 and 2—for *definitely poor* and in Tables 3 and 4—for *extremely vulnerable* as per V_{cz}.[2] Estimates based on V_{cl} are not considered because they can at times be misleading. Rank-order 1 is assigned to the worst district and 9 to the best. A composite index of the five dimensions representing 'human' poverty is constructed in the last column of Tables 1, 2, 3 and 4. The index is constructed by taking the rank order for each district, under each dimension, and then adding the scores for each district. The worst district gets a score of 1, and (if there is no tie) the best gets a score of 9, the higher (lower) the sum the better (worse) is the overall performance. The sum of rank orders gives the Borda score, and the ranking based on these scores is the Borda ranking.[3] Both Borda scores and Borda rankings are calculated for the five *human* poverty dimensions. These rankings are used to identify districts that are *definitely poor* in terms of achievements under each dimension and those that are *extremely vulnerable* to be classified as poor. Important to note is that all the districts report incidence of *definite* poverty in almost all dimensions and are *extremely vulnerable* to be classified as poor. The difference is in terms of the extent of incidence (percentage of households deprived of basic amenities).

The Borda ranking according to definite human poverty depicts the poorest quality of life in the North-west district followed by South-west district. The North district which had high incidence of human poverty in 2001 shows some improvement per 2011 figures, while the incidence has increased in the West and South districts of Delhi. Central district is at the top followed by East district. Living conditions in the North-east have improved while they remain the same in the New Delhi district.

On analysing the extreme vulnerability Borda ranking (2011 estimates), North-west district appears to be *extremely vulnerable* followed by South and New Delhi districts, in the same order. New Delhi which had the lowest vulnerability ranking in 2001 is now among the top three districts to have higher incidence of

[2]Appendix 1 explains the 'definitely poor' and 'extremely vulnerable' categories.

[3]Dasgupta and Weale (1992), Dasgupta (1993, 2001) and Qizilbash (1997) have used Borda score in well-being rankings.

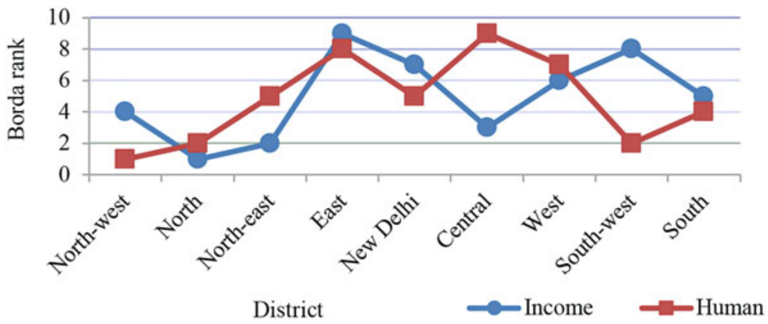

Fig. 1 Definite poverty rankings (2001)

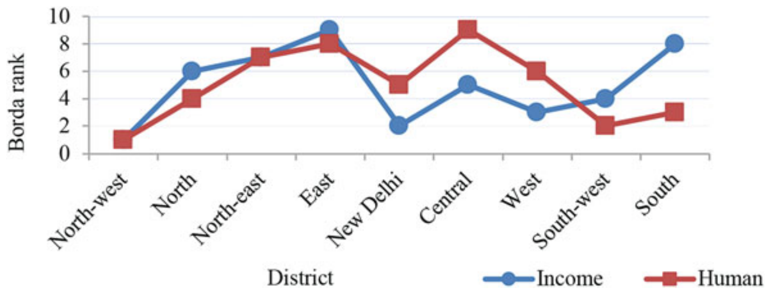

Fig. 2 Definite poverty rankings (2011)

extreme vulnerability. East district has the lowest number of households in the *extremely vulnerable* category followed by the Central district. North-east district has moved up from being the poorest in this category in 2001 to an average position in 2011. Central district has also been successful in reducing the percentage of households in this category. The other districts have more or less remained at the same position between 2001 and 2011.

