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An Annotative Bibliography of Research on the Economic Effects of Climate Change on Agriculture

by

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Introduction

Anthropogenic emissions of carbon dioxide and other "greenhouse" gases have the potential to substantially warm climates worldwide. While the timing and magnitude of global warming is uncertain, scientists on the Intergovernmental Panel on Climate Change (IPCC) predict that average global temperature may increase by 1.5-4.5°C (2.7-8.1°F) over the next 100 years. Changes in precipitation will likely accompany any changes in temperature. However, the magnitude, and even direction of these changes is difficult to predict with much confidence on a regional basis.

The agricultural sector may be profoundly affected by future changes in temperature, precipitation, solar radiation, and carbon dioxide concentrations. Over the past decade, there has been a growing body of research examining the potential impacts of climate change on agriculture. The purpose of this paper is to report and summarize recent research on the potential economic impacts of global climate change on agriculture. To that end, an annotative bibliography of articles is presented in this paper.

This paper does not summarize all of the manuscripts that have been written on the potential economic impacts of climate change on agriculture. Thus, no claims are made that this is a comprehensive review. For the most part, the articles summarized in this paper are published works in either books, or in academic journals. While the review is not all inclusive, this paper does present a sizable and representative survey of the literature on this topic.

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The summary of papers that follows are presented in alphabetical order according to the lead author's last name. This is followed by a summary of the manuscript, which usually includes its purpose, methodology, uniqueness, key findings, and policy and/or research recommendations. Finally, a listing of related papers, if there are any, is presented.

Literature on the Economic Impacts of Climate Change on Agriculture

Adams, R.M., B.A. McCarl, D.J. Dudek, and J.D. Glyer. "Implications of Global Climate Change for Western Agriculture." Western Journal of Agricultural Economics. 13(December 1988):348-56.

This article explores possible economic implications of climate change for western U.S. agriculture. Climate data from two general circulation models (Goddard Institute of Space Studies-GISS; and Princeton Geophysical Fluid Dynamics Laboratory-GFDL models) are used to simulate agronomic and economic impacts of climate change due to a doubling of atmospheric CO_2. Changes in both irrigated and dryland crop yields under each changed climate scenario are computed using CERES crop growth simulation models. Changes in regional crop yields are used with a spatial equilibrium model to simulate climate change effects on regional agricultural patterns. The economic model is also run under a variety of scenarios that include technological change, increases in demand for agricultural commodities, and inclusion of the direct effects on crop yields of CO_2 enrichment. The base results (no change in technology, demand, or direct CO_2 fertilizer effect) are highly dependent on climate scenario: the GISS climate scenario results in a $5.8 billion loss in economic surplus, or 5% of the 1982 value of U.S. crop and livestock commodities. The harsher GFDL climate scenario results in a $33.6 billion loss in economic surplus, or 28% of the 1982 value of U.S. crop and livestock commodities. However, in even the most extreme scenarios, food security is not an issue for the U.S. The authors contend that consumers will pay slightly higher food prices, but domestic production will more than meet domestic needs. According to the results, U.S. exports experience a major reduction, however. Since the rest of the world is treated exogenously in this study, the effects of climate change on U.S. agricultural trade are uncertain. Improvements in technology and/or the inclusion of a direct CO_2 effect drastically mitigate the negative effects of climate change for the U.S., while increases in demand make the negative effects more severe.

Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Ritchie, B.A. McCarl, J.D. Glyer, R.B. Curry, J.W. Jones, K.J. Boote, and L.H. Allen, Jr. "Global Climate Change and U.S. Agriculture." Nature. 345(May 1990):219-24.

