What Does Climate Change Mean for Agriculture in Developing Countries? A Comment on Mendelsohn and Dinar

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Mendelsohn and Dinar review much of the important work on the implications of climate change for agriculture, focusing particularly on developing countries. Their message is that efficient economic adaptation significantly reduces the estimated effects of climate change. Few dispute that some amount of adaptation is likely and that its *potential* contribution to reducing the negative impacts of global warming is large. One such study (Darwin and others 1995), which analyzed the global impacts using an ecozone (land class) methodology, found that without adaptation, average cereal production yields fell roughly 20 to 30 percent in four different climate scenarios. Through various channels of adaptation (modifying crops and techniques on existing farmland, shifting crops to new land, and responding to changing market prices), these losses were reversed, resulting in small increases in production worldwide (0 to 1 percent) even before considering the positive effects of carbon dioxide (CO_2) fertilization (table 1). Striking, however, are both the initial shock in cereal production in the study reported in table 1 and the range of impacts on yields (without adaptation) estimated by a variety of studies for different sites around the world (shown in table 2).

The Ricardian method reported by Mendelsohn and Dinar and the ecozone (land class) method of Darwin and others (1995) are similar in that they use cross-sectional evidence to estimate the adaptation response to climate change that occurs over time. Darwin and others (1995) use this evidence to estimate productivity shocks that are introduced into a general equilibrium model. As Mendelsohn and Dinar note, the Ricardian method is limited because it does not account for market effects, that is, the fluctuation of prices reflecting market conditions. The result is thus strictly applicable only to a closed economy. Mendelsohn and Dinar note that this bias will be small if the global price effect is small, and they cite a study by Reilly, Hohmann, and Kane (1994) that shows small price effects in some scenarios. This single study is

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Table 1. *Percentage Changes in the Supply and Production of Cereals for the World*

Study	*No adaptation, no market response*	*On-farm adaptation, no market response*	*On-farm adaptation, market response, land use fixed*	*On-farm adaptation, market response, land use response*
GISS	–22.9	–2.4	0.2	0.9
GFDL	–23.2	–4.4	–0.6	0.3
UKMO	–29.6	–6.4	–0.2	1.2
OSU	–18.8	–3.9	–0.5	0.2

Note: Climate change scenarios from the Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), United Kingdom Meteorological Office (UKMO), and Oregon State University (OSU) general circulation models (GCMs) that have been logged at the National Center for Atmospheric Research for use by other researchers. These scenarios represent simulated changes in climate when CO_2 levels are doubled in the atmosphere.

Source: Darwin and others (1995).

Table 2. *Impact on Crops of Climate Resulting from a Doubled CO_2 Environment*

Region[a]	*Crop*	*Yield impact (percent)*	*Discussion*[b]
Latin America	Maize	–61 to increase	Argentina, Brazil, Chile, Mexico. Range is across GCM scenarios, with and without the CO_2 effect.
	Wheat	–50 to –5	Argentina, Brazil, Uruguay. Range is across GCM scenarios, with and without the CO_2 effect.
	Soybean	–10 to +40	Brazil. Range is across GCM scenarios, with CO_2 effect.
Former Soviet Union	Wheat	–19 to +41	Range is across GCM scenarios and region, with
	Grain	–14 to +13	CO_2 effect.
Europe	Maize	–30 to increase	France, Spain, Northern Europe. With adaptation, CO_2 effect. Longer growing season; irrigation efficiency loss; northward shift.
	Wheat	Increase or decrease	France, United Kingdom, Northern Europe. With adaptation, CO_2 effect. Longer growing season; northward shift; greater pest damage;
	Vegetables	Increase	lower risk of crop failure.
North America	Maize	–55 to +62	Canada, United States. Range across GCM scenarios and sites; with/without CO_2 effect.
	Wheat	–100 to +234	
	Soybean	–96 to +58	United States. Less severe effect or increase in yield when CO_2 effect and adaptation considered.