The last part of the analysis focuses on comparing *definite human* poverty rankings with rankings based on *income* poverty (Figs. 1 and 2). According to the *definite human* poverty rankings, Central district is at the top indicating that the access to basic amenities in the district is the best (a small percentage of population falls in the *definite* poverty category) among all the districts. However, *definite income* poverty estimates do not suggest such a situation. Similarly, South-west district which is among the top three on *income* poverty dimension in 2001 depicts a high incidence of *human* poverty. Looking at 2011 figures, *definite income* poverty is apparent in the West district, whereas this district does not even appear in the bottom three in any of the dimensions of *human* poverty. So is the case with New Delhi which has high incidence of *definite income* poverty, does not appear poor on *human* poverty dimensions. On the other hand, North district which has a reasonable rank on *income* dimension fails on two *human* poverty dimensions and the third which is just below the average rank. Such contrasting results are distinctly observed for South and Central districts of Delhi.

5 Conclusion

Measuring and expressing the quality of life is critical to the development process and will help set the priorities and pace of advancement. In practice, however, the quality of life has been difficult to define and measure, in part because it depends on what people intrinsically value, but largely because of the multiple dimensions that influence living conditions and the way people perceive them. This paper provides an account of quality of life in the city state of Delhi by combining an assessment of the living conditions of people residing in Delhi with my own assessment of their poverty levels. The indicators depicting living conditions are taken from India Census 2001 and 2011. I explain the notions of 'income' and 'human' poverty and develop an analytical framework for capturing 'vagueness' that arises when concepts like poverty, well-being or quality of life are quantified. The notion of 'vagueness' here is to do with the difficulty in defining sharp boundaries and precise distinctions between 'poor' and 'non-poor'. Using the fuzzy sets logic, I have made an attempt to capture this *vagueness* in order to arrive at estimates that reflect true picture.

To summarize the availability and quality of urban amenities accessible to the residents of Delhi, it is found that the overall tap water provision for the households in Delhi, according to 2001 figures, stood at 75% approx., which increased to almost 85% in 2011 (considering both treated and untreated sources). Use of tube wells increased during this period from 3.2 to 8.7%, while the use of hand pumps declined. Use of electricity for cooking remained the same; less than 1%, whereas LPG usage increased from nearly 68 to 90% and that of kerosene, biogas, coal lignite, firewood, crop-residue, etc., dropped. The figures for kerosene dropped from close to 24% to almost 5%. Kerosene is also considered as an alternative source of lighting, after electricity, though in recent years electricity dominates as the main source of lighting for nearly 99% of the households in Delhi. The use of solar energy as an alternative source of lighting has not picked up in Delhi; less than 1% of the households tap solar energy. The situation regarding the type and availability of toilet facility within premises, which was poor per 2001 figures has improved; around 22% of the households did not have this facility in their homes, which is brought down to 10.5%. Area under tree cover in Delhi has reduced (from 28.7 to 26.5%), while it has increased under dense bushes from 15.7 to 16.5%.

Of the five dimensions of *human* poverty considered any urban development process or plan would need to consider which among these amenities are poorly provided to the residents of Delhi. Taking the *definitely poor* and *extremely vulnerable* categories identified using the 2011 Census, the results indicate that the availability of toilet facilities within premises is the poorest among all the amenities.

More than 7% of the households use public toilets and close to 3.3% defecate in open. LPG/PNG remains inaccessible to 9.8% of Delhi's population; around 4.4% of the households are dependent on coal, lignite, firewood, crop residue, cow dung as cooking fuel. Wells, tanks, ponds, river, canal, spring are main sources of drinking water for close to 1.5% of households, and nearly 0.1% of the households use other oils or have no lighting provision at home.

In order to summarize our findings for city planner in a clear and concise manner, I have constructed a composite index of five dimensions of *human* poverty using Borda Rule. This index is constructed at the district level, and districts with relatively high percentage of households deprived of basic amenities (classified as 'definitely poor') per 2001 Census are: North-west, North, South-west and South (in order of decreasing severity). The Census, 2011, suggests that these districts continue to remain at the same position: North-west, South-west, South and North.

The application of fuzzy sets approach to quality of life examined in terms of poverty of lives illustrates that policy should target not only the *definitely poor* but also the *extremely vulnerable* to achieve sustained long-run results.

