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IIEP Working Paper

Adaptation to Climate Change in Low-Income Countries: Lessons from Current Research and Needs from Future Research*

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Abstract.
Abstract. This paper constitutes the introductory essay for the special issue of *Climate Change Economics*, edited by Malik and Smith, forthcoming in 2012, examining adaptation to climate change in low-income countries. The paper first characterizes different types of adaptations from an economic perspective. It then puts in context the contributions of two articles that address the problem of making adaptation decisions in the face of uncertainty with an emphasis on developing country circumstances. The paper then proceeds to examines data and methodological problems faced in empirical research on adaptation, and, as part of a broader review, examines contributions of two articles that present econometric evidence on adaptation in Ethiopia and India. The paper then introduces issues in the emerging research area of interactions between autonomous and planned adaptations and discusses contributions in the CCE special issue, particularly on how government agricultural extension affects farm household adaptation and how a government 'awareness' campaign encouraging behavioral responses to heat waves can reduce mortality. Finally, the paper identifies important questions on adaptation in low-income countries that still remain largely unaddressed.

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I. Introduction.

There is broad scientific consensus that climate change will continue over the next several decades even if greenhouse gas emissions are reduced drastically (IPCC 2007). The impacts of climate change are anticipated to be greatest in low- and lower-middle-income countries where most of the world's poor live (Parry et al. 2007, World Bank 2010a). In most of these countries, climate change is expected to worsen existing environmental and resource problems and generate new ones, thereby endangering livelihoods, intensifying conflicts over resources, and inducing greater migration within and across national boundaries (World Resources Institute et al. 2005, McLeman and Smit 2006).

Given the inevitability of climate change, a critical question is how societies can best adapt to it. Adaptation can take a very wide variety of forms (World Bank 2010b, 2010c, Adger et al. 2007). To date, attention has primarily focused on adaptation undertaken by governments, i.e., planned (or policy) adaptation, such as construction of sea walls and bans on development in low-lying areas. But private "agents," that is, households and firms, as well as community groups outside formal government structures, will likely undertake much of the adaptation to climate change. This "autonomous" adaptation can itself take a range of forms. Examples are altering crop or livestock varieties, changing livelihoods, increasing exploitation of common pool resources, and migrating temporarily or permanently within a country or internationally (Mendelsohn 2000, McLeman and Smit 2006). A number of questions pertain to autonomous adaptations:

- To what degree can such adaptations reduce the impacts of climate change?
- What are the obstacles to autonomous adaptations in low-income countries?
- What is the likelihood of undesirable (inefficient) adaptations being undertaken because of poor information or distorted incentives?
- Are autonomous adaptations likely to be timed appropriately given market imperfections and imperfect information?
- What types of autonomous adaptations are likely to generate negative externalities that increase the likelihood of resource degradation, and how can these externalities be mitigated?
- What role can governments play in fostering desirable (efficient) autonomous adaptations?
- What are the gains from improving public knowledge about adaptations?
- What is the interplay between autonomous adaptation and planned adaptation?

Research on these and related questions are essential to understanding the role of autonomous adaptation in coping with the impacts of climate change and to identifying and creating the conditions necessary for desirable autonomous adaptations to be undertaken in low-income countries (Fankhauser et al. 1999). As Mendelsohn describes in his survey of adaptation in this special issue, a start has been made at answering some of these questions, in particular the first two listed above. Others, however, have received little, if any, attention, such as the interplay between autonomous and planned adaptation. Accordingly, research on autonomous adaptation is the main focus of this special issue, with the objective of making progress in addressing some of the aforementioned questions.

A major impediment to both autonomous adaptation and planned adaptation is uncertainty. When making adaptation decisions, both private agents and governments face uncertainty about the nature, magnitude and timing of climate impacts (Heal and Kriström 2002, Dessai et al. 2009, Mearns 2010, World Resources Institute et al. 2011). This uncertainty about impacts is compounded by uncertainty about the effectiveness of possible adaptations. Farmers, for example, are likely to face uncertainty about the profitability of a new crop variety that is better suited to changing climate conditions.

The uncertainties associated with adaptation decisions are often of a different character than those accommodated by the expected utility framework conventionally used by economists: uncertainty in the form of *risk*, where the set of possible outcomes is known and probabilities can be assigned to each outcome. In the climate change setting, probabilities associated with possible outcomes may not be known with confidence, and the set of outcomes itself may be unknown. Moreover, the nature and magnitude of uncertainties is likely to change over time as a result of learning.

Researchers have only started to grapple with the problem of making adaptation decisions in the face of these time-varying uncertainties. Thus, another focus of this special issue is on identifying and applying decision-making frameworks that can accommodate these uncertainties and their time-varying nature.

In the next section, we set the stage by briefly characterizing different types of adaptations from an economic perspective. In Section 3, we then examine the problem of making adaptation decisions in the face of uncertainty and describe the contributions of the two papers in this special issue that address this problem. Section 4 introduces data and methodological problems faced in empirical research on adaptation. Section 5 turns to autonomous adaptation and, as part of a broader review, examines contributions of two papers in this special issue that present econometric evidence of adaptation in Ethiopia and India.