Table 2 *(continued)*

Region[a]	*Crop*	*Yield impact (percent)*	*Discussion*[b]
Africa	Maize	–65 to +6	Egypt, Kenya, South Africa, Zimbabwe. With CO_2 effect; range across sites and climate scenarios.
	Millet	–79 to –63	Senegal. Carrying capacity fell 11–38 percent.
	Biomass	Decrease	South Africa; agrozone shifts.
South Asia	Rice	–22 to +28	Bangladesh, India, Indonesia, Malaysia,
	Maize	–65 to –10	Myanmar, Philippines, Thailand. Range over
	Wheat	–61 to +67	GCM scenarios and sites, with CO_2 effect; some studies also consider adaptation.
Mainland China and Taiwan, China	Rice	–78 to +28	Includes rainfed and irrigated rice. Positive effects in NE and NW China, negative in most of the country. Genetic variation provides scope for adaptation.
Other Asia and Pacific Rim	Rice	–45 to +30	Japan and Republic of Korea. Range is across GCM scenarios. Generally positive in northern Japan; negative in south.
	Pasture	–1 to +35	Australia and New Zealand. Regional variation.
	Wheat	–41 to +65	Australia and Japan. Wide variation, depending on cultivar.

Note: Except as noted, model results use "equilibrium" scenarios from doubled CO_2 GCM experiments. In these experiments, atmospheric carbon is doubled and the climate model is run for 10 to 15 model years (until the climate stabilizes under the new CO_2 level). The newest generation of climate model experiments, so-called "transient" climate scenarios, attempt to more realistically describe a time path of climate change reflecting gradual increase in CO_2 levels, but these scenarios have only recently become available for crop model analysis.

a. In all regions except Latin America and Other Asia and Pacific Rim, the comments apply to all the crops studied.

b. Indicated here is the basis for the range of crop yield estimates given, including the countries in which site studies were conducted; whether the range is across different sites, different GCM scenarios, or both; whether adaptation was considered; and whether the studies included the direct effect on crops of higher ambient levels of atmospheric CO_2—the so-called "fertilization effect." Apart from its effect on climate, CO_2 has direct physiological effects on plants. Generally, experimental evidence shows that higher levels of ambient CO_2 increase crop yields. The magnitude of this "fertilizer" effect on crops is much debated. As a result, many studies estimate the impact of climate change both with and without this effect.

Source: Summarized from Reilly and others (1996).

not conclusive. Mendelsohn and Dinar, in fact, argue that global crop models are poorly calibrated but still use the price results from those models to support the validity of the Ricardian method.

In fact, unless one estimates the effect of climate change worldwide, there is no obvious bound on how much the world market price for agricultural products can change (in either direction) and hence no way to determine the direction or magnitude of the bias. If adaptation proves to be as effective as Mendelsohn and Dinar or Darwin and others (1995) estimate, and if the CO_2 fertilization effect does increase yields by 10 to 15 percent, the prices of agricultural commodities may, in fact, *decline* sharply. Although a price decline would certainly be an economic benefit for consumers, agricultural exporting nations could sustain significant welfare losses. Reilly, Hohmann, and Kane (1994) make the point that exporting countries bear the largest per capita losses (among cases with CO_2 fertilization and adaptation that they examine) under scenarios in which the world prices of agricultural commodities fall. The point is that nobody has good estimates of the global impact. If the goal is to provide guidance for individual nations or regions, then results based on the hypothesis that the net global impact will be zero (or at least small) must be treated with extreme caution.