This study links models from atmospheric science, agronomy, and economics to investigate potential agronomic and economic impacts of climate change on U.S. agriculture. The results from two general circulation models (Goddard Institute of Space Studies-GISS; and Princeton Geophysical Fluid Dynamics Laboratory-GFDL models) are used to simulate agronomic and economic impacts of climate change due to a doubling of atmospheric CO_2. To simulate the agronomic effects on crop yields, crop yield simulation models (SOYGRO, CERES-Maize, and CERES-Wheat) are used for various regions of the U.S. The models are run assuming a direct CO_2 fertilizer effect, with photosynthetic rates for soybeans, wheat, and maize increased by 35%, 25%, and 10%, respectively. The authors also estimate changes in ground- and surface- water availability using a simple hydrologic mass-balance approach reflecting the interaction of evaporation, rainfall, and temperature predictions from the general circulation models. The economic impacts of climate change are estimated using the predicted yields with a spatial equilibrium model of the U.S. This model considers production, processing, domestic consumption, imports, exports, and input procurement for most crop and livestock commodities. The economic (and agronomic) results are highly dependent on the climate scenario: the GISS scenario results in a composite price decrease of nearly 20%, production increase of 9% for field crops and 6% for livestock, and an increase in economic welfare of $10 billion. The GFDL scenario results in a composite price increase of 34% for field crops and 8% for livestock, a production decrease of 20% for field crops and 2% for livestock, and a loss of economic welfare of over $10 billion. The amount of irrigated land in agriculture is predicted to increase, and the regional pattern of U.S. agriculture will change due to climate change. Another version of this paper is in the following source:

> Adams, R. M. "Global Climate Change and Agriculture: An Economic Perspective." American Journal of Agricultural Economics. 71(December 1989):1272-79.

Arthur, L.M., and F. Abizadeh. "Potential Effects of Climate Change on Agriculture in the Prairie Region of Canada." Western Journal of Agricultural Economics. 13(December 1988):216-24.

This article examines the potential impacts of long-term climatic change on Canadian prairie agriculture (the provinces of Alberta, Saskatchewan, and Manitoba). The study uses the double CO_2-induced changed climate scenarios from two general circulation models (GCMs): the Goddard Institute of Space Studies model (GISS), and the Princeton Geophysical Fluid Dynamics Laboratory (GFDL) model. To quantify potential yield effects under each climate change scenario, the study employs both physiological and statistical agroclimatic yield models. The economic impacts are computed by using the yield results for each scenario with a linear programming model which maximizes net revenue subject to physical, biological, and economic constraints for the sector. Crop prices are held constant at 1985-86 levels. It is unclear whether a direct CO_2 fertilizer effect is included in this study since the authors make no mention of it in this article. Both the agronomic and economic results vary considerable by region and climate scenario. Both scenarios predict average temperature will increase in all areas by 2.6 to 4.6ºC, in some areas the increase in precipitation is enough to compensate for the increased evapotranspiration. The percentage change in net revenues due to climatic change range from a 7% loss in

Alberta under one of the GFDL scenarios to an 8% increase in Saskatchewan under a different GFDL scenario. Since only two out of 12 combinations of climate scenarios and regions results in a loss in net crop revenue, the results suggest that climate conditions may generally be more favorable to most of the prairie agriculture in this region, provided that certain adjustments are made in response to the changing climate (e.g., earlier planting to take advantage of a 30-60 day longer growing season).

Brklacich, M., and B. Smit. "Implications of Changes in Climatic Averages and Variability on Food Production Opportunities in Ontario, Canada." Climatic Change. 20(January 1992):1-21.

The implications of changes in climatic averages and variability on food production in Ontario, Canada are investigated in this article. This analysis is among few that have looked at the implications of changes in climatic variability, which may have more important social implications than changes in long-term averages. The study uses the results of the Goddard Institute of Space Studies climate model under an assumed doubling of atmospheric CO_2. These results are superimposed onto monthly average climatic variables from 1951-80. The climate change scenario assumes the length of the frost-free season would increase considerably, total seasonal (but not daily) precipitation would increase, evapotranspiration would increase by more than the increase in rainfall, and annual variability of precipitation would increase. A crop productivity model is used to estimate the yield impacts of climate change on corn, soybeans, and wheat. The new yields are then used in a linear programming model to estimate net return and cropping pattern impacts. Other procedures are used to estimate regional and provincial impacts of climate change. Under the climate change scenario, average net returns increase by 24% due to an increase in corn production at the expense of soybean production, which is less profitable in the region. The results also indicate that annual variability in net revenue increases under the changed climate, due primarily to increased variation in precipitation. The changed climate also has regional ramifications, with an apparent gain for Northern Ontario and loss for Southwestern Ontario. While changes in averages for climate variables are found to have a modest impact on food production in Ontario, low precipitation levels coupled with climate warming would reduce food production below the current level.