Section 6 introduces issues in the emerging research area of interactions between autonomous and planned adaptations and discusses contributions in this special issue, including how government agricultural extension affects farm household adaptation and how a government ‘awareness’ campaign encouraging behavioral responses to heat waves can reduce mortality. Another paper estimates combined planned and autonomous responses to reducing tropical cyclone damage. Finally, Section 7 identifies important questions that are still largely unaddressed.

2. An Economic Taxonomy of Adaptations

A widely-cited definition of climate change adaptation is "adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities" (IPCC 2001). This is a very broad definition, and is by no means the only one in the literature. Mendelsohn (this issue) offers a narrower definition that is more useful from an economic standpoint: “Adaptation is any change in behavior or capital that an actor (household, firm, or government) makes to reduce the harm or increase the gains from climate change.” Both these definitions recognize that climate change can be beneficial and that adaptation can be an action taken to reap or enhance the benefits. Our focus, and that of all the papers in this special issue, is on adaptation to the adverse effects of climate change.

As noted earlier, adaptation to climate change can be undertaken by a range of economic agents and institutions: from individual households to community groups to national governments. In this paper we have chosen to classify adaptation as either autonomous or planned. But this is only one of several possible classification schemes. Mendelsohn divides adaptation into two broad categories: private adaptation and public adaptation. Private adaptation only yields benefits to the agent undertaking it, while public adaptation has a public good character and yields benefits to a number of agents, not just the agent undertaking the adaptation. Though private adaptation is closely related to what we classify as “autonomous” adaptation, and public adaptation is closely related to what we classify as “planned” adaptation, they are not identical. Under our interpretation, planned adaption is adaptation undertaken by a government agency and need not have a public good character. Correspondingly, autonomous adaptation is adaptation undertaken by households, firms, or collections of these, and could have a public good character, as we illustrate further below.[1]

As Mendelsohn stresses, adaptations, whether of the private or public variety, are socially desirable only if they are efficient, i.e., they yield positive net social benefits. In a setting with no market imperfections and perfect information, self-interested behavior will lead households and firms to undertake efficient private adaptations. In the case of public adaptations, the public good character of the adaptation implies the need for government provision at the local, regional, or national levels, given the likely underinvestment in such adaptations by private agents.

The conclusion that households and firms will undertake efficient private adaptations needs to be tempered when markets or information are imperfect. Market imperfections can take a variety of forms. Mendelsohn highlights the effects of common property, poorly protected private property rights, and limited access to capital markets—

[1] It is worth mentioning that our use of the terms “autonomous” and “planned” differs from that of some other authors, in particular Smit et al. (2000) and IPCC (2001). In their use of the terms, autonomous adaptation has a spontaneous character and is a reaction to climate change, whereas planned adaptation is anticipatory. Thus, in their usage, private agents can undertake both autonomous and planned adaptations. See Malik et al. (2010) for a more detailed discussion of classification schemes, including the distinction between short-run and long-run adaptation.

imperfections that are typical in low-income countries. These imperfections can result in private agents not undertaking adaptations that are efficient, or undertaking others that are inefficient.

3. Adaptation Decision-Making and Uncertainty

Imperfect information, or uncertainty, is also likely to have a significant effect on the adaptations undertaken by private agents and governments. The problems posed by uncertainty are well recognized in the literature on both climate impacts and mitigation (e.g. see Heal and Kriström 2002, Cline 2007, Hall et al. 2007, and World Resources Institute et al. 2011). The consequences of uncertainty in the context of mitigation policy have been highlighted by Weitzman (2009), who has emphasized the need to consider possible "fat tails" in the distribution of the consequences of climate change when formulating climate policy.

Uncertainty about climate impacts is clearly also relevant to adaptation: uncertain climate impacts make it difficult to determine *how* to adapt and *when* to adapt. Decision-making under uncertainty when it takes the form of risk can be conducted using the standard von Neumann-Morgenstern expected utility framework. This framework is not without its critics, and the problem of making decisions in the face of risk is by no means a simple one, especially in the presence of irreversibilities and large potential sunk costs (e.g., see Kolstad 1996, Fisher and Narain 2003, and Pindyck 2007).

In the climate setting, the uncertainty faced by decision-makers goes beyond risk: (1) the set of possible outcomes may not be well known—with the likely existence of "unknown unknowns;" and (2) even if the set of possible outcomes is known, the probabilities associated with the outcomes may be difficult to determine with any degree of confidence (Dessai and Hulme 2004, Lempert and Collins 2007, Lange and Treich 2008, Millner et al. 2010).

The problem of "unknown unknowns" is an inherently difficult one that cannot be addressed easily using standard decision-making frameworks. The usual premise is that with additional research or time, the outcome space can be better defined. The setting in which the outcome space is known but the probabilities associated with each outcome are not known with confidence, if at all, is often referred to as "deep uncertainty" (Lempert et al. 2004, Lempert and Collins 2007); in the more recent economic literature on climate, it is referred to as "ambiguity" (Lange and Treich 2008, Millner et al. 2010).[2]

[2] The term "deep uncertainty" is generally not used in the economics literature. It has gained currency among researchers studying decision-making frameworks for coping with the uncertainties associated with climate change (e.g., Lempert et al. 2004, Lempert and Collins 2007). It refers to settings in which decision makers cannot agree on the model of a phenomenon relating actions to outcomes, or on the prior probability distributions of the parameters of the model (CCSP 2009). It is similar in spirit to the notion of "Knightian uncertainty," which refers to uncertainty that is unmeasurable (unlike risk). This use of the term "deep uncertainty" encompasses "ambiguity."

