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Economic Development under Climate Change

*Channing Arndt, Paul Chinowsky, Sherman Robinson,
Kenneth Strzepek, Finn Tarp, and James Thurlow**

Abstract

The papers in this special issue represent some of the most comprehensive analyses of the implications of climate change for developing countries undertaken to date. The papers employ a bottoms-up systems approach whereby the implications of climate change are evaluated using structural models of agriculture and infrastructure systems. The authors of the paper hail from multiple disciplines. This comprehensive, multi-disciplinary, structural approach is designed to allow for more robust insight into the potential implications of climate change. The approach also allows for experimentation with alternative policy options for achieving development objectives in the context of climate change.

1. Introduction

Climate change presents a highly complex challenge for developing countries, particularly low income countries. While the challenge of climate change is relatively new, the

* Arndt: Department of Economics, University of Copenhagen, Øster Farimagsgade 5, building 26, 1353 København K, Denmark. Tel: +45-3-532-3010, Fax: +45-3-532-3000, E-mail: channingarndt@gmail.com. Chinowsky: Civil, Environmental, and Architectural Engineering, University of Colorado, ECOT 441, UCB 428, Boulder, Colorado 80309-0428, USA. Robinson: Institute of Development Studies, University of Sussex, Brighton BN1 9RE, UK. Strzepek: Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, 77 Massachusetts Ave, E19-411, Cambridge, MA 02139-4307, USA. Tarp and Thurlow: UNU-WIDER, Katajanokanlaituri 6 B, FI-00160 Helsinki, Finland. This special issue is an initiative of UNU-WIDER's "Development under Climate Change" project. We are grateful for financial contributions to this project by the governments of Finland and Sweden. We also acknowledge core financial support to UNU-WIDER from the governments of Denmark and the UK. The articles in this volume benefitted from discussion, critique, and input from numerous people. For bringing us together and getting us going, we would like to thank Aziz Bouzaher, Jean-Christophe Carret, and Sergio Margulis of the World Bank. Comments by workshop participants at the International Food Policy Research Institute were also valuable. All errors and omissions are the responsibility of the authors.

types of challenges posed by climate change for economic development are in many ways familiar. Since its inception, development economics has mainly focused on large-scale phenomena involving multiple impact channels and complex interactions. In addition, uncertainty and the need to cope with short term shocks in order to proceed on a positive long term development path have often been central considerations. In this way, climate change shares many characteristics with traditional development issues. Overall, climate change complicates the already formidable task of fomenting long run development.

The United Nations University's World Institute for Development Economics Research (UNU-WIDER) recognizes the need for inter-disciplinary research on climate change. Its "Development under Climate Change" research program brings together economists, scientists, and engineers in order to provide new tools and evidence for policy makers in developing countries. This special issue of the *Review of Development Economics* illustrates the current state of research linking climate change to economic development. It presents detailed analysis of the implications of climate change for five country cases: Bangladesh, Ethiopia, Mozambique, Tanzania, and Zambia.

The analyses concentrate on potential impacts of climate change, focusing on changes in temperature and precipitation, as well as alternative adaptation strategies. Two broad channels of impact, agriculture and infrastructure, are in focus. The latter impact channel, roads and hydropower, which are often the most valuable public infrastructure stock, receive detailed consideration. Across all of the analyses, particular attention is devoted to variations in climate outcomes with special emphasis on extreme events, such as droughts and floods.

Even though some potentially important channels, such as implications of warmer climates for human health, are not considered in the analyses presented in the following pages, the papers in this special issue, taken as a whole, represent some of the most comprehensive analyses of the implications of climate change for developing countries undertaken to date. The papers employ a bottom-up systems approach whereby the implications of climate change are evaluated using structural models of agriculture and infrastructure systems. In order to deliver a comprehensive analysis, the authors of the papers, by necessity, hail from multiple disciplines. This comprehensive, multi-disciplinary, structural approach allows for more robust insight into the potential implications of climate change. The approach also allows for experimentation with alternative policy options for achieving development objectives in the context of climate change.