The list of concerns about using evidence from cross-sectional data to estimate the impact of time-series phenomena is long. One problem is that of controlling for all the other phenomena (either included in the estimated relationship but poorly measured or not included for lack of data) that might be affecting the estimated relationship between climate and agricultural production. Nordhaus (1996), who investigated the relationship between wages and climate to get at the direct value of climate in people's everyday lives, used sophisticated econometric techniques to obtain better estimates of the parameters. The study showed that the impact of global warming on climate amenities could not be reliably determined. (As used here, climate amenity refers to the value people place on living in a warm and sunny climate rather than a cold and snowy or hot and humid climate.) The relation between agricultural productivity and climate in cross-sectional evidence would seem to be much stronger, on the face of it, than the relation between wages and climate. Nevertheless, more robust measures of the reliability of the statistical estimates would be useful.

A second major concern with cross-sectional evidence is that it represents at best a long-run equilibrium response. The Ricardian method and similar reduced-form approaches do not provide much information on how one gets from point A (current climate and current production practices) to point B (new climate and new production practices). Darwin and others (1995) provide a bit more insight into the channels of adaptation by dividing the response into three categories: changes that occur on the farm, in the market, and in land use. Although these distinctions are somewhat artificial, they show that farmers are able to adjust even without much market response and without moving agricultural production to entirely new areas. Table 2 illustrates, however, that *without* adaptation, the impacts at individual sites can be dramatic in both directions. Although tables 1 and 2 are difficult to compare directly, if one assumes that the overall picture presented in table 2 is roughly consistent with the "no adaptation" column in table 1, it appears that at finer geographic detail the response can be much more varied. In fact, many of the crop yield estimates in table 2 were part of a study by Rosenzweig and Parry (1994), which, when aggregated to a global estimate, generated reductions in yields that were almost identical to those reached by Darwin and others (1995) in the case of "no adaptation."

In comparison with the reduced-form statistical approaches, agronomic models provide evidence on which technological solutions would increase yields (for instance, more fertilizer, changes in the planting date, new varieties of crops), but they do not offer any insight into whether farmers will actually choose these techniques or even whether these strategies would be economically beneficial responses. Reilly and Schimmelpfennig (forthcoming) point out that the techniques used by most studies maintain hypotheses about whether adaptation will occur autonomously or not. Hence, Mendelsohn and Dinar are concerned that crop response models introduce adaptation in an ad hoc manner, whereas cross-sectional evidence *assumes* agents will detect the changed climate even in a highly variable environment and will know which adaptations will work. Time-series data can be misleading as well because they capture the response to unexpected weather events, whereas in the process of climate change, agents may learn that some of these events are becoming more or less frequent and thus decide to adapt. If one assumes that dynamics do not matter, as implied by the use of cross-sectional evidence, then adaptation can and should be left to the market. If detection is expected to be difficult and agents need to learn the correct response, then the cross-sectional evidence shows the ultimate potential of adaptation. But public policy actions may be needed to realize this potential fully. If irreversibilities that slow the adaptive response are present, the costs may be greater than those estimated by cross-sectional methods unless or until the climate stops changing. Thus I believe it can be said only that the *potential* of adaptation is large.

The growing literature reviewed by Mendelsohn and Dinar and presented briefly here raises at least three broad questions. First, how are these estimates to be used—of what policy relevance are they? Second, how certain are researchers of these estimates? Third, given these estimates, what should be done now?

What Is the Policy Relevance of These Estimates?

The research agenda behind much of this climate change work is to develop estimates that clarify the damages associated with increased greenhouse gas emissions and the benefits of reducing emissions, as proposed, for example, under the Kyoto Protocol of the Framework Convention on Climate Change (FCCC 1998). Integrated assessment efforts sometimes represent the problem as a generalized and dynamic cost-benefit analysis, where the benefits of the mitigation policy are the avoided damages to agriculture, coastlines, health, and other sectors (Nordhaus 1998). Most of the estimates focus on climate change associated with the equivalent of doubling the pre-industrial levels of CO_2 in the atmosphere, with global average temperature changes of 2.5° to 5.2° C.[1] The low end of this temperature range is not predicted to occur until 2070; the high end is not predicted until well after 2100.