Making decisions in the face of uncertainty, whether the uncertainty is in the form of risk or ambiguity, is a vexing problem for governments.[3] It is also a problem for individual or groups of households and firms when making their adaptation decisions. The uncertainty faced by firms and households compounds the uncertainty faced by governments, given that governments will likely need to predict the adaptation decisions of firms and households when formulating policy towards both mitigation and adaptation.

3.1 Autonomous Adaptation Given Ambiguity

The paper by Eichberger and Guerdjikova (E&G) in this issue examines autonomous adaptation in the face of ambiguity. It is one of only a handful of papers in the literature to do so. Ambiguity arises in the context of the profitability of a new technology for which there are few data on returns. Given changes in climate, the new technology potentially has higher expected returns than a traditional technology for which there are extensive data on returns. The example E&G use to motivate their model is that of a community of farmers, each contemplating adoption of a new, unfamiliar farming technology given changes in climate. But the model can be applied to any autonomous adaptation decision that entails adoption of a new, unfamiliar technology.

The behavior of agents in the face of this ambiguity is modeled using a special form of the case-based decision theory (CBT) developed by Gilboa and Schmeidler (2001). In the face of ambiguity, the special form of CBT allows for agents in the community to be characterized as "pessimists" or "optimists" (Eichberger and Guerdjikova 2011). Absent any information, optimists behave as if the technology will yield the best possible outcome with certainty, while pessimists behave as if the technology will yield the worst possible outcome with certainty. As data on the actual performance of the two technologies accumulates over time, both types of agents update their beliefs about them.

Optimists play a key role in the adoption of the new technology. Their willingness to bear the associated ambiguity and to experiment yields data on the returns from the new technology—data that are used both by the optimists and the pessimists to update their beliefs about the new technology and, as such, are a public good. These additional data reduce the ambiguity associated with the new technology, inducing pessimists to adopt it if it has generated sufficiently high returns.

Consistent with intuition, E&G find that if the share of optimists in the community is small, a socially undesirable equilibrium emerges in which only the optimists adopt the new technology; the pessimists, who constitute a majority, stick with the traditional technology. E&G examine two different forms of government intervention that could induce a shift to a more desirable equilibrium in which a majority of agents adopt the new technology. The first is subsidizing adoption of the new technology, either directly or

[3] Though there is a consensus among researchers across disciplines of the problems posed by uncertainty about climate impacts for decisions about adaptation, there is disagreement about the degree to which reductions in such uncertainty are necessary to undertake effective planned adaptation. See Mearns (2010) for an overview of the debate.

through income guarantees. E&G show that neither subsidy may be efficient: the required subsidy may exceed the average increase in returns from its adoption.

The second intervention is government provision of additional data on the performance of the new technology, through controlled experiments, field demonstrations, or dissemination of information about the technology generated elsewhere. The additional data reduce the ambiguity associated with the new technology. E&G show that this intervention can bring about the desired change in behavior, and in some cases may be self-financing, with pessimists, in principle, willing to pay for the data because of the reduced ambiguity the data yield.

E&G's paper highlights some important issues in the discussion of adaptation, both broadly and in the context of low-income countries. The first of these is the potential role of government in alleviating the obstacles faced by households, firms, and communities when making adaptation decisions. An obvious role is provision of: (1) forecasts of climate change, (2) information about its impacts, and (3) information about possible adaptations. E&G identify a subtle channel through which government information provision can be beneficial: by reducing the ambiguity that is likely to be inherent in many of the adaptation options considered by households, firms, and communities. Two of the empirical papers in this issue show that governments are already playing such a role, with apparently beneficial effects.

Their paper also demonstrates the importance of targeting when introducing a new, unfamiliar adaptation technology. The technology should first be promoted among those who are most willing to experiment with new technologies. Adoption by these "optimists" can, in time, reduce the reluctance of pessimists to adopt the new technology. In the agricultural extension case examined empirically in this issue by di Falco et al., this could mean working with the proverbial "model farmer."

E&G's paper also illustrates the subtle distinction between private adaptation and autonomous adaptation. By definition, private adaptation only yields benefits to the agent undertaking the adaptation. In E&G's model, adoption of the new technology by a single individual yields benefits to the entire community, via information provision and as such generates a public good. Accordingly, it is an example of an autonomous adaptation but not a purely private adaptation.

3.2 Planned Adaptation Given Risk

Information and its role in making adaptation decisions are also central to the paper by Linquiti and Vonortas (L&V). Unlike E&G, L&V consider public (and planned) adaptation in the form of investments in coastal defenses to protect against sea-level rise. Damages from sea-level rise (and higher storm surges) are expected to disproportionately affect populations in low-income countries. L&V examine the decision problem facing a coastal planner in a setting in which sea-level rise is uncertain, as are the damages that it will cause. Uncertainty diminishes over time either because of improved forecasts or simply because of observations on sea-level rise and the magnitude of assets at risk. L&V assume that uncertainty is in the form of risk alone and do not consider ambiguity.

L&V argue that investments in coastal defenses can be viewed as real options, which should be “exercised” when and if available information indicates it is socially desirable to do so. As L&V point out, coastal defenses can be augmented incrementally over time, as improved information is obtained about the magnitude of sea-level rise and the potential value of the damages that it may cause.