In conclusion, the link between income and levels of deprivation is weak and misleading, especially when measuring urban poverty. The multidimensional nature of poverty examined in this paper implies that a simultaneous focus on a number of different policies relating to water, electricity, housing, environment is needed if the policy wishes to improve the quality of life of people. It also helps in identifying the actual *definitely poor* category. However, the challenge for policy is not just in identifying these groups precisely, but also ensuring that the people who are *vulnerable* to being classified as poor do not fall into poverty and to prevent the poor from getting poorer. Groups that have been categorized as *vulnerable* occupy a fragile position and the likely transitions from the *vulnerable* to the *definitely poor* category would diminish the effectiveness of policies and interventions directed at improving the quality of life.

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Appendix 1: Application of the Concept of Vulnerability Using Fuzzy Set Theoretic Poverty Measures

Ceroli and Zani (1990) were the first to develop the simplest fuzzy poverty measure. They developed an ordinal method of scoring where the lowest score is assigned to the highest level of deprivation (Qizilbash and Clark 2005: 107). Assuming that P denotes rank-order score, then P'_j is the score at and below which someone is definitely poor in dimension j. P''_j is the score at or above which someone is definitely non-poor. Individual i's degree of membership to the set of the poor in dimension j can be written as Z_{ij} . It is 1 if $P_{ij} \leq P'_j$, and 0 if $P_{ij} \geq P''_j$. If $P'_j < P_{ij} < P''_j$, then:

$$Z_{ij} = \left(P''_j - P_{ij}\right) / \left(P''_j - P'_j\right) \tag{2}$$

Z_{ij} measures how far one is, in rank terms, from being *definitely non-poor* in any particular dimension. Intuitively, it can be taken as a measure of vulnerability in the relevant dimension.

Cheli and Lemmi (1995) developed an alternative fuzzy set theoretic measure which is both fuzzy and relative. Given the sampling distribution of x_j arranged in increasing order according to k as $H\left(x_j\right)$, then for $k > 1$ the degree of membership is given by:

$$g\left(x_j^{(k)}\right) = g\left(x_j^{(k-1)}\right) + \left\{\frac{H\left(x_j^{(k)}\right) - H\left(x_j^{(k-1)}\right)}{\left(1 - H\left(x_j^{(1)}\right)\right)}\right\} \tag{3}$$

$g\left(x_j^{(k)}\right)$ denotes the degree of membership to the set of the poor for class ranked, k in terms of x_j. It lies in the [0,1] interval and is a measure for dimension j only. The Cheli and Lemmi's measure can also be treated as a measure of vulnerability signifying how close someone is to being *definitely poor* in a particular dimension. The membership values between 0 and 1 indicate a vulnerable group, with higher values signalling higher levels of vulnerability. The way vulnerability is assessed in this analysis, it has to do with the possibility of being classified as poor and not exactly the risk of becoming poor.

In Tables 5 and 6, the first row relates to a particular dimension (e.g., sources of drinking water, fuel used.), and the second row gives the rank associated with each category and the third and fourth rows show the Ceroli and Zani measure (V_{cz}) and Cheli and Lemmi measure (V_{cl}). The next nine rows give the headcount index, in percentage terms, for each district from the Census data.

Distinction is made between someone who is non-poor and someone who is *definitely poor* in each of the selected dimensions depicting living conditions. Only the worst-off category in each dimension is *definitely poor* in that dimension. 0 signifies non-poverty, and 1 signifies definite poverty and any number between 0 and 1 measures the level of vulnerability. For the study, any number above or equal to 0.65 but less than 1 is taken to signify extreme vulnerability. Though the two measures identify exactly the same groups as definitely poor and non-poor for each dimension, the difference arises only in the levels of vulnerability.

A majority of households in Delhi use tap water for drinking and a small percentage (around 3% in 2001 and 1.4% in 2011) draws water from wells, tanks, ponds, river or canal. In fact, Census 2011 makes a further distinction between treated and untreated tap water sources. The use of tank/pond/river is treated as the most deprived category, and the use of wells as the second most deprived category.