The remainder of this paper is structured as follows. The next section in this overview considers the issue of vulnerability to climate change. Section 3 compares structural versus reduced form analysis. Section 4 highlights some of the methods that were developed for these analyses and principal insights obtained. Section 5 concludes that, while much has been learned, there is a great deal that remains unknown. Accordingly, suggestions for future research are in focus.

2. Vulnerability to Climate Change

A country's *vulnerability* reflects the degree to which its social and economic systems are susceptible to the adverse effects of climate change, including variability and extreme weather events like droughts and floods. Climate change vulnerability assessments measure a country's *exposure*, *sensitivity* and *adaptive capacity* (Yohe and Tol, 2009; Fussler and Klein, 2006).

Exposure is determined by the nature of climate changes predicted for a country. While there is general agreement that anthropogenic climate change will lead to higher average global surface temperatures and precipitation over coming decades, there is far less consistency among global models over changes for specific countries or regions (Solomon et al., 2007). Therefore, measurement of a country's exposure to climate change is subject to considerable uncertainty. This derives from both economics and climate science. First, it is impossible to accurately predict future changes in the global economy, such as the rate of population and economic growth and the emergence of new technologies. Different assumptions about these demographic and economic trends, as well as assumptions about policy, lead to different levels of greenhouse gases (GHG) in the future. Second, even if GHGs are accurately predicted, there are still differences in the way climate models capture the earth-atmosphere relationship. This leads to different climate change projections at the global level and even wider variation for individual countries and regions. Evidence suggests that the source of climate change uncertainty is fairly evenly divided between economics and climate science (Sokolov et al., 2009).

Much of the debate surrounding climate change and its implications for developing countries has centered on this issue of uncertainty. One way to reduce countries' exposure to climate change is to implement global policy that limits future GHG emissions. While this does not reduce uncertainty within the climate science, it does reduce the variation in emissions and therefore overall uncertainty. It is not surprising then that most of the economics research on climate change has been conducted at the global level and has focused on the implications of mitigation policy (see Tol, 2009). In contrast, the case studies in this volume reflect a growing body of literature examining the economics of climate change for developing countries. While as a group developing countries are currently responsible for about half of all emissions, most developing countries, particularly low income countries, are individually "climate-takers" in a manner analogous to the "small-country" assumption in economic theory. Hence, they exercise much more direct policy control with respect to adaptation than with respect to mitigation. In this vein, the case studies assume that a country's exposure to climate change is given, and then incorporate climate uncertainty within their analysis.

The *sensitivity* of a country's socioeconomic system reflects the potential damages (or benefits) associated with different climate change outcomes. Climate sensitivity depends on a country's initial conditions, including its economic structure, geographic and agro-ecological characteristics, and natural and environmental resources. For example, agriculture's sensitivity to declining annual rainfall or increased temperatures is determined by multiple factors, including the technologies of cultivated crops, whether these are rainfed or irrigated, and the availability and management of alternative water resources. From an economywide perspective, countries may be more sensitive to climate change when agriculture is an important contributor to national and household incomes. Moreover, agricultural impacts may be aggravated (or offset) by impacts on other sectors, such as road infrastructure and energy. The country-specificity and interaction of impact channels highlights both the complexity of climate change vulnerability assessments and the need for an "integrated systems approach." Many of the case studies in this volume examine multiple impact channels and consider economy-wide implications.

A country's *adaptive capacity* is the third dimension of its vulnerability. While climate sensitivity reflects a system's initial structure, adaptation to climate change refers to changes in behavior. Adaptation occurs at multiple scales, i.e. farm/firm, market, and national levels. Some adaptive capacity already exists and is therefore considered

endogenous (or “autonomous”) to the economic system (Smit et al., 2000), such as a farmer’s adoption of more drought-resilient crops or internal migration to more favorable zones including urban zones. A number of studies empirically examine autonomous adaptation in response to current or historical climate variability, primarily within agriculture (see, for example, Deressa et al., 2009). So far, few of these insights have been incorporated into country vulnerability assessments (Füssel and Klein, 2006).

