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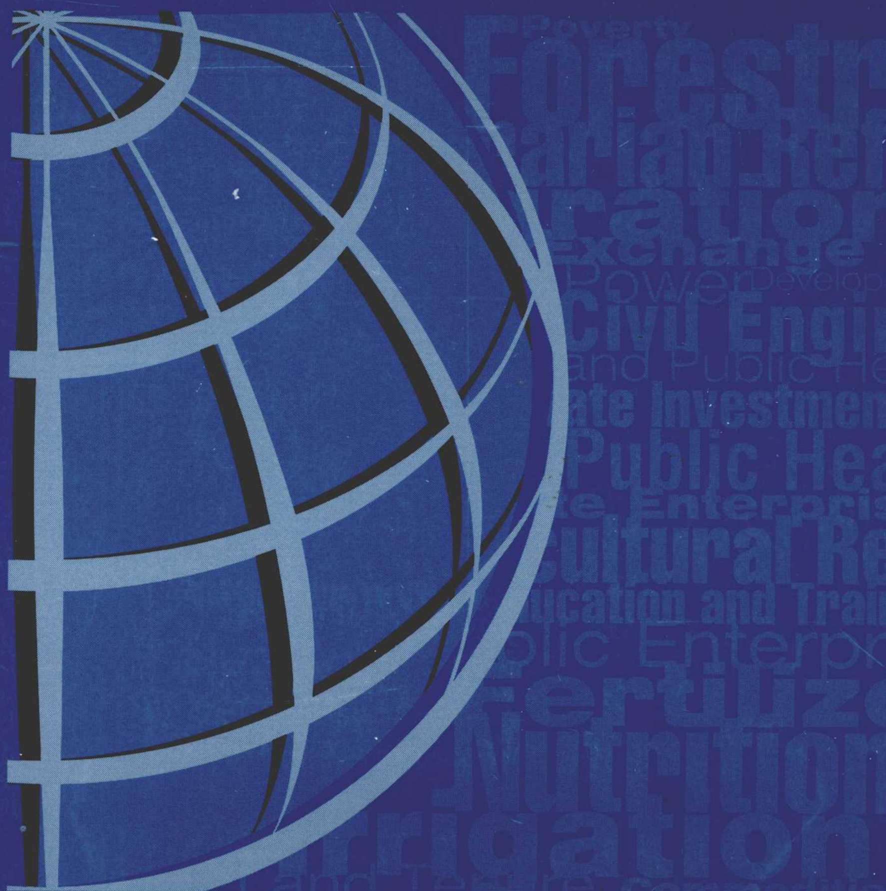
# Measuring the Impact of Climate Change on Indian Agriculture

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## FOREWORD

The impact of climate change on agriculture in industrial countries has been studied by many scientists and economists. However, less is known about the economic impact of climate change on developing countries. With their warmer climates, labor-intensive low-capital practices, and alternative crop mixes, and with their less-developed market structures, developing countries are likely to respond differently to possible climate change scenarios than are industrial countries. A recent study applied several analytical frameworks, using data from India, to measure the climate responsiveness of the Indian agricultural sector. The results, reported here, indicate the potential for substantial private adaptation in developing countries.

Alexander F. McCalla
Director
Rural Development Department

## ABSTRACT

New scientific evidence made scientists more confident that greenhouse gases may lead to future climate change. Research on measuring the economic impacts climate change might cause has proceeded world-wide, but most of the empirical research has focused on developed countries. It has been commonly believed that developing countries are more vulnerable to climate change because of their reliance on low-capital agriculture. It has been assumed, but never tested, that low-capital agriculture would have more difficulty adapting to climate changes.

Country-wide economic analyses have been completed only for the United States even though experts have extrapolated results to all countries. Agronomic studies of crop yield reductions support this wisdom implying large potential agricultural damages in India, for example. The vulnerability of low-capital agriculture to climate change, however, depends upon whether the affected farmers can adjust to changing climates. The recent research in the United States suggests that adaptation by private producers would reduce *damages* to agriculture from climate change, and carbon fertilization would actually lead to net agricultural *benefits* from climate change.

The set of studies in this report, explores farm performance across climates in India. The goal of the study is to examine farm behavior and test if there is any evidence that farmers in developing countries, such as India, currently adjust to their local climates. The reported studies measure the climate sensitivity of low-capital agriculture. They test whether actual farm performance is as sensitive to climate as agronomic models predict assuming no adaptation. The studies also compare the climate sensitivity of low-capital farms against the results already calibrated for United States agriculture.