A push to foster adaptation through research on the likely effects of both climate change and adaptations to that change has been growing, for three reasons. First, it may be economically sensible to spend something on adaptation and a bit less on reducing greenhouse gas emissions. Second, if one despairs about reducing emissions, given the costs and difficulties of reaching and enforcing a global agreement, adaptation may be the only defense. Finally, because inertia in earth and energy systems means that several decades of climate change are virtually inevitable, those who are ill prepared to adapt (either to avoid losses or to take advantage of new opportunities) may lose comparative advantage to those who are better prepared. In fact, work by Rosenzweig and Parry (1994), as reported in Reilly and others (1996), shows the paradoxical result that cereal production in developing countries was lower with adaptation than without. This decline occurred because the adaptation response was stronger in the industrial countries. As a result, world prices were lower, agricultural comparative advantage shifted to the industrial countries, and developing countries had less incentive to grow cereal crops. This finding does not mean that adaptation is a bad idea—if developing countries had not adapted at all, the shift would have been greater. It does indicate, however, the danger of basing results on partial equilibrium models or even on market or general equilibrium models of a single nation or region.

The general conclusion that adaptation (to the extent it is economically justified) makes sense is tautological. But the value of the empirical work for identifying particular adaptation options is negligible or nonexistent. First, most of the work assumes that adaptation occurs without intervention from anyone. Researchers figuratively position themselves in low Earth orbit and observe that food continues to be produced and people continue to inhabit the land. The contrast between the results in table 2 and those reviewed by Mendelsohn and Dinar (or between the first and last columns in table 1) suggests that something quite powerful must happen to get from estimated yield losses of 20 percent (or more) to the conclusion that effects are minor or positive for the globe and for most countries. To the extent that one is interested only in adding up the damages, perhaps one can assume that everything that needs to happen will happen. But part of what may need to happen is for other researchers to muck around on farms, in agribusiness, and in government agricultural institutions to help point the direction.

Second, the time frame of 2070–2100 and beyond is irrelevant for decisions today about possible adaptation measures. Most of the capital in agriculture will be replaced several times over in the next 70 years. It would be nonsense to optimize a system today for conditions far in the future and ignore the next three decades. It would be nonsense to optimize for conditions in 2070–2100 when most decisions can wait until 2069 or at least 2050, when much better forecasts will be available (if for no other reason than that the conditions in 2050 will already be known). Even where the lifetime of a project is long (for example, a large dam), almost any positive discount rate will make irrelevant to today's decision the question of whether there is water in the river in 2100 or farmers who need it.[2]

Third, the level of uncertainty in these forecasts is unknown. For any particular country, evidence and other simulations of doubled CO_2 effects suggest that predicted crop yields will vary, in either direction, by up to 100 percent of the nation's average predicted yield under the same scenario. I discuss some of the reasons for this large, subjective assessment of uncertainty later. If the assessment is reasonable, this level of uncertainty poses significant challenges for the development of adaptation strategies. It is extremely dangerous to develop a strategy based on two or three scenarios when so little is known about where these sit within the distribution of possible outcomes.

Fourth, these studies are insufficiently detailed or too incomplete—or both—to be of much guidance. In work using these crop response model results and a fairly detailed food trade model, Reilly, Hohmann, and Kane (1994) showed that in most countries the economic impact had as much or more to do with the effect of climate change on world prices as with the impact of climate on agricultural yields within the country. In fact, net exporters of agricultural commodities generally benefited economically from climate change if world prices rose (climate change was, on net, bad for world production) even if they suffered yield losses. They suffered economic losses if world prices fell regardless of whether the climatic effects on agriculture in the country were positive or negative. The situation for food-importing countries was reversed. The difficulty with the argument in Darwin and others (1995) suggesting that global changes in prices may be small is that their study aggregates agricultural commodities to only three categories—grains, other crops, and livestock—and so cannot begin to investigate realistic changes in comparative advantage in the key export crops that are important for specific countries.