The real options approach directly addresses the issue of *when* adaptation should be undertaken. The approach is also consistent with an argument made by Mendelsohn (this issue) that in the presence of uncertainty some mix of reactive and anticipatory adaptation is likely to be most effective for capital-intensive adaptations. Reactive adaptation is adaptation undertaken once local climate has changed, whereas anticipatory adaptation is undertaken before changes in climate are observed. The principle underlying the real options approach is to make adaptation decisions in a manner that allows for decisions to be re-evaluated and modified as new information becomes available. This principle is consistent with the “adaptive” decision-making framework advocated in the recent literature on climate decision-making (e.g., Climate Change Science Program 2009).

L&V evaluate the benefits of using a real options approach by constructing a detailed Monte Carlo simulation model that is calibrated for two coastal cities in low-income countries: Dhaka (Bangladesh), which is on a riverine delta, and Dar-es-Salaam (Tanzania), which is on the Indian Ocean. It is the first paper to apply a real options approach to coastal defenses in low-income countries.

L&V model the behavior of a boundedly-rational coastal planner who can pursue real-options-based (“flexible”) strategies or “inflexible” strategies in which decisions are made only at the start of the planning horizon. They consider strategies that are influenced by economic factors as well as strategies that are based purely on meteorological factors. The two “economic strategies” consider the costs of constructing and operating coastal defenses, and the economic damages resulting from lost benefit flows from inundated assets as well as lives lost and populations displaced. L&V measure damages in terms of lost benefit flows from inundated assets, instead of the more common measurement of the value of inundated assets, which allows for a more accurate evaluation of adaptation strategies that induce very different patterns of asset creation and destruction over time.

The boundedly-rational coastal planner is plausibly assumed to not have the sophistication and information required to formulate and solve the complex stochastic dynamic programming problem necessary to fully implement the real options approach. Instead, the planner solves a simpler optimization problem.

L&V find that the relative performance of the strategies depends on the discount rate employed and on the severity of sea-level rise. At the lower discount rate, the flexible strategies tend to outperform the inflexible ones. At the higher discount rate, there is less consistency in their findings; in some cases the inflexible strategies outperform the flexible ones.

Interestingly, in some cases the non-economic strategies perform better than the economic strategies. L&V attribute this to the bounded rationality of the planner. The objective function used to evaluate the performance of the strategies does not coincide with the simpler objective function employed by the planner. In the context of low-income countries, the assumed bounded rationality of coastal planners is especially plausible. Planners are unlikely to have the resources needed to fully implement a real options approach. Under these circumstances, L&V's analysis indicates that it is difficult to identify a single strategy that is preferred in all cases. What is perhaps most encouraging about their work is the finding that the simple meteorologically-based flexible strategy, which has low informational and computational requirements, performs reasonably well in most cases.

Bounded rationality is arguably likely to be an even more prominent feature of decision-making by private agents. In some interesting, recent work, Franck (2009) shows that bounded rationality on the part of residents and investors in coastal communities affected by storms can result in significantly lower investments and longer economic recovery times compared to a setting in which all agents are rational. The bounded rationality assumed by Franck takes a very plausible form: residents and investors perceive the risk of storm events to be higher than it actually is during periods of storm activity and lower than it actually is during periods of inactivity. This is likely to be a pervasive form of bounded rationality among private agents when making adaptation decisions. As noted in Section 4.2 below, available evidence suggests that farmers' perceptions of changes in climate do not closely match meteorological data. Accordingly, efforts to predict and estimate the types and magnitudes of autonomous adaptation responses need to consider the possibility of bounded rationality on the part of private agents, instead of simply hewing to the usual assumption of rationality.

4. Data and Methodological Challenges of Empirical Research on Adaptation

4.1. Estimating Costs and Benefits

Research on quantification of the costs and benefits of adaptation is still in its early stages. Several estimates of adaptation costs have been published by development agencies. The World Bank (2010b) estimated the cost between 2010 and 2050 of adapting to a 2^{o}C warmer world by 2050 to be in the range of $70 billion to $100 billion per year, but there is climate and technological uncertainty. Beyond this, the report expressed caveats including limited focus on migration, limited range of adaptations, and the need for better information on environmental services, along with a need for “integration with local, bottom-up perspectives," to "better understand economics of local actions.” Progress is being made in this regard, exemplified by the contributions in this special issue.

For example, Hsiang and Narita (this issue) develop a tropical cyclone (TC)-specific refinement of Mendelsohn’s (2000) model, to analyze how higher TC risk influences costly adaptive investment. They generate a key prediction that when exposed to physically similar storm events, “populations with high TC risk and/or high capital densities should suffer relatively low losses,” due to their greater incentives to invest in storm protection. The predictions then help define the focus of their empirical work, that “populations with higher initial depreciation due to cyclones” are predicted to “exert greater effort towards protecting themselves.” The econometric specification provides well-defined quantitative conclusions; in particular, the negative and significant climate interaction term indicates that increasing average wind speed exposure of a country leads to quantitatively substantial reductions in marginal damages and deaths. These impacts are large in standard deviation terms, and the authors interpret the results as consistent with the observation that “high-risk populations suffer lower marginal losses, relative to their low-risk counterparts, when both groups are struck by physically identical events.” Results also confirm the implication of their model that economies with higher capital density invest more in adaptation.