The analyses feature the Ricardian approach, a cross sectional analysis of farm performance across different climate zones. The method uses an economic measure of farm performance: farm value or net farm income. Performance is compared across a large landscape where farms exist in different local climates. By regressing farm performance on long term climate, one can empirically measure long run climate sensitivity. Other important factors determining economic performance, such as access to markets and soil quality must also be included in the analysis. The approach carefully measures long run climate responses, and not short-run adjustments or weather effects. Although the method does not explicitly identify how farmers have adjusted, the measure of economic performance captures the consequences of all the adjustments farmers currently undertake in responding to their local climates.

Each of the Ricardian studies emphasizes a different methodology--all leading to similar estimates of climate change impact. The pooled data analysis (Chapter 4) examines overall expected effects. The year by year analysis (Chapter 5) examines annual fluctuations in climate sensitivity, while controlling for annual prices and weather. The climate-technology study (Chapter 6) examines the interaction between endogenous technology and climate sensitivity in India and Brazil, respectively.

The results indicate that existing farms are only mildly climate sensitive implying a substantial amount of adaptation. This adaptation is predicted to reduce potential warming damages by one-third to one-half. The analysis further suggests that the climate response



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functions for farmers in India and Brazil are similar to the estimated functions for United States farmers. Low-capital agriculture appears to be no more climate sensitive than modern farms.

These results suggest that warming alone will hurt agriculture in tropical (developing) countries relative to temperate countries. Damages from 8-12% are predicted by the Ricardian models. These results, however, do not include the effect of carbon fertilization. Carbon fertilization reduces the predicted damages in the agronomic models from 28% to 16%. Adding a 12% increase from carbon fertilization to the Ricardian estimates would drive the overall effects to near zero. The net results suggest that global warming will have only small effects on aggregate developing country agricultural sectors.

The adaptation being measured in these Ricardian studies is largely private efforts by farmers to maximize net income given local environmental conditions. Each farmer is making different choices depending upon the conditions he/she faces. Because these subtle adaptations make farmers better off, we expect that farmers will engage in these activities as climate changes. These subtle adjustments reduce the overall sensitivity of agriculture to climate change.

Technical change has been important to both India and Brazil over the years, substantially increasing productivity. However, agronomic research has not systematically focused on changing the climate sensitivity of crops. Investments in new technology have consequently not historically changed climate sensitivity in India or Brazil. This does not rule out the possibility of an important public research response to warming, it merely indicates that historic efforts have had no effect.

Although aggregate agricultural sectors may not be at risk to climate change, individual farmers may still suffer large damages. Some areas will suffer from higher than average temperature changes and some areas may experience deleterious precipitation effects. The entire sector may not be affected because these effects will average out, but this does not protect local areas. Further, the aggregate sectors in developing countries may be less sensitive because important components of these sectors tend to lie in more temperate zones. Damages in marginal areas may have little impact on the aggregate because they contribute little to the aggregate outcome today. Poor people dependent on these local areas may be highly vulnerable to warming even when national agricultural impacts are minimal.

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Chapter 4 in this volume is based on Chapter 2 of Sanghi's 1997 University of Chicago Ph.D. Dissertation "Global Warming and Climate Change Sensitivity: Brazilian and Indian Agriculture." The work leading to Chapter 4 had benefited greatly from comments by Sherwin Rosen, George Tolley, Robert Evenson, and Participants in the Agricultural Economics Workshop and Natural Economics Seminar at the University of Chicago and Yale University, respectively.

The help extended by Indian Meteorological Department in providing the climate and weather data sets used in Chapter 5, is gratefully acknowledged. The first author of Chapter 5 would like to acknowledge the extensive help received from Apurva Sanghi in handling various aspects of the work.

Chapter 6 in this report is based largely on McKinsey's unpublished 1997 Yale Ph.D. Dissertation, "Climate and Technology Impacts in Indian Agriculture."

Michele Rigaud prepared the first version of each chapter for publication, and Fulvia Toppin prepared the final version of each chapter, including typesetting of the entire report.


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# 1 OVERVIEW

Ariel Dinar and Robert Mendelsohn

## INTRODUCTION

As scientists are more confident now that greenhouse gases will lead to future climate change there has been growing interest in understanding the economic impacts climate change might cause. Many observers are concerned that changes in climate will in turn lead to significant damages to both market and nonmarket sectors. In an effort to understand the entire picture of the effects of climate change, it is necessary to examine all sectors affected by climate change, although systems that are highly managed like agriculture may be less sensitive than systems that are managed less.