Some of these limitations affect the usefulness of these forecasts even for the global cost-benefit calculus. It would be useful to have uncertainty bounds and to know more than just a few point estimates of impacts 70 to 100 years in the future. The limitations are fatal for adaptation actions other than the most general. It would be more useful to recommend climate monitoring, more research, or better forecasts—but even for these, it is unclear how much more money and effort should be spent. When researchers are forced to come up with robust strategies, the adaptation story is similar to the literature on reductions in emissions. In other words, researchers should look for adaptations that will improve resiliency to existing weather variability—so-called no-regrets adaptations. Even such seemingly innocuous recommendations might go wrong. One might well regret investing heavily in irrigation to reduce vulnerability to drought if climate change means that the river itself will dry up.

Are the Estimates of the Impact of Climate Change Valid?

The body of work referenced here presents a somewhat negative result. Researchers went looking for the impact of climate change, and even under the fairly extreme scenarios of warming that might not occur until after 2100, they found little or no effect. Logically then, if the problems, even in these extreme cases, are so slight, less warming between now and 2070 should have even smaller effects. One would then conclude that it is unnecessary to reduce emissions or do anything else to adapt to climate change.

Are there errors in this logic? At issue is whether these are in fact "extreme" scenarios. There are both socioeconomic and biophysical reasons why these scenarios are extreme only in terms of average surface temperature change. Yet the evidence is that mean changes in temperature have little impact on agriculture production; extremes of temperature, rainfall, and storm events are what cause negative agricultural outcomes.

On this subject the literature offers few strong conclusions. Will tropical storms (hurricanes and cyclones) increase in number or intensity? The hydrological cycle will speed up; will that mean more intense rainfall and more frequent droughts? Will seasonal changes from cold to warm or from wet to dry become more variable? Will the El Nino-Southern Oscillation phases become more intense, or will they remain in one phase for longer periods of time? Will monsoons and other rainfall patterns change their seasonal or geographic pattern? The lack of convincing evidence forecasting these changes does not rule out any chance of their happening. A shift in rainfall patterns of 100 or so miles or by a month or two could lead to far larger changes in precipitation in a particular region than is suggested by the estimated global average changes of 7 to 15 percent. Agricultural studies have largely imposed mean warming and precipitation changes from climate predictions on the climate of today without exploring the implications of the many dimensions of climate that could change.

Are there catastrophes (low probability–high consequence events) that could upset even the global mean estimates? The executive summary of the report of the Intergovernmental Panel on Climate Change (Bruce, Lee, and Haites 1996:5) argues that the "consideration of risk aversion and application of the precautionary principle provide rationales for action beyond no regrets." The possibility of catastrophic consequences occasionally enters discussions of climate change. The melting of the West Antarctic ice sheet, a runaway greenhouse effect from the release of methane hydrates in permafrost or shallow coastal regions, and changes in the ocean's conveyor belt are events that have been suggested, and in some cases examined and dismissed, as being highly improbable. If these are real possibilities, there may be adaptation actions that governments could take to minimize the consequences. The strategies that would be helpful will not be understood if researchers persist in considering only the center of the distribution.

The adjustment process and the potential that adjustment could increase costs has not been factored into many of the recent analyses. Thus, while the "dumb farmer" studies referred to by Mendelsohn and Dinar are perhaps overly pessimistic, their recent studies may be overly optimistic. If one could trust that the rate of change in the global climate is an indicator of the rate of change in local climate, then one could comfortably dismiss adjustment costs for market sectors. But a smooth response to climate change can hardly be assumed, particularly in the case of precipitation that can change dramatically for local areas if the storm track changes by 50 or 100 miles. Because no realistic transient climate scenarios have been developed, it is impossible to rule out a pattern of climate change in which local areas are stable for some period of time and then change rapidly over a few years. Such a pattern could impose serious adjustment costs even with accurate forecasting and forward-looking behavior.