Strikingly, Hsiang and Narita find a very small and fairly precise adaptive response – on the margin just 3% of new risk is “mitigated by new long-run adaptations.” This smaller estimate is consistent with their theory in that adaptive responses to marginal climate changes will be small where the cost function for adaptation is very convex. Thus the authors infer that in the current equilibrium, the “marginal cost of adaptation already increases sufficiently fast that it prevents additional investments.” More generally, the results serve to alert us that even when careful economic analysis identifies behavior consistent with economic theory and is statistically significant, the quantitative responses may still remain small, thereby pointing to limited capacity for adaptation.

4.2 Estimating Future Impacts of Climate Change via Historical Analogues

Climate science reveals that some climate change has already occurred and is beginning to impact sub-Saharan Africa and South Asia. One constraint to research on adaptation is that a large majority of such impacts will occur in the future. Another is the difficulty in differentiating climate change from outlier weather events within previous climate distributions. A useful general approach is to study *climate change analogues*. We use this term to mean examination of the impacts of, and responses to, the types of meteorological or weather events predicted to become more widespread and intense as climate change progresses. Recent literature has used a similar term – *climate analogues* – in a current-period *spatial* sense of searching for cities with a current climate that is similar to expected future living conditions in another city (Hallegate et al. 2007; Kopf et al. 2008); or regions with current agricultural conditions expected to be like those in other regions in a future period (Ramírez-Villegas et al. 2011). This is also an interesting approach and is undoubtedly of particular value for educating policymakers and the general public.

In the sense in which we use the term, climate change analogues include drought and water shortages, storm damage and flooding, and heat waves, along with historical planned and autonomous responses to such conditions. In effect, some contributors to this issue have taken this tack: di Falco et al.'s examination of responses to existing droughts, and Das and Smith's article on a government awareness program in response to increasingly severe heat waves. Further work taking this approach will be valuable going forward. Of course, this approach also has limits, as climate patterns move outside the range of past experience. We may conjecture that to the extent that most climate adaptations are similar to adaptations to standard weather variability (as noted by di Falco et al., this issue), as climate patterns move beyond the historic ranges, adaptations may need to evolve beyond the standard strategies. Correspondingly the study of local analogues may be insufficient.

4.3 *Expanding Data Types and Improving Data Quality*

Identifying climate change occurrences or analogues also raises issues of data quality more generally. Weather stations are much sparser in low and lower-middle income countries. Satellite data are increasingly used but are also limited to date. An effort is underway in many countries to increase the number of weather stations, motivated inter alia by the growth of weather insurance. Available data are extended in various ways; for example, in this issue di Falco et al. use the Thin Plate Spline method of spatial interpolation to adjust for sparse distributions of weather stations.

There have been great advances in household data in developing countries enabling research previously impossible, as stressed by Angus Deaton.[4] These household data are

[4] Angus Deaton, presentation to the Northeast Universities Development Consortium Conference, November 12, 2011.

increasingly in the form of large, panel datasets; the Bill and Melinda Gates Foundation has been augmenting resources available for them. Good opportunities exist to add questions relevant to climate change adaptation to such surveys before they go out to the field. Other household datasets are of medium scale but address unique special topics of interest in a detailed way. This is the case for the di Falco et al. study in this issue, which uses in-depth data on adaptation from about 1,000 households. Several papers have sought to document farmers' perceptions of climate change (e.g. Dinar et al. 2008, Maddison 2006, and Thomas et al. 2007). These studies can be highly informative; though in some cases perceptions do not closely track the available objective meteorological data.

Where household data are not available, researchers are using more aggregated data for hypothesis testing. Das and Smith (this issue) use district-level data to identify effects of a government awareness program to help citizens prepare for and survive worsening regional heat waves. The data's panel properties enable quasi-experimental designs to be used; the authors utilize difference-in-difference and difference-in-difference-in difference methods to identify effects of program activity on heatstroke deaths.

Hsiang and Narita use national-scale longitudinal data to investigate differential national changes in TC impact. The Hsiang and Narita study uniquely combines a physical model to parameterize TC exposure and risk as in the Nordhaus (2010) U.S. study, with broad, cross-country analysis as in Kahn (2005). To do so they employ a physical model to identify country-specific TC-loss functions utilizing data from 233 countries.
This provides variations in TC climatologies while avoiding Kahn's unsupported exogeneity assumption that "reported incidence of disasters is exogenous to all other determinants of disaster losses."

Alternative strategies have also been used. For example Deressa (2007), following a methodology pioneered by Mendelsohn et al. (1994), measured climate change impacts on farm profits in Ethiopia using a Ricardian approach of imputing costs of climate variability through changes in land value at the sub-district level.

One approach exemplified by these studies is combining data drawn from multiple sources. In this issue, Hsiang and Narita combine physical data on TCs with economic data from the World Bank, UN and Emergency Events Database; the analysis in Das and Smith combines health, meteorological, census, forestry, and program data. There are undoubtedly many other such opportunities waiting to be pursued.

4.4 *Researching Productivity of Climate Change Adaptation Measures*

Research on the productivity (and more generally the impacts) of adaptation investments is also still at an early stage. Yet it is an essential component of the economic analysis of autonomous adaptation. Estimating farm-level production functions for poor households, di Falco et al. (this issue) found that each of their adaptation variables - changing crops, soil conservation, and tree planting - were positive and significant. They conclude that these actions reduced climate change risk and increased agricultural productivity.