Although several sectors have been studied, none have received more attention than agriculture. Research on this topic has proceeded world-wide, but most of the empirical research has focused on developed countries. Country-wide economic analyses have been completed only for the United States (Smith and Tirpak 1989 and Mendelsohn and Neumann 1998), but experts have extrapolated results to all countries (IPCC 1996b).

In the United States, the initial studies suggested large negative agricultural effects in terms of crop yield reduction, loss of fertile soils, and increased cost of production (Smith and Tirpak 1989). More recent analyses, that have incorporated more up to date climate forecasts and adaptation, however, consistently find that American agriculture will be resilient to climate change (Crosson 1993; Kaiser et al. 1993; and Mendelsohn, Nordhaus, and Shaw 1994). The agricultural sectors of other developed countries in temperate climates are expected to react similarly.

There have been many studies of climate change impact on agriculture in the United States and other developed countries (IPCC 1996a) but only two world-wide agricultural studies (Rosenzweig and Parry 1992 and Darwin et al. 1995). These world-wide analyses, however, have limited empirical evidence in developing countries. For example, Rosenzweig and Parry limit their inquiry to grains and Darwin et al. base their evaluation only on broad ecosystem types.

However, it is not clear what effect climate change will have on agriculture in the rest of the world because, agricultural systems are different in developing countries. These agricultural systems may be less adaptable, and tropical and subtropical ecosystems may respond differently to climate change. Developing countries may be more vulnerable to climate change than developed countries because of the low-capital intensity of developing economies, the incomplete markets, the predominance of agriculture and other climate sensitive sectors, and their relatively warm baseline climates. However, empirical research in developing countries is limited so these hypotheses have yet to be tested.

Further, no studies have measured what adaptation is likely to occur in developing countries. Recent research in the United States suggests that private adaptation is a critical

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component of climate change impacts (Mendelsohn and Neumann 1998). The absence of information about adaptation in developing countries consequently needs to be addressed.

This report provides information on a series of associated analyses done on the agricultural system in India. The analyses utilize available information in the country to estimate the climate sensitivity of agriculture. Although we apply methodologies developed in the United States, careful attention is paid (see next section) to adapting these methods to developing country conditions. For example, the studies pay careful attention to technological development, family labor, and incomplete cost data.

The analysis features the Ricardian approach which compares agricultural outcomes across farms under different climate conditions. It comprises background studies and Ricardian studies. Chapter 2 provides an extensive literature review that includes studies addressing also climate change impact on sectors other than agriculture. In Chapter 3 several Global Change Models (GCM) are employed to provide a range of temperature and rainfall values that may result from predicted changes in carbon dioxide levels in the future. Results from these GCM models are used later for simulation of Ricardian models' results. Each of the Ricardian studies emphasize a different methodology. The pooled data analysis (Chapter 4) examines long run response of farms to climate by Indian farming districts. The year by year analysis (Chapter 5) explains annual fluctuations in climate sensitivity by using regressions of a cross section of Indian agricultural districts for several years. This analysis measures how climate sensitivity varies from year to year in response to several variables, including prices, weather. The climate-technology study (Chapter 6) of Indian districts explores the role endogenous technology plays on farmer's climate sensitivity. The analysis examines whether technology has altered climate sensitivity and whether climate change might alter technical change..

In the next section, we briefly explain the methodology used in each chapter. In third section we summarize the overall results from India, and we conclude with some general policy observations and directions for continued research.

## THE ANALYTICAL FRAMEWORK

The analyses in the studies rely upon the Ricardian method, an empirical approach that was developed by Mendelsohn et al. (1994). The Ricardian model examines a cross section of farms (in the case of India the unit analysis is a district) across the studied country. India is a country large enough so that farms face a variety of climates. By examining the economic performance of farms across different climates, one can estimate climate sensitivity. Economic performance is measured, in the different studies, through annual net revenues. These economic welfare measures include expected effects such as differences in crop productivity, but they also include less obvious effects such as impacts on costs of fertilizer, pesticides, and operations.

The Ricardian analysis is a natural experiment, an experiment which occurs in nature and is not controlled by the researcher. One of the drawbacks of a natural experiment is that uncontrolled factors can bias the results. Bias will occur if the uncontrolled factor (such as land quality) is correlated with the variables of interest (in this case climate), affects net revenues, and is omitted from the analysis. In the Ricardian model, it is therefore important to try to measure and statistically control for variables which might affect farm value or net revenue and be correlated with climate. The analyses consequently include measures of soils, market access, solar radiation, technology, household labor, and capital. However, in all cases, these measures are not perfect so that some component of these variables may still be affecting the results. This is the primary weakness of the Ricardian method and paradoxically the strength of the production function approach. The production function models are largely based on controlled experiments done in laboratory and field settings so they are not subject to these same problems.