Council for Agricultural Science and Technology. "Preparing U.S. Agriculture for Global Climate Change." Task Force Report No. 119. June 1992.

This report addresses the following question: can U.S. agriculture and forestry sustain more production and stash away more greenhouse gases in the future under a warmer climate characterized by more people and greater trade? The study looks at agricultural adaptation issues in great detail, concluding that the "public response should be to provide a wider and more flexible portfolio of assets for adaptation." The authors first present a baseline scenario of future agriculture without climate change, where it is concluded that U.S. agriculture will be able to accommodate demand for its products at reasonable social costs, but investments will be needed to improve efficiency in resources, particularly water. Next, the report looks at a climate change scenario using the historical evidence of technological change in U.S. agriculture as a context. If agricultural research follows similar directions as in the past, and if adoption of new technologies are encouraged, then most of the negative impacts of climate change should be mitigated. Farmers will adapt to a changed climate, but how they adapt will depend upon the severity of the impacts, and the technological and managerial options available. The authors argue that even under extreme climate change scenarios, e.g., analog of the Dust Bowl, simulations have indicated that production can be maintained due to the benefits of CO_2 fertilization, new technologies, and assuming water is available. While land resources will not be very limiting, water will become less available due to reallocation to non-agricultural uses regardless of whether there is climate change. Today, the U.S. irrigates one-seventh of harvested cropland, or one-third the value of crops. Expansion of irrigation in response to climate change will be difficult. The report concludes that policy makers should encourage adaptations so that the social costs of climate change are lessened. To this end, the authors recommend a diversified portfolio of ten agricultural assets the U.S. has to prepare for climate change. These assets include: land, water, energy, physical infrastructure, genetic diversity, research capacity, information systems, human resources, political institutions, and world market. Another article based on this report is:

> Drabenstott, M. "Agriculture's Portfolio for an Uncertain Future: Preparing for Global Warming." Economic Review Federal Reserve Bank of Kansas City. 77(Second Quarter 1992):5-20.

Crosson, P. "Climate Change and Mid-Latitudes Agriculture: Perspectives on Consequences and Policy Responses." Climatic Change. 15(October 1989):51-73.

This article examines the potential impacts of a doubled CO_2 climate on mid-latitudes agriculture. Unlike many previous studies, the author examines climate change in the context of future economic, demographic, and technological conditions, which will be very different from current conditions. Crosson feels that when viewed in this context, climate change will not have a serious negative effect on world agricultural capacity, but points out that the evidence is very "thin" for this argument. Instead, most of the impact of climate change will be on shifts in regional comparative advantage. Current research suggests a northward shift in the world's grainbelt of several hundred kilometers for every 1^{o}C increase in temperature. If true, and if the increase in temperature is on the higher end of the 1.5-5.5^{o}C estimated increase, the shift in the grainbelt would eliminate much of the wheat-maize-soybean producing capacity of the U.S., while increasing such capacity in Canada and the former Soviet Union. The article also points out needed change in policy to capture gains and minimize losses due to a changed climate. Crosson argues that the technological and institutional adaptation strategies need to be flexible to deal with climate change.

Easterling, W.E., III, P.R. Crosson, N.J. Rosenberg, M.S. McKenney, L.A. Katz, and K.M. Lemon. "Agricultural Impacts of and Response to Climate Change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region." Climatic Change. 24(June 1993, Special Issue):23-61.