Considerable scope exists for utilizing production function studies to analyze climate adaptation. In one recent study, Fishman (2012) combined data on daily rainfall, crop yields and irrigation to estimate rice crop impacts of intra-seasonal rainfall variability. Simulations showed irrigation could reduce losses due to dry weather, but the effect varied with ground water depletion. No evidence was found that irrigation mitigates increased heat exposure.

At a higher level, broader international and longer-term research can be conducted, albeit at the expense of more restrictive (and perhaps less realistic) assumptions. Hsiang and Narita (this issue) generate a new dataset of every country's exposure to every TC event over the period 1950-2008. They use these data to identify "the response of normalized damages and normalized deaths to TC exposure," allowing them to implicitly measure the extent of adaptation in the long run. Many opportunities for further adaptation apparently remain unexploited, as reflected in the authors' findings of great variation in adaptive effort across countries.

Finally, some valuable experiments can be conducted. In principle one can randomize at least the rollout sequence of government programs, including awareness campaigns and agricultural extension across districts.

5. Contribution to Empirical Research on Autonomous Adaptation by Households and Farmers

In this section, we examine the ways in which people adapt to climate change, with an emphasis on household and farmer accumulation of knowledge. We also examine research into factors predicting the incidence and extent of various forms of autonomous adaptation.

5.1. How People Adapt

One of the most basic research questions is: how do farmers (and households more generally) in low-income countries adapt to climate change autonomously? Progress has been made in answering this question in this collection regarding rainfall, temperature, and drought. The paper by di Falco et al. examines the probability of adaptation through appropriately changing crops and tree planting. They find positive impacts not only of individual and community autonomous adaptive responses, but also a constructive influence of formal government agricultural extension services. Community adaptations included farmer-to-farmer (social) learning. Government responses included provision of information about future climate changes.

Regarding heat waves, the paper by Das and Smith examines several autonomous behavioral responses that, once learned, do not need ongoing inputs from government. These include carrying a water bottle and oral rehydration solution, wearing head cover, attending to young children, learning symptoms of heat stroke, and utilizing basic first aid principles. Das and Smith find that such behavioral responses can be effectively encouraged through government policies, specifically a “massive awareness campaign” on “dos and don’ts” during heat waves. The results provide evidence that districts included in the campaign have experienced reductions in heat stroke deaths during heat waves attributable to this campaign, in comparison to other districts, as well as to non-heat wave periods.

5.2. Knowledge

Both di Falco et al. and Das and Smith highlight the central importance of improving adaptation capacity through household knowledge. For example, results of di Falco et al. underline the need to provide farmers with “appropriate and timely information on future climate changes.”

Results from di Falco et al. indicate that farm households with good access to formal and farmer-to-farmer agricultural extension and with information about future climate change are more likely to undertake adaptation measures. But the two channels of learning are not perfect substitutes. Both government and farmer-to-farmer extension are positively correlated with the probability of adaptation through changing crops, but only government extension seems to affect the probability of adopting soil conservation.

Moreover, the provision of information on future climate change has a positive and significant effect on changing crops and planting trees. However, it has a negative and significant effect on the probability of undertaking soil and water conservation. The authors posit that “farmers prefer strategies that may deliver a quicker pay off in terms of productivity.”

5.3. Other Determinants of Autonomous Adaptations to Climate Change

In research on public perceptions of observed climate change, it has been found that perhaps a third of those who say they have observed climate change have nevertheless taken no actions in response (Dinar et al. 2008). In contrast, in Egypt most respondents report at least one adaptation. At the individual level, other things equal, more experienced and better-educated farmers are more likely to undertake adaptation (Dinar et al. 2008). Heads of household also have a higher probability of taking adaptation measures, presumably because the household head controls household resources and benefits most from adaptive measures; and farmers working on rented land are less likely to adapt than those who own land, presumably because owners receive the benefits of land improvements, or at least a larger share of them (Dinar et al. 2008). Other findings include higher probability of adaptive behavior among males (Alpizar et al. 2009) and wealthier households (Brouwer et al. 2007).

Using the climate change analogues approach introduced in section 4.2, research in this issue has found adaptive responses to drought, storm impacts, and heat waves. A recurring theme of the findings was that government can play a constructive role in facilitating the effectiveness of autonomous adaptation, notably by providing information.

6. Interactions between Planned and Autonomous Adaptation

As the examples of government awareness campaign and agricultural extension indicate, processes of planned and autonomous adaptation overlap. Thought of over time, adaptation may begin as a "bottom-up" process, with government stepping in to provide positive or negative incentives.[5] Observation of autonomous adaptation may provide a decentralized market signal for broader, policy adaptation. Generally, autonomous adaptation efforts may help guide planned adaptation, even if the autonomous efforts achieve only limited success. Moreover, government may design a policy in response to concerns or problems of the public, but the new or amplified adaptation behavior may begin only once the government policies are in place.

Thus, we can think of adaptation as a continuum. At one end is the purely autonomous adaptation by private agents; on the other end is the purely planned adaptation by government, including large-scale infrastructure construction and changes in regulations, such as building codes. Between these extremes likely reside the majority of adaptations, which involve both private agents and governments.[6] More research is needed on a variety of forms of adaptation that involve a combination of some autonomous and some planned adaptation.