The most important advantage of this empirical cross sectional approach is that the measurements include private adaptation. Private adaptation entails changes that farmers make to adjust their operations to the environment they are in. Some of these adaptations increase productivity and some reduce costs. The issue this study addresses is whether there is evidence of adaptation of Indian farmers to changes in climate. If they do, the expectation is that they would change behavior in response to climate change.

A valid criticism of the Ricardian approach is that it has historically assumed no price effects. Past studies have assumed that prices will not be affected by any change in the exogenous variables, namely climate. With the US studies (e.g., Mendelsohn et al., 1994), the Ricardian analyses were largely limited to a single time period so that prices were virtually identical across the sample. By assuming zero price effects, the Ricardian models tended to underestimate damages and overestimate benefits (Cline 1996 and Mendelsohn and Nordhaus 1996). However, this bias was calculated to be small in most relevant examples of climate change (Mendelsohn and Nordhaus 1996). In the multi-year India study (Chapter 5), a repeated cross-section of districts is utilized which permits exploration of the role output prices play. The results suggest that prices do not explain much of the intertemporal variation in net revenues and their omission does not appear to significantly bias the climate coefficients.

Among the methodological and empirical difficulties addressed by the studies in this report we should mention several which have some more general implications:

1. Input prices are difficult to measure. Specifically, a great deal of the labor in developing country farms, such as in India, is provided by family members who are not paid competitive wages. We do not have a good measures of the amount of time the family members devote to farming. In order to control for household labor, dummy variables were included which identify farms which rely on household labor. Unfortunately, the farms which rely most heavily on family labor are also likely to be smaller, use more labor intensive technologies, and consume some or all of their production. It is consequently difficult to interpret the dummy variable.
2. Animal work is poorly priced. Although we have official prices for bullocks in India, these prices do not reflect the cost of keeping a bullock but rather simply the price of buying one. Since some areas grow bullock feed and others do not, we suspect that the cost of keeping a bullock might vary across India. Again, we proxy for the cost of bullocks by treating them as a fixed input and introducing bullocks per hectare as an independent variable.

Many farms are subsistence. Not only do these farms depend solely on farm labor, but they are largely the sole consumers of their own output. Subsistence farms thus face different input prices (depending on family size and wealth) and different output prices (depending on personal consumption and market access). The data from this study focuses on purchased inputs and sold outputs. We consequently believe the analysis captures only the market farm sector and does not represent subsistence farms.

## SUMMARY OF THE STUDIES' RESULTS

Reviewing, in Chapter 2, a wide range of the existing studies on agricultural impacts of climate change, reveals a number of useful insights, some of which are also reported in the studies in Chapters 4-6.

1. The overall impacts of climate change on global agriculture, even assuming large local impacts, is expected to be small when trade is incorporated.
2. Carbon fertilization could offset the harmful impacts of climate change so that yields may be only marginally affected.
3. Adaptation is likely to mitigate some harmful effects so that with carbon fertilization, yields are likely to increase at least in developed countries.
4. Less is known about the ability of developing countries to adapt to climate change so certain climate scenarios may still cause regional disasters even if global production is not affected.
5. Only the major grains, which favor cool temperate zones, have been extensively studied so the effects of climate change on the remainder of agriculture types remains uncertain.

The purpose of the study reported in Chapter 2 is to develop climate scenarios - based on the projections of several GCMs - to be used as input to an analysis of the impacts of potential climate warming on agriculture in India. The study uses the projections from three GCMs to develop projections of temperature and precipitation in India under a scenarion of doubling of $CO_2$ from pre-industrial levels. Three models used, the Geophysical Fluid Dynamics Laboratory (GFDL), the United Kingdom Meteorological Office (UKMO), and the Goddard Institute for Space Studies (GISS) models, as a basis for assessing the impacts of climate warming on the region.

The information produced by the GCMs indicates that the continued emission of trace gases into the earth's atmosphere will likely result in increases in both temperature and precipitation for India. While there will be significant spatial variation in the expected increases, data are presented for the country as a whole. Micro-scale modeling of climate systems is not advanced enough to make reasonable projections at a local scale, and the general projections must suffice. Solar radiation and evapo-transpiration likely will not change appreciably (or, at least, the models are inconsistent in their projections of these variables). Changes in soil moisture are unknown, since it depends on other factors besides the ones projected by the GCMs, including runoff, soil depth and percolation.