In contrast, exogenous (or “planned”) adaptation refers to behavioral changes that might not occur in the absence of climate change (Smit et al., 2000). A typical example is government investment in coastal barriers to protect infrastructure from rising sea levels. A less obvious example is increased education investments in order to make workers and labor markets more flexible and thus more resilient to a wider range of future climate change realizations (see Arndt et al., 2011). If a Ministry of Finance were forced to choose between these two options, it may not be immediately clear which is the better choice. In all cases, the response would be probabilistic with the options performing relatively better or worse under alternative states of nature. These two examples of adaptation policy also highlight the interaction between climate change and economic development, and thus the overlap between adaptation and development strategies.

This volume reflects the growing recognition of the intersection of climate change and development economics. The case studies represent the current state of climate vulnerability assessments for developing countries. Countries’ sensitivities and adaptive capacities are measured under uncertainty.

3. Structural versus Reduced Form Analysis

General circulation models (GCM) are large and complex representations of land, atmosphere, and ocean physical dynamics. Nevertheless, at the end of the day, these models essentially produce projections of precipitation and temperature both through time and across space. By and large, the implications of these changes in climate patterns remain to be divined using other analytical approaches. The challenge of converting GCM outputs into biophysical and then ultimately economic impacts has been undertaken by a broad class of models grouped under the rubric of integrated assessment models (IAM). Tol and Fankhauser (1998) provided an overview of the representation of climate change impact in more than 20 IAMs in use in the mid-1990s.

Despite (or perhaps because of) the deep complexity of climate change impacts, the IAMs have tended to employ simple representations of biophysical and economic systems. Impacts were almost invariably estimated using reduced form representations of impact. A very simple example of a reduced form representation of the economic implications of climate change would be a function that is convex in the change in temperature such as: $I_t = \alpha(T_t - \bar{T})^\beta$ where I is economic impact or cost, the subscript t represents time, and T represents temperature with a bar indicating a baseline value. If $\alpha > 0$ and $\beta > 1$, the marginal economic costs of climate change rise as temperature anomalies increase.

While these models have the advantage of being relatively easy to use and of providing a first order estimate of empirical impact based on available empirical evidence, they have serious disadvantages. In particular, they lump a long causal chain of events into a simplified algebraic relationship. If this causal chain of events naturally evolves through time or is changed deliberately by policy, the only options for capturing these effects is through changes in the parameters (e.g. α , β in the simple example

provided above). Unfortunately, the empirical basis for these changes is often lacking precisely because the new conditions or policies have never been observed.

The models and results presented in this special issue represent another step in a trend towards reliance on structural relationships and explicit causal chains. Structure has a strong influence on outcomes (Arndt et al., 2000). To the greatest degree possible, the models employed here rely on fundamental relationships in hydrology, hydropower output, crop growth, infrastructure design and economic general equilibrium. This chain of models can be seen as an attempt to “open the black box” of IAM modeling through specification of specific impact mechanisms and causal chains. This is complex but particularly important in developing country contexts where climate change impacts are widely expected to be large relative to national income. Explicit definition of the causal chain allows for a formal assessment of the relative size of alternative impact channels. In addition, the structural approach provides for much greater latitude in exploring the potential implications of alternative policies. Finally, as the structural models increase in detail, heterogeneity of impacts and vulnerabilities become apparent across sectors, regions, and household groups.

4. Highlights of Approaches and Insights

Rather than present a summary of each paper (which can be obtained from the abstracts), we prefer to highlight some of the novel aspects to the approaches employed and some of the insights obtained.