Table 5 Availability of drinking water facility (2001 Census)

	Tap	Tubewell	Handpump	Well	Tank, pond, river, canal, spring
Rank	1	2	3	4	5
V_{cz}	0.00	0.25	0.50	0.75	1.00
V_{cl}	0.00	0.13	0.89	0.89	1.00
North-west (%)	80.10	0.62	15.08	0.12	4.09
North (%)	82.00	0.71	10.81	0.04	6.44
North-east (%)	61.51	0.48	36.82	0.01	1.18
East (%)	80.03	1.64	17.13	0.01	1.20
New Delhi (%)	92.20	0.86	6.74	0.01	0.19
Central (%)	92.78	0.80	5.67	0.07	0.67
West (%)	78.00	2.15	18.03	0.01	1.81
South-west (%)	67.92	9.62	18.91	0.03	3.52
South (%)	70.94	6.97	19.23	0.02	2.84
NCT of Delhi (%)	75.33	3.23	18.68	0.04	2.72

Table 6 Availability of drinking water facility (2011 Census)

	Tap water from treated source	Tap water from untreated source	Tube well/ Borehole	Hand pump	Well (covered and uncovered)	Tank, pond, river, lake canal, spring
Rank	1	2	3	4	5	6
V_{cz}	0.00	0.20	0.40	0.60	0.80	1.00
V_{cl}	0.00	0.29	0.68	0.94	0.94	1.00
North-west (%)	79.15	6.57	4.50	6.71	0.15	2.92
North (%)	83.09	4.87	1.44	7.28	0.19	3.13
North-east (%)	77.11	5.11	5.69	11.64	0.06	0.39
East (%)	92.26	2.43	3.49	1.46	0.03	0.32
New Delhi (%)	91.28	4.19	1.33	2.19	0.07	0.93
Central (%)	93.23	3.00	2.48	1.16	0.08	0.04
West (%)	84.19	4.72	6.31	4.18	0.05	0.55
South-west (%)	71.90	8.00	16.26	2.22	0.10	1.52
South (%)	61.54	11.14	19.47	6.88	0.13	0.84
NCT of Delhi (%)	78.01	6.37	8.68	5.54	0.10	1.30

The second worst category with V_{cz} = 0.75 and 0.80 is considered as *extremely* vulnerable, while it is not so as per V_{cl} = 0.89 and 0.94. The difference is mainly because V_{cl} is a relativist measure. It is worth noting, that the North-east district with the lowest percentage (61.5) of households with tap water provision in 2001

Table 7 Type of cooking fuel used by households (2001 Census)

	Electricity	LPG	Biogas	Kerosene	Coal, lignite	Cow dung, crop residue, firewood
Rank	1	2	3	4	5	6
V_{cz}	0.00	0.20	0.40	0.60	0.80	1.00
V_{cl}	0.00	0.68	0.68	0.93	0.93	1.00
North-west (%)	0.07	65.73	0.19	26.09	0.19	7.73
North (%)	0.05	70.00	0.40	22.67	0.06	6.83
North-east (%)	0.04	58.20	0.38	30.45	0.19	10.76
East (%)	0.03	74.72	0.24	19.98	0.11	4.91
New Delhi (%)	0.14	71.30	0.22	24.17	0.07	4.09
Central (%)	0.03	69.26	0.30	26.04	0.12	4.23
West (%)	0.03	72.51	0.15	22.15	0.13	5.02
South-west (%)	0.05	69.64	0.30	21.20	0.07	8.73
South (%)	0.05	66.68	0.35	25.70	0.19	7.03
NCT of Delhi (%)	0.05	68.04	0.27	24.40	0.15	7.10

Table 8 Type of cooking fuel used by households (2011 Census)