Rather than using a general circulation model, this study constructs an "analog" climate from historical data for the 1930s to examine the potential impacts of climate change for the MINK region. This warmer and drier climate was superimposed onto two technological and economic scenarios, one reflecting current conditions (1984-87) and the other representing technical and economic conditions predicted for the year 2030. The impact of this climate on crop yields is captured using the EPIC model, and the direct effects of CO_2 enrichment based on laboratory experiments are incorporated. Under the worst case scenario, where there is no CO_2 enrichment and no farm-level adjustments to the new climate, production of corn, sorghum, and soybeans decrease, while dryland wheat production remains the same and irrigated wheat production increases for both the current and 2030 scenarios. About 80% of the negative effects from the analog climate is eliminated assuming farm-level adjustments with current technologies and CO_2 enrichment. For the 2030 scenario, there is actually a small increase in overall production given CO_2 enrichment and farm-level adjustments based on anticipated technologies for 2030. Animal agriculture is virtually unaffected by the analog climate, except for feed prices. For further information on the MINK study, see the special issue of Climatic Change (June 1993), which is devoted exclusively to the results of this study. Other versions of this article are in the following:

> Crosson, P. "Impacts of Climate Change on the Agriculture and Economy of the Missouri, Iowa, Nebraska, and Kansas (MINK) Region." In Agricultural Dimensions of Global Climate Change. eds. Kaiser, H.M., and T.E. Drennen, St. Lucie: St. Lucie Press, 1993.

Easterling, W.E., III, P.R. Crosson, N.J. Rosenberg, M.S. McKenney, and K.D. Frederick. "Methodology for Assessing Regional Economic Impacts of and Response to Climate Change: The MINK Study." In Economic Issues in Global Climate Change: Agriculture, Forestry, and Natural Resources. eds. Reilly, J.M., and M. Anderson, Boulder: Westview Press, 1992.

Kaiser, H.M. "Climate Change and Agriculture." Northeastern Journal of Agricultural and Resource Economics. 20(October 1991):151-63.

This article provides an overview of the economic impacts of climate change on agriculture. The article begins with a discussion of the scientific evidence on global climate change, with an explanation of the greenhouse effect, a presentation of the predictions of five general circulation models, and a discussion of the discrepancies in the results from these models. Next, the author looks at the results of three previous economic studies including a global, U.S., and farm-level study. The reader should gain a basic understanding of some of the empirical evidence on potential economic effects on agriculture from a changed climate. The article concludes with an agenda for future research needs. The author argues that there are important limitations in the physical and biological models used for impact analyses that need to be improved upon. The grid sizes of general circulation models, which are currently about as large as the state of Colorado, have to be reduced in order to capture smaller-scale climate factors. Also, improvements in the way these models represent land surfaces, clouds, and oceans need to be made. The author feels that more studies are needed on how climate change will impact the variability of climatic variables. Also, one of the most critical needs for crop simulation models is a better understanding of the potential positive benefits of CO_2 enrichment on crop yields, as well as the potential negative effects accompanying climate change such increased tropospheric ozone. In terms of economic models, the author contends that there is a need for more global studies and greater use of dynamic models that allow for economic, demographic, and technical conditions to change with the change in climate. The role of government programs in influencing agricultural adaptation, and the impact of climate change on irrigation supply and demand needs to be better understood as well.

Kaiser, H.M., and T.E. Drennen, eds. Agricultural Dimensions of Global Climate Change. St. Lucie: St. Lucie Press, 1993.

In addition to addressing the potential impacts of climate change on agriculture, this multidisciplinary book explores other social and scientific issues concerning agriculture and global climate change. The book includes 15 chapters written by scholars from a variety of fields. Topics include: current scientific evidence of global climate change; potential impacts on world and regional agriculture; contribution of agriculture to greenhouse gas emissions; status of international negotiations to formulate a response to the risk of climate change; ethical issues to guide the policy debate; and resolving communication problems between policy makers and scientists. The primary aim of the book is to give the reader a thorough understanding of the central issues surrounding this complex problem. The book summarizes relevant findings on potential agricultural impacts and contributions and points out key areas that need further research to clear up uncertainties. A unique feature is a discussion of why there are communication problems between scientists and policy makers on climate change research and policy, and suggestions for possible ways to reduce this communication gap.