With regard to the socioeconomic response, a real question remains about the ability of agents to detect and adapt successfully to climate change, given the huge variability in weather from year to year. Moreover, misguided responses to changes are possible, if not likely. Countries that lose comparative advantage in agricultural exports may erect trade barriers to protect their market share; existing conflicts over water rights within and among countries may prevent the efficient allocation of water if it becomes more scarce; investment in irrigation may expand in areas that should be abandoned; cropping in flood-prone regions may continue if insurance and disaster assistance encourage such behavior or if farmers cannot detect whether the flood is part of the normal weather pattern or a signal of a major shift in the hydrological regime.

The long-run response estimated using cross-sectional evidence essentially assumes that farmers rely on decades of weather records and experience in farming to guide their selection of farming strategies. With climate change, this historical experience is no longer automatically relevant. If the signal is simple and clear—gradual warming—farmers can look to nearby warmer regions for guidance. But because patterns of rainfall, temperature, storms, and extreme events over the season are more important than mean changes, the weather record and the farming experience of nearby warmer regions will not be relevant unless climate change involves the wholesale shifting of climate with all moments of the distribution and patterns of extreme events intact.

What Should Be Done Now?

Researchers like myself who have been looking at this subject for nearly 20 years sometimes forget about the air of unreality that taints the discussion of climate change. It is easy to seize on one or two scenarios for a period 100 years hence and overinterpret the predictive content of the estimates. The best remedy for this lack of reality is to think seriously about what should be recommended today. It is important to take this question seriously, applying the model used in predicting hurricanes. If the hurricane hits with no evacuation warning, the costs are high. But evacuating millions of people if the hurricane turns away or if the forecasted point of landfall is imprecise is also disruptive and costly. Too many false alarms, and no one will believe the forecast when it is right. Given the large degree of uncertainty in the estimates of the effects of climate change on agriculture, researchers can only wish that their forecasts were more precise. Additional work is needed to clarify whether adaptation will indeed resolve any problems and to explore the full range of ways in which climate could change. A better assessment of the uncertainty involved in the forecast (although not as helpful as a firm prediction) is more helpful than a firm prediction that is wrong.

Notes

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1. Equivalent doubled CO_2 refers to an additional radiative forcing in the atmosphere as if atmospheric concentrations of CO_2 had doubled. Some of this forcing may be due to other gases such as CH_4 (methane) and N_2O (nitrous oxide).

2. There are some well-known issues with discounting that have been discussed in the context of climate change (Lind and Schuler 1996). From a normative perspective, discount rate decisions imply judgments about intergenerational equity. If there is growth in per capita income, then any equity criterion that favors the poor should be biased toward higher discount rates to allocate more consumption to the present, poorer generation. From a positive perspective, there are also well-known problems with evaluating a few decisions in the economy (for example, adaptation to climate change) at a different rate than other investments in the economy. Agricultural adaptation to climate change largely involves normal investments farmers make in equipment and machinery rather than the large international commons problem of controlling long-term climate change. Weitzman (1998) makes the compelling case that with uncertainty in the discount rate, “the far distant should be discounted at the lowest possible rate,” although he is hazy about what is the “far distant future” or what would be the “lowest possible discount rate.” If economic stagnation and falling incomes are imaginable, then negative discount rates are possible. He also notes that one must evaluate the problem in the context of the life of the investment. A dam is among the longest-lived projects related to agriculture, with a lifetime of perhaps 50 to 100 years (Reilly 1995). This lifetime is not so different from those of transportation infrastructure, power plants, and major building projects. The Weitzman result of declining discount rates for the far distant future thus may be of some importance for dams, but one would want to apply such a rate consistently across other similarly long-lived investments in the economy. And, under any circumstances, it is useful to know the flow of benefits over the entire life of the investment, rather than just a single year near the end of its life.

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