Autonomous Adaptation in Agriculture and the Scale of Analysis

When considering the implications of climate change, a natural place to start is the agricultural sector. This is particularly true in our case countries where: (i) agriculture remains a very important sector in terms of GDP, (ii) agriculture is predominant in terms of employment, and (iii) food represents a high share of household consumption. Because of the importance of agriculture, the case studies for Bangladesh, Tanzania, and Zambia focus exclusively on the agricultural sector. In this sub-section, we consider market responses to climate change, or autonomous adaptation, at various levels in the system.

The farm is the first level of response to a changing climate and is one that has received considerable attention in the literature. As pointed out by Mendelsohn et al. (1994), farmers can change their cropping patterns in response to climate change. With fixed prices, changes in crop productivity will drive farmers' response decisions with greater area allocated to crops that are positively affected by climate change or to crops whose productivities have been least negatively impacted.

For each of the case countries presented in this special issue, a general equilibrium approach to modeling the implications of climate change is adopted. This has potentially large implications. For example, because prices are not fixed, farm level decisions are made through combined consideration of price and productivity effects. Within this framework for a specific country case, autonomous adaptation may not move resources out of the production of crops that are strongly affected by climate change. For crops with weak links to international markets, productivity declines induced by climate change may be more than offset by rising domestic prices. In this case, farmers may have incentives to shift resources *towards* rather than away from some strongly affected crops. This would accentuate rather than ameliorate the real GDP impact of the climate

induced productivity shifts. Crops like cassava in Mozambique and teff in Ethiopia have the properties of generating a relatively large share of agricultural value added but with weak links to global markets. Hence, these effects are implicit in the analyses of Mozambique and Ethiopia.

The links between price changes and climate impacts are also highlighted in a regional context by Ahmed et al. (2012). When trade links are present, relative productivity impacts become important. They focus their analysis on maize, which is the principal staple crop, and consider historical correlations in production outcomes between Tanzania and its major trading partners. They conclude that Tanzania has the potential to substantially increase its maize exports to other countries. If global maize production is lower than usual as a result of supply shocks in major exporting regions, Tanzania may be able to export more maize at higher prices, even if it also experiences below-trend productivity. They also find that diverse destinations for exports can allow for enhanced trading opportunities when negative supply shocks affect the partners' usual import sources. Trade restrictions, like export bans, prevent Tanzania from taking advantage of these opportunities, foregoing significant economic benefits.

Sectoral Coverage and Linkages

Although the agricultural sector remains a priority for climate change analysis, climate change impacts are not limited to implications of temperature and precipitation changes for crop and livestock production. Other sectors are likely to be impacted with potentially large economic implications.

The first specific perspective on this is the paper by Block and Strzepek (2012) that addresses energy in the context of hydropower in Ethiopia. In this paper, the authors provide explicit models that demonstrate how climate change may affect plans by the Ethiopian government to enhance power supplies to the country through the use of hydropower. As documented by the authors, the potential drying of the climate can reduce the water supply available within the Blue Nile basin which in turn can invalidate the projections for water availability to power the planned hydropower facilities. These results for hydropower are then combined with results from crop and infrastructure in the paper by Robinson et al. (2012), which provides a highly comprehensive assessment of climate change implications for Ethiopia.

Detailed consideration of the impacts of climate change on infrastructure is presented in the papers by Chinowsky and Arndt (2012) and Arndt et al. (2012). They show that climate change can have significant effects with implications for long-term infrastructure planning. As presented in the context of Mozambique and focusing on roads, they detail how increases in precipitation, temperature, and flooding can result in increased maintenance and construction costs. These cost increases constrain the accumulation of critical economic infrastructure. In a new methodological development, the road infrastructure model is both run independently and is incorporated directly into a CGE model of Mozambique. The road infrastructure model interacts with the CGE model through productivity effects (across multiple sectors) related to the rate of infrastructure accumulation and through the budget allocations to road construction and maintenance. With these models in hand, the authors also consider changes in road investment policies and practices in order to adapt to future climates. They conclude that, given the crucial role of infrastructure accumulation for long-term development, choices regarding infrastructure design and placement serve as important elements to achieving long run development under climate change.