Kaiser, H.M., S.J. Riha, D.S. Wilks, D.G. Rossiter, and R. Sampath. "A Farm-Level Analysis of Economic and Agronomic Impacts of Gradual Climate Warming." American Journal of Agricultural Economics. 75(May 1991):387-98.

This article explores the potential agronomic and economic impacts of gradual climate warming on a representative Minnesota grain farm over a 100 year period, 1980-2070. The analysis is based on a model that links a stochastic weather generator, dynamic crop simulation models, and a farm-level linear programming (MOTAD) model to simulate impacts on grain yields, cropping patterns, and farm-level profitability over time. Several climate warming scenarios are examined ranging from a mildly warmer and wetter climate to a more severe hotter and drier climate. One of the main contributions of this work is that it models climate change as a gradual, evolving phenomenon, where changes in temperature and precipitation are modeled dynamically. The agronomic results indicate that soybean and sorghum yields at this relatively cool location are not adversely impacted by all three climate change scenarios; in fact, both crops experience increases in yields over time due to adoption of later maturing, higher yielding plant varieties. Corn yields are found to be adversely affected by the more severe climate change scenario. Crop prices follow an opposite pattern, with corn prices (inflation adjusted) increasing, soybean prices remaining relatively stable, and sorghum prices declining over the 100 year simulation. In terms of farm profits, the Minnesota model farm is better off under all three climate change scenarios, than under no climate change. This study finds that Minnesota farmers can effectively adapt to a gradual changing climate (warmer and either wetter or drier) by adopting later maturing plant varieties, switching crop mix, and adjusting the timing of field operations to optimally respond to a longer growing season due to a warmer climate. An earlier version of this paper is in the following source:

> Kaiser, H.M., S.J. Riha, D.G. Rossiter, and D.S. Wilks. "Agronomic and Economic Impacts of Gradual Global Warming: A Preliminary Analysis of Midwestern Crop Farming." In Economic Issues in Global Climate Change: Agriculture, Forestry, and Natural Resources. eds. Reilly, J.M., and M. Anderson, Boulder: Westview Press, 1992.

Kaiser, H.M., S.J. Riha, D.S. Wilks, and R. Sampath. "Potential Implications of Climate Change for U.S. Agriculture: An Analysis of Farm-Level Adaptation." Paper submitted to Climatic Change. 1994.

This paper examines potential agronomic and economic impacts of several climate change scenarios on grain farming in the U.S. The analysis is based on a protocol that links climatic, agronomic, and economic models to form an integrated model. Three climate scenarios are investigated for their relative impacts on crop yields, cropping patterns, and farm-level profitability. The climate scenarios are simulated for representative farms in the states of Iowa, Illinois, Nebraska, Minnesota, Ohio, Georgia, and North Carolina. The agronomic results indicate that the mild climate scenario has little impact on crop yields and that farmers can adapt to increasing temperatures and precipitation by selecting later maturing varieties. Corn and soybean yields are negative impacted at all sites in the more severe climate scenario. Northern states are less severely affected by both climate scenarios in terms of soybean and sorghum yields. The economic results suggest crop prices are fairly sensitive to the rate and form of the assumed climate change scenario. Under the milder climate change scenario, corn prices (inflation adjusted) increase and sorghum and wheat prices decrease. Soybean prices increase, but at a lower rate than in the no climate change case. In the more severe climate change scenario, sorghum prices, as well as soybean and corn prices have the largest increase over time. Farm profits are lower under climate change than in the no climate change case. However, there is little difference in farm profits between the mild and the severe climate change scenarios.

Kane, S., J. Reilly, and J. Tobey. "Climate Change: Economic Implications for World Agriculture. Agricultural Economics Report No. 647. Economic Research Service, U.S. Department of Agriculture, October 1991.