As Linquiti and Vonortas (this issue) point out, one of the simplifying assumptions underlying their analysis is the omission of a behavioral link between decisions about coastal defenses and the location decisions of firms and households. Better coastal defenses will increase the attractiveness of locating, or remaining, in lower elevations, while weaker defenses will induce movement to less vulnerable areas. This link is an important one, and illustrates an issue that has received little attention in the literature: that planned and autonomous adaptation decisions are interlinked. Planned adaptations, such as coastal defenses, will influence autonomous adaptation decisions, such as location choices. Simultaneously, autonomous adaptation decisions, such as the location decisions of firms and households, will influence socially optimal decisions on planned adaptations.

The extent and character of autonomous adaptation are thus influenced by policy-based adaptation. The nature of interactions between autonomous adaptation and planned

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[5] Government action may improve efficiency or may be rent seeking in character.

[6] Beyond the scope of this paper and special issue, it is likely that some adjustments will be far-reaching in scope, involving government, civil society, and private sector actors simultaneously. For example when institutions – both formal and informal, such as social norms (North, 1990) – must be altered to effectively adapt when coordination problems are involved.

adaptation play an important role in determining the welfare implications of adaptation behavior. These interactions are fundamental to any coherent strategy focused on the welfare of those threatened by climate change; yet they are largely overlooked in research to date.

Appropriate autonomous adaptation may be hampered by distorted incentives associated with existing government policies. Imperfect information, distortions in the financial system, or other market failures pose further obstacles. Fankhauser et al. (1999) develop the idea that for autonomous adaptation to be effective, individuals must have the right incentives, knowledge, resources and skills. A government role is to provide "a conducive environment" for adaptation, including the right legal, regulatory, socioeconomic environment for autonomous adaptation. In particular, the government needs to provide the right incentives to farmers for taking adaptive actions. For example, if the government subsidizes certain crops heavily such that farmers do not suffer losses from the changing climate, they will have less incentive to adapt by themselves.

In general, autonomous and planned adaptation may act as complements or substitutes (e.g. Fankhauser et al. 1999). For example, consider the interaction of farmers responding to increasing temperature by planting new varieties (autonomous adaptation), and government research institutes developing new heat resistant seeds (planned adaptation). Farmers' willingness and capability to adopt the new varieties increase the marginal benefit of such research; and availability of new varieties more appropriate to local conditions increases farmers' marginal benefit of switching to the new seeds. On the other hand, if autonomous adaptation reduces the need for planned adaptation and vice versa, then they are substitutes. For example, if government, in anticipation of increased precipitation variability, constructs larger reservoirs and digs larger irrigation systems (planned adaptation), the farmers will have less need to make their own (autonomous) adaptations such as changing crops or conserving water.

7. Conclusions and Needs from Future Research

The papers in this special issue make clear contributions to improving our understanding of autonomous adaptation and to decision making about adaptation in the face of uncertainty. At the same time, they uncover needs for future research on the economics of adaptation in low-income countries.

Methodology. Several of the papers offer methodological innovations that can be further developed and applied. For example, Eichberger and Guerdjikova's paper shows how formally incorporating ambiguity into a model of autonomous adaptation can yield new insights on the barriers to such adaptations, and government interventions that can reduce these barriers. Similarly, the real options approach employed by Linquiti and Vonortas to examine investments in coastal defenses can fruitfully be applied to other types of adaptation decisions—both planned and autonomous—in which decision makers have flexibility with regard to both the timing and magnitude of adaptation investments. In the context of low-income countries, it would be particularly valuable to identify real options strategies that perform reasonably well under a variety of circumstances, yet require limited information and analytical sophistication on the part of the decision maker.

Robust Decision-Making. Identifying such strategies would be in keeping with the principle of "robust decision making" advocated by a number of researchers studying decision-making in the context of climate policy (e.g., see Lempert et al. 2006, 2007, and Climate Change Science Program 2009).[7] Robust decision-making departs from the conventional economic conception of decision-making in that it pursues "robustness" rather than optimality. Definitions of robustness differ, but include a willingness to sacrifice some optimality in return for less sensitivity to potentially mistaken assumptions, or achieving reasonable performance under a wide range of scenarios. The output of robust decision-making typically takes the form of a set of tradeoffs across options (or policies), instead of the ranking of options generated by the optimization framework traditionally employed by economists. Robust decision-making has not been embraced generally by economists, but deserves careful consideration given the "non-standard" nature of the uncertainties associated with climate change and adaptation.

Timing and Sequencing of Adaptations. The paper by Linquiti and Vonortas highlights an issue of broad importance: the optimal timing of adaptation responses given time-varying uncertainty about the nature, magnitude, and timing of climate changes. This issue is also alluded to by di Falco et al. when attempting to explain differences in the prevalence of various adaptation responses among farmers. Farmers' perceptions of the relative timing of climate changes influence which adaptations they undertake first. Given that there are often multiple possible adaptations that can be undertaken, the question of optimal timing becomes a question of optimal sequencing of adaptations. This is an issue not just for individual agents determining which adaptations to undertake and when, it also arises in the context of the sequencing of planned and autonomous adaptations when the two are inter-related. The optimal sequencing of adaptations has received modest attention (Fankhauser 2009, World Bank 2010), but deserves much more.