	Electricity	LPG/ PNG	Biogas	Kerosene	Coal/ Lignite	Firewood, crop residue, cow dung
Rank	1	2	3	4	5	6
V_{cz}	0.00	0.20	0.40	0.60	0.80	1.00
V_{cl}	0.00	0.90	0.90	0.96	0.96	1.00
North-west (%)	0.05	85.97	0.07	7.86	0.14	5.90
North (%)	0.03	92.11	0.08	4.61	0.05	3.11
North-east (%)	0.02	90.62	0.10	5.76	0.15	3.36
East (%)	0.02	92.63	0.07	4.45	0.03	2.79
New Delhi (%)	0.37	88.43	0.04	6.77	0.06	4.33
Central (%)	0.16	89.35	0.04	7.68	0.09	2.68
West (%)	0.04	91.12	0.07	4.93	0.24	3.59
South-west (%)	0.03	91.86	0.05	2.97	0.06	5.03
South (%)	0.03	91.54	0.19	3.89	0.17	4.18
NCT of Delhi (%)	0.04	90.23	0.09	5.26	0.13	4.23

shows improvement per 2011 figures. Close to 77.1% of the households in this district have access to tap water from treated source and another 5.1% from untreated source. The use of tube wells/boreholes seems to have increased while that of hand pumps has fallen across all the districts.

In the case of fuel used for cooking (Tables 7 and 8), the use of cow dung, firewood, and crop residue is treated as the most deprived category, while the use of electricity is considered as the most expensive method of cooking since in addition to the electricity cost such a method of cooking also requires different kinds of vessels and cooking appliances that are relatively expensive. Households using electricity predominantly for cooking are *definitely non-poor*. Anyone who uses coal, lignite is *extremely vulnerable* according to V_{cz}, whereas V_{cl} classifies LPG as *extremely vulnerable*. The fact that type of cooking fuel used has an absolute component meaning that V_{cz} is significant here.

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Part IV
Reflections on Institutional Contributions of Kanchan Chopra

A Few Words on Kanchan Chopra's Role in the Early Years of the International Society for Ecological Economics

Richard B. Norgaard

I knew Professor Chopra before the founding of INSEE in 1998, but I am having difficulty remembering the context in which I first came to know her. I had made several trips to India before 1998 during which I would likely have met her. Kanchan Chopra may also have come to an ISEE biennial meeting before 1998.

On behalf of the Institute of Economic Growth, she graciously invited me to give its 10th V. T. Krishnamachari Lecture in 1998 that, given my modest performance, I surely should not have accepted. Yet the lecture brought me to Delhi, and I was also able to participate in the founding gathering of the Indian Society for Ecological Economics (INSEE) the next day. This was an especially joyous event for me. The participants at the founding of INSEE were dedicated, both connected to and critical of government, and top scholars.

She helped organize a strong delegation from INSEE to attend the 2000 biennial ISEE meeting in Canberra. The International Society was finally feeling international with a significant Asian contingent. While a good number of INSEE members would be at ISEE biennial meetings, it was Kanchan Chopra who was most likely to present a view from the South, to participate vocally in the member meetings, and be talking in the hallways between events. I remember her being at the meeting in Sousse, Tunisia, in 2002 and in Montreal, Canada, in 2004.

Most importantly, among others, Kanchan Chopra was central to bringing the ISEE meeting to Delhi in 2006. If my recollection serves me correctly, the INSEE delegation took responsibility for hosting the 2006 meeting during the 2000 meeting in Canberra. Surely, I am unduly fond of the Delhi meeting for I received the Boulding Prize that year, but there was a strong combination of keynote speakers, and the attendance was strong and lively. I especially remember the intense discussions outside in the patio spaces during breaks. Thanks to Kanchan and to all who made the 2006 ISEE biennial meeting so memorable.

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Birth of INSEE and My Association with Kanchan Chopra

Gopal K. Kadekodi

The day, when about 50 of environmental, ecological scientists, sociologists and economists, met at India International Centre, New Delhi, in September 1998, it was a great day in Indian environmental and ecological research and movement. For many of us, it sounded like what Neil Armstrong had said on 21 July 1969, '*That's one small step for man, one giant leap for mankind*'. In the last meeting of the day evening, chaired by Gopal K. Kadekodi, it was all one voice echoed to establish a society for the cause, to be named as Indian Society for Ecological Economics. Came in a single thought, in the voice of Anil Gupta of IIM, Ahmedabad, to announce that Kanchan Chopra shall be the first President of the Society. The entire group overwhelmingly approved. At that launch meeting itself, there were more than fifty academicians who signed the document of approval of the society.