This is a study of the potential impacts of global climate change on world agriculture. The study constructs a moderate climate change scenario in terms of crop yield changes throughout the world on the basis of previous agronomic studies. In addition, sensitivity analysis, with a broad range of possible crop yield changes for various countries, is conducted to determine how sensitive world and country production, prices, and economic welfare are to possible yield changes. The authors do not include a CO_2 fertilizer effect, nor farm management adaptation strategies in the study. Thus, as the authors point out, the results probably overstate the potential negative impacts. A partial equilibrium world agricultural trade model is used to simulate the impacts of various crop yield change scenarios on production, prices, and producer and consumer welfare. Under the moderate climate change scenario, there is a slight increase in world production, a slight decrease in composite price (-4%), and a marginal improvement in world economic welfare (0.01%). While the more severe yield change scenario results in gainers and losers, the authors argue that interregional adjustments in production and consumption would dampen the effects of climate change on world markets. Consequently, the economic impacts on domestic economies tend to be quite small even under severe yield reduction scenarios for parts of the world. Similar to other studies, the comparative static approach is used in this study, while factors such as technology, population, and income are not changed. As a result, the study isolates the impact of climate change solely on national and world agricultural markets. Various versions of this study can also be found in the following sources:

Kane, S.M., J.M. Reilly, and J. Tobey. "An Empirical Study of the Economic Effects of Climate Change on World Agriculture." Climatic Change. 21(May 1992):17-35.

Kane, S.M., J.M. Reilly, and J. Tobey. "A Sensitivity Analysis of the Implications of Climate Change for World Agriculture." In Economic Issues in Global Climate Change: Agriculture, Forestry, and Natural Resources. eds. Reilly, J.M., and M. Anderson, Boulder: Westview Press, 1992.

Tobey, J., J. Reilly, and S. Kane. "Economic Implications of Global Climate Change for World Agriculture." Journal of Agricultural and Resource Economics 17(1992):195-204.

Kokoski, M.F., and V.K. Smith. "A General Equilibrium Analysis of Partial Equilibrium Welfare Measures: The Case of Climate Change." American Economic Review. 77(June 1987):331-41.

This article is more of a methodological than empirical contribution to the literature. The authors use a computable general equilibrium model (CGE) to demonstrate that partial equilibrium welfare measures provide reasonable approximation of true welfare changes for large exogenous changes, where climate change is used to illustrate this point. Seven hypothetical scenarios are constructed based on the physical changes (e.g., crop yield changes due to climate change) predicted by previous studies, but are fed into the CGE model as percentage changes in input costs for each economic sector. For example, under Scenario 7, which represents a 2^{o}C temperature increase and 20% decrease in precipitation changed climate, unit costs of production for agriculture, energy, durables, and service sectors are assumed to increase by 42%, 9%, 10%, and 10% respectively. The CGE model predicts the following changes in commodity prices for this scenario: -12.8% for labor, -4.8% for land, -0.6% for capital, 5.0% for energy, -1.4% for chemicals, 5.4% for durables, -7.4% for construction, 1.1% for services, and 38.9% for agriculture. The authors contend that while their modeled economy does not represent a specific economy, the results imply that focusing on individual sectors only for measuring impacts from environmental change may produce erroneous results. Also, the distributional implications may be important and should therefore not be ignored.

Lewandrowski, J.K., and R.J. Brazee. "Farm Programs and Climate Change." Climatic Change. 23(January 1993):1-20.

This article examines the role U.S. farm programs could have on influencing the agricultural sector's ability to successfully adapt to climate change. The authors contend that current agricultural programs discourage such farm management adaptation strategies as altering crop mix (e.g., support prices of crops not well suited to the new changed climate, or provide disaster payments when crop fails, or prohibiting imports through import quotas), and investing in water conservation techniques (e.g., subsidize irrigation water). Because U.S. farm programs alter expected returns, as well as the risk associated with production decisions, the behavior of the farmer is also affected by these programs. Thus, while current programs would likely hinder farmer adaptation, these programs could be modified to encourage adaptation to climate change. Several modifications are suggested. The first would be to expand the flexibility provisions of the 1990 Farm Bill, which would lower output restrictions and thereby allow farmers to make crop mix decisions without effecting their level of support. Another change in policy is to remove institutional barriers to the development of a Western water market. Finally, the authors recommend basing disaster payments on a moving average crop yield over several years which include poor years. Thus, if climate change affects a specific crop more severely than others, this would get reflected in the yield base for disaster payments and would send a signal to the farmer to switch to another crop. An earlier version of this paper appeared in the following:

> Lewandrowski, J.K., and R.J. Brazee. "Government Farm Programs and Climate Change: A First Look." In Economic Issues in Global Climate Change: Agriculture, Forestry, and Natural Resources. eds. Reilly, J.M., and M. Anderson, Boulder: Westview Press, 1992.