Adaptation in Agriculture. The paper by di Falco et al. demonstrates the importance and potential effectiveness of disseminating information to farmers about future climate changes and adaptation options, with roles for both formal government extension and informal farmer-to-farmer dissemination. A general problem that di Falco et al. point out when attempting to identify adaptation responses and their effectiveness is the difficulty in distinguishing between adaptation and improvements in agricultural practices associated with routine agricultural development. As di Falco et al. observe, most adaptation strategies employed thus far are similar to strategies used to cope with droughts, floods, and other "routine" extreme weather events. However, as climate change progresses and average and extreme weather conditions depart farther from what has already been experienced, adaptation may well need to take new forms. Assessing the potential effectiveness of such new forms of adaptation is a more difficult task, but one that obviously merits attention.

[7] Depending on the application, robust decision-making may require more analytical and computational sophistication than an optimization framework, and in such cases would be more difficult for planners in low-income countries to implement.

It is not surprising that much of the existing empirical work on autonomous adaptation has focused on agriculture, given its importance in low-income countries and in the livelihoods of the rural poor. While the importance of agriculture in such countries is indisputable, autonomous adaptation in other areas deserves close attention. We identify a number of these below.

Migration. Increased threats to rural natural-resource-based livelihoods are expected to magnify already sizable rural to urban migration. Migration theory and empirical evidence indicate that reductions in rural productivity spur migration to urban areas due to the increased wedge between rural and urban unskilled expected incomes. Research on this problem is in its early stages. For example, using annual country panel data for sub-Saharan Africa, Marchiori et al. (2011) estimate that between 1960 and 2000, temperature and rainfall variations caused a net displacement of 2.35 million people in sub-Saharan Africa. Using IPCC scenarios, they project that climate variations will lead to an additional displacement of 1.4 million people per year. On a global scale, estimates of the potential number of people displaced by climate change in the year 2050 range from 200 million to 700 million (Warner et al. 2009). Migration as a form of autonomous adaptation needs much more study.

Urban Adaptation. Limited attention has been given to adaptation in urban areas (notable exceptions are Bicknell et al. 2009 and Moser et al. 2010). The need for urban adaptation will be magnified by the aforementioned increase in rural migrants. Approximately one billion people live in informal urban settlements that offer poor-quality housing, little or no access to public services, and are often located on high-risk sites. Climate change is likely to worsen water availability and increase the severity and frequency of extreme weather events such as storms, floods and landslides. Informal settlements and other urban areas lacking infrastructure and services are particularly vulnerable to these risks. In addressing these risks, attention will need to be given to the interactions between planned and autonomous adaptation. For example, regulatory measures such as stricter land use and building codes may be adopted in some urban areas. But such regulatory measures can put pressure on land and housing prices, potentially exacerbating homelessness and poverty. The likely response, given the expected rise in the value of less vulnerable urban land, is greater movement of low-income families into environmentally degraded, vulnerable spaces.

Adaptation and Conflict. The likelihood of climate change exacerbating conflict has received considerable attention recently. For example, there is a growing literature documenting the link between rainfall levels and violence (e.g. Miguel et al. 2004, Blattman and Miguel 2010, Hsiang et al. 2011). In the literature on climate and conflict, adaptation is generally viewed as a means of moderating the impacts of climate change, thereby reducing both the likelihood and magnitude of conflicts (e.g., Barnett and Adger 2007, Stark et al. 2009). A careful examination of adaptation, both autonomous and planned, indicates that in some settings adaptation can increase the potential for conflict and instability rather than reduce it (as illustrated below), contrary to the prevailing view in the literature. This possibility, and the corresponding need for “conflict-sensitive adaptation," has recently been recognized by Tanzler et al. (2011) and Sayne (2011). More attention needs to be given to the relationship between adaptation and conflict.

Externalities and Competition for Resources. Adaptation to climate change can alter access to natural resources and place increased pressure on already scarce resources. For example, in Nigeria, feed and water shortages caused partly by drought and desertification have induced nomadic pastoralists to move south, outside of their traditional grazing routes. In turn, sedentary farmers have responded to weather-related changes by cultivating more land. This has left pastoralists with little uncontested land on which to graze and water their animals, leading to violent farmer-pastoralist conflicts (Sayne 2011). A similar dynamic has played out in the Sahel of Sudan (Bronkhorst 2011). Because this competition for resources is new or intensified, traditional institutions and mechanisms for allocating resources may be rendered ineffective. In Kenya, increased drought, together with other factors, has induced traditional pastoralists to adopt more sedentary livelihoods, settling near fixed water sources. The absence of established institutions for managing natural resources in these areas has led to environmental degradation. Similarly, in coastal areas of Bangladesh, water from tube wells has become increasingly prone to salt water contamination. This has induced inhabitants of affected areas to draw water from unaffected wells in neighboring areas, fueling tensions with inhabitants of these areas (Bangladesh Institute of International and Strategic Studies and Saferworld 2009). Much more attention needs to be given to establishing, or strengthening, formal and informal institutions for managing these increased demands on natural resources if resource degradation (or depletion) and conflict are to be avoided.

Relationships Between Planned and Autonomous Adaptation. In our opinion, one of the most pressing research needs is a better understanding of the relationships between planned and autonomous adaptation. This has been a recurrent theme in this paper, and it arises in a number of the papers in this special issue. We conclude with a call for more research on this topic.

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