The three Ricardian studies of India (Chapters 4, 5, and 6) produce consistent results of climate change impact on Indian agriculture. All three studies find Indian agriculture sensitive to warming. Specifically, the studies find that net revenues fall precipitously with warmer April's but also are sensitive to warmer January and July temperatures. Crop revenues increase with

October temperatures. Net revenues are also sensitive to precipitation, but the effects are smaller and offsetting. Wetter January's increase farm values and wetter April's reduce farm values. July and October effects are small. Because the effects across seasons are small and offsetting, changes in annual precipitation have little effect.

The pooled analysis (Chapter 4) suggests that climate change will have an overall negative impact on Indian agriculture. A warming scenario of +2.0°C rise in mean temperature and a +7% increase in mean precipitation levels will create a 12% reduction in net revenues for the country as a whole. Rising temperature is damaging and increasing precipitation is beneficial. These effects will vary by season and region. There are regional impacts from warming even within India. Coastal and inland regions of Gujurat, Maharashtra, and Karnataka are most negatively affected. The high-value agricultural regions of Punjab, Haryana, and Western Uttar Pradesh show a small loss. The agriculturally low-value, hot and dry districts of Rajasthan and Central India are negatively impacted. Districts in many Eastern states (Andhra Pradesh, Orissa and West Bengal), however, benefit mildly from warming. These regional outcomes are largely caused by initial climate differences between regions.

The repeated annual analysis (Chapter 5) measures a lower climate sensitivity than the results in Chapter 4 due to a different data set used. A warming scenario of +2.0°C rise in mean temperature and a +7% increase in mean precipitation levels will create an 8% reduction in net revenues for the country as a whole. The repeated analysis reveals also that estimated climate sensitivity varies from year-to-year. For example, annual marginal effect of temperature alone varies between -150 and +280 Rs/ha, while inclusion of weather reduces the variance to values between -100 and +100 Rs/ha. Although the average effects reported above continue to hold in most years, there are exceptions when warmer January and July temperatures appear to be beneficial. Combining effects across seasons, there are four years between 1970 and 1986, where warming appears beneficial (1974, 1976, 1978, and 1984). Neither annual weather nor annual prices can explain all of this intertemporal variation.

The climate-technology analysis (Chapter 6) introduces endogenous technical change into the model. Technical change was measured by three variables, namely, intensity of modern high yielding varieties, intensity of multiple cropping, and irrigation intensity. It was found that technology and climate interact to affect net revenue in agriculture in India. Climate affects technical change: warmer areas generally have less irrigation and modern varieties but a little more multiple cropping. Wetter areas have less irrigation, modern varieties, and multiple cropping. These results are consistent with the general observation that the most significant technological improvements have come in areas which are more temperate. However, the overall effect is small so that warming is not expected to have a substantial impact on modernization. A simulation of a combined warming scenario of +2.0°C rise in mean temperature and a +7% increase in mean precipitation levels will create a 35% reduction in net revenues for the country as a whole. Also examined in Chapter 6 is the question whether technical change has altered climate sensitivity. It was found that higher levels of technology can help reduce sensitivity to warming but may increase damages from increased rainfall. However, the magnitude of these effects is small, so that technological change has not really affected the climate sensitivity of agriculture in India.

## CONCLUSION

Ricardian models were estimated for India and Brazil in order to determine the climate sensitivity of agriculture in both countries. The results of our Ricardian investigation of the climate sensitivity of Indian agriculture confirms that agriculture in both countries is sensitive to warmer temperatures. However, the analyses suggest that the climate response functions are not very different from the estimated function for the United States. The slightly more harmful effects found in India and Brazil are due to the warmer baseline conditions in these more tropical countries.

The Ricardian model, which captures farmer adaptation, predicted much smaller damages to agriculture, compared with other approaches reported in the literature. The results suggest that farmer adaptation will mitigate from 40% to 60% of the potential damages from warming. In addition to farmer adaptation, there is also a possible research response to warming. However, the study of technical change indicates only a small interaction between climate and technical change in the past.

These results suggest that overall, warming will hurt agriculture in India relative to temperate countries. However, with the mild climate scenarios predicted for the next century, carbon fertilization, and private adaptation, these effects are likely to be small.

One important policy implication that emerges from our analysis, given the important role of private adaptation, is that governments should encourage private adaptation. Private adaptation is expected to be efficient and imposes no burden on the public budget. Measures may include development and dissemination of new technologies and practices.

Although the analyses reported here provide some important initial insight into the climate sensitivity of a developing country economy, additional analyses are needed. For example, little is known about subsistence farming and what will happen to the poor families dependent on local climate conditions. Future biological research would probably have to be focused more specifically on warming for it to affect climate sensitivity. Agricultural studies should also be conducted in other regions of the world which have not yet been studied.

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