Mendelsohn, R., and W.D. Nordhaus. "The Impact of Climate on Agriculture: A Ricardian Approach." American Economic Review, forthcoming, June 1994.

This paper examines the impact of climate factors on land productivity as measured by land price. The authors call this a Ricardian approach since it looks at the direct impact of climate on land values. The analysis is based on cross sectional data for almost 3,000 counties in the 48 contiguous states in the U.S. for 1982. Regression analysis is used with land price per acre as the dependent variable and a set of climatic, soils, and socioeconomic independent variables. Specifically, a quadratic functional form is fitted with the following climatic variables: monthly temperature and precipitation for January, April, July, and October. The independent variables capturing the impact of soil quality on land prices include: percent of land that is flood-prone, percent of land that is wetland, potential soil erosion of land, salinity of soils, whether soil is sandy or clay, and slope length of soils. Socioeconomic independent variables in the regression equation include: population density, net migration, and per capita income. Finally, the impact of solar energy on land prices is approximated by latitude and altitude variables. After fitting this equation, marginal analysis is conducted for temperature and precipitation. It is found that a 1°F increase in temperature for January, April, July, August, and annually leads to a -\$89.83, \$21.72, -\$166.30, \$158.36, and -\$76.06 change, respectively, for farm values per acre in the U.S. Generally speaking, an increase in temperature is only beneficial for agriculture in the Autumn of the year. Similarly, a 1 inch increase in precipitation for January, April, July, August, and annually leads to a \$50.25, \$108.51, \$4.18, -\$56.53, and \$26.58 change, respectively, for farm values per acre. Based on a 5°F increase in temperature, farm values would decrease by \$309 per acre and annual gross farm revenue would decrease by \$35 per acre. Using the 445.362 million acres of cropland in the U.S. in 1982, the impact of 5°F increase in temperature would be to lower farm values in the aggregate by \$137.6 billion and farm gross revenue by \$15.4 billion. These losses represent 24.7% of total farm revenue from crops and 39.4% of total farm values in 1982. Based on a 5% real rate of interest, the present value of the annualized impact on farm revenue is \$308 billion.

Oram, P.A. "Sensitivity of Agricultural Production to Climatic Change." <u>Climatic Change</u>. 7(March 1985):129-52.

This article examines the sensitivity of agriculture to climate change and other environmental factors for regions of the world. An assessment of current methods that measure the suitability of various regions for growing various crops is discussed.

Also, suggestions are made for how to simulate the impact of changes in climatic factors on productivity and location of crops and livestock. The author feels that if it takes 100 years for the earth's temperature to increase by 2^{o}C, then a gradual adaptation process is feasible and it may be possible to "cope with it on more than an emergency basis." A more important concern to the author is an increase in climatic variability that may arise from a changed climate. Current and past yield variability (in terms of coefficients of variation) for various regions and crops is discussed. Crop yield variability is already quite high due, in part, to weather variability and further increases in climate variability will have serious implications for agricultural production. The article concludes with a discussion of future developments that will play an important role in how climate change will impact society. The author believes that given current estimates for world population growth and a slowly changing climate, world agriculture should be able to meet world food demands. However, a rapid change in climate coupled with greater variability will cause a "difficult situation" for the next century. There is still room for yield improvements to mitigate negative consequences of climate change on agricultural production, especially in developing countries. Recognizing that there is a positive relationship between yields and yield variability, an important question for scientists to address is whether to develop new plant varieties that will maximize yield with the outcome of increased variability, or concentrate on minimizing yield variability with lower potential yields.