Kanchan Chopra had put in lots of thoughts, negotiating with the International Society for Ecological Economics (ISEE), in particular with the then President Richard Norgaard of University of California, Berkeley, to conceive an Indian chapter of the ISEE. Norgaard was also present in the first meeting of the academicians with common interest held at New Delhi. She spent enormous time and energy in contacting most of the scholars and policymakers to agree to have such a society in India. The entire world of environmental and ecological researchers and policymakers in India owe a great debt to her zeal, skill in drafting the constitution, and having it registered under Cooperative Society's Act of India. Moreover, she was also instrumental to have an office establish within Institute of Economic Growth, to manage the affairs of INSEE. The responsibility of the first President was not easy either. To showcase the existence of the society, she managed to have the first conference of INSEE at Institute for Social and Economic Change, Bangalore, at which over one hundred and fifty scholars from all over India

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attended. The theme of that first conference was Interdisciplinarity in Environmental Research: Concepts, Barriers and Possibilities.

Much later, she was also elected as President once again in 2010–11. The research community is happy that her association is continuing as ever.

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I should now hasten to add at least a few more lines about Kanchan Chopra. My association with her began as early as in 1973 at the Institute of Economic Growth (IEG), New Delhi. Both of us were in the same academic unit of IEG, then called Investment Planning and Project Evaluation. We shared the basic responsibility of training officers from various state and central governments on methodology of planning, investment decision making and project appraisal techniques, including cost-benefit techniques.

Just then, while I was engaged in various researches on natural resources such as iron ore extraction, coal mining, petroleum exploration and extraction, I became more and more interested in the management of land (including forests) and water resources. Kanchan was deeply into agricultural development, particularly on the impacts of large irrigation dams, and water resource management in general. Our research interests converged so much so that we started thinking about land and water management with the pool of peoples' power. That is how our first major research study on participatory watershed development was launched in IEG, sometime around 1977–78, with our field studies in Sukhomajri and surrounding villages of Haryana state, with book publication under the title *Participatory Development.*

Since then, our common research interests grew so much deep into the management of such natural resources that we started collaborating and pooling our ideas on land-related employment programmes, links between natural resources and locals dependent on forest and water resources. A major integrated research study on land, water, forests, biodiversity was carved out to identify the links between then, factors that can empower the locals to sustain such resources subsequently coined as *Chakriya Vikas Yojana*. A book was published subsequently under the title *Operationalising Sustainable Development.* Various theoretical nexus between the people and the natural resources clubbed with heavily concentrated on the field studies in Palamu District of then Bihar now Jharkhand are presented in that book.

Our interests also grew about what people think about such natural resources. That drove our researches towards identifying and measuring value of natural resources, including environmental resources. Hence, a number of valuation research ventures emerged between us on Ganga basin studies, to NTFP and forest resources, water resources, biodiversity, wildlife and many such entities. Articles were jointly published in several journals.

When a challenge was made by policymakers about integrating contributions of environmental and natural resources to national income, we undertook several studies together on measuring what is commonly called Green GDP. Today, I am unable to even recollect the different studies that we worked together sharing our theoretical and empirical ideas and policy imperatives to make the measurement of green GDP a practical one. Today, with degree of pride, I must mention that without the close research association from Kanchan, I would not have moved so much in the arena of theoretical and econometric aspects on the nexus between people, natural resources and policymaking and implementation. A secret of our joint studies was, an unwritten understanding, not to step into each other's arena of expertise, yet taking an inclusive approach to complete the research studies for the benefit of the society.

Our daily meetings around 11 am over a cup of coffee on the second floor of IEG are still a vivid memory pot for me. We would meet along with several of our research assistants and associates and indulge in various theoretical and practical discussions on the research projects and their impact on the society. I still remember what exactly Kanchan said on the day of my retirement from IEG, on 30 September 1998 that, 'I would wonder if my own researches become curtailed with Gopal's departure from IEG?' But we never parted working together on research front. Our research exchanges were always of mutual benefit, a win-win situation, and continuing as ever. Apart from anything else, we are also good family friends, which will hopefully continue to cherish us forever.