Climate Uncertainty and Stochastic Analysis

A defining characteristic of climate change studies is the high degree of uncertainty inherent in the measured impacts and adaptation policies. As mentioned earlier, a major source of uncertainty is the climate change projections. This is due to differences in global economic projections and in the GCMs' understandings and capturing of the earth–atmosphere relationship. As a result, the predicted climate changes can vary considerably across scenarios, especially once “down-scaled” to the country level.

Given this climate uncertainty, each of the studies in this volume examines a range of possible scenarios. Thurlow et al. (2012b) initially adopted a single climate change scenario in their study of Zambia, and then conducted sensitivity analysis using two hypothetical scenarios in which predicted precipitation varies around the initial projection. This is a modest advance over studies that use only a single projection.

In contrast, Robinson et al. (2012) examined four climate change projections for Ethiopia based on pairings of global emissions scenarios and climate models. These four pairings are selected so as to reflect the full distribution of climate change projections, as measured by a climate moisture index. This purposeful selection of projections is also adopted for the country and the country-focused economy-wide analyses of Mozambique and Tanzania. The Thurlow et al. (2012a) study of Bangladesh differs slightly in that it draws on a much larger sample of projections to reflect the distribution of possible climate change outcomes. The wide variation in the economic damages observed in most of the studies highlights the importance of explicitly incorporating climate uncertainty into the analysis, primarily by using a range of climate change scenarios.

While much attention has been paid to the uncertainties surrounding anthropogenic climate change, there is also considerable uncertainty arising from current climate or weather variability. One commonly adopted approach is to assume that future weather patterns will follow the same sequence of events as historical weather patterns. However, Thurlow et al. (2012b) measured the economic damage caused by extreme weather events in Zambia, and found that damage responses to fluctuations in weather patterns are strongly non-linear. This suggests that the sequencing and severity of extreme events in a study's baseline scenario will influence the scale of the incremental damage caused by anthropogenic climate change. A stochastic approach to incorporating historical variability into the baseline appears to be warranted and remains an important topic for future research.

The case studies introduce two novel approaches to incorporating stochastic weather fluctuations into an economic analysis of climate change. Thurlow et al.'s (2012b) study of Zambia uses an index sequential approach to draw series of future weather patterns from the historical climate distribution. Similarly Thurlow et al. (2012a) conducted Monte Carlo simulations of future weather sequences drawing from the historical climate series. Both studies measure and compare the economic damages caused by historical and future climate changes. The authors find that the damage from future anthropogenic climate change is significantly smaller than that already caused by current climate variability—at least over the simulation period. This suggests consistency in the need for strategies to adapt to both current and future climate change. However, the Bangladesh study finds that the seasonal distribution of climate-related damages will change significantly as a result of future climate change, suggesting that current and future adaptation strategies may require different kinds of interventions.

5. Suggestions for Future Research

While the studies in this special issue contribute both methodologically and empirically to incorporating climate change considerations into development analysis, a considerable amount of further work is needed. The studies presented here ignore potentially important impact channels such as the implications for human health and the implications of cyclones and other extreme events. Analysis of extreme events is inherently probabilistic and falls under the rubric of more effective treatment of uncertainty. Most of the analyses in this volume use scenarios from a purposefully selected range of general circulation models, which helps to define the range of likely outcomes. Nevertheless, development and use of distributions of future climate outcomes would provide a far superior basis for decision-making, allowing, for example, risk assessments for alternative investment programs/policies.

In sum, the papers in this special issue represent much of the current state of knowledge on the implications of climate change for growth and development, but this is a growing field of analysis and its importance for development and international economics will become ever more pressing as climate change manifests itself over the coming decades.

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