Parry, M.L., and T.R. Carter. "An Assessment of the Effects of Climatic Change on Agriculture." Climatic Change. 15(October 1989):95-116.

A summary of an international project on climate change impacts on agriculture in cool temperate and cold regions is presented in this article. The regions include Saskatchewan (Canada), Iceland, Finland, Northern Europe, former Soviet Union, and Japan. The paper summarizes two broad sets of experiments: (1) "impact experiments," which examine potential impacts assuming no adaptation to climate change; and (2) "adjustment experiments," which look at several adjustments to mitigate negative effects at the farm and government levels. Under the impact experiments, which are unrealistic but give an indication of key vulnerabilities, the following results are summarized. The length of the growing season and the rate of plant growth will both increase under climate change. For example, under the doubled CO_2-induced climate change predicted by the Goddard Institute of Space Studies model, the growing season increases by 4-9 weeks, and the maturation period for current varieties of spring wheat is reduced by 4-14 days in southern Saskatchewan. The article summarizes the potential impacts of this climate change scenario on yields for various crops in the cool temperate and cold regions. The article then examines four possible adjustments to climate change. The first simply involves changing crop mix to crops that are better suited to the new climate, e.g., switch from spring planted cereal crops like wheat, barley, and oats to winter varieties such as winter wheat. The second adjustment involves soil management strategies such as managing fertilizer applications (e.g., decreased applications in warmer and increased applications in colder conditions) and better field drainage. The third adjustment is to purchase new equipment, added labor, and increased storage facilities to increase grain production efficiency. Finally, off-farm purchases to compensate for climate change impacts on farm production is discussed as a strategy. The authors also briefly discuss regional and national responses to climate change, including changes in regional land-use allocation and changes in national agricultural policy.

Reilly, J.M., and M. Anderson, eds. Economic Issues in Global Climate Change: Agriculture, Forestry, and Natural Resources. Boulder: Westview Press, 1992.

The economic impacts of global climate change, as well as the economic forces contributing to this phenomenon are considered in this book. The book is composed of 26 chapters organized into seven major sections. Part 1 provides an overview of the science of global change, while part 2 considers several broader perspectives. The main emphasis of the book is on parts 3 and 4, which include 11 chapters that examine possible implications of global climate change for climate sensitive sectors including agriculture, natural resources, and forestry. Part 5 examines agriculture and climate change from an international perspective, including an analysis of Australia, Mexico, Europe, former Soviet Union, and Japan. A review and critique of previous chapters is contained in the three chapters that compose part 6 of the book. Part 7 looks at data and research priorities for future research. This is the first book, to my knowledge, that is devoted exclusively to economic issues regarding agriculture and global climate change. The types of analyses are diverse, ranging from empirical to theoretical, farm-level to global, and static to dynamic. In some studies summarized in this book climate change is treated as being exogenous, while others endogenize it using climate models. As a result, the book offers detailed analyses of climate change from a wide variety of perspectives.

Reilly, J., N. Hohmann, and S. Kane. "Climate Change and Agriculture: Global and Regional Effects using an Economic Model of International Trade." MIT-CEEPR 93-012WP, Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, 1993.

The authors of this study use a partial equilibrium world trade model called SWOPSIM (Static World Policy Simulation) along with the crop yield results of Rosenzweig et al. (1993) to determine the economic impacts of climate change based on the SWOPSIM model. All of the changes in yields under the three climate models from the study by Rosenzweig et al. (1993) are reported in the appendix of this report. Unlike Rosenzweig et al.'s economic model, SWOPSIM can summarize the economic impacts of climate change into changes in country welfare, as well as changes in prices and production. The results of this study are similar to Rosenzweig et al. (1993), which implies that the two economic models generate relatively robust results based on the same crop yield impact. The authors find sizable negative impacts in terms of global welfare in the case of no adaptation and no CO_2 fertilization, ranging from \$115.5 billion (in 1989 U.S. dollars) to \$248.1 billion, depending on climate change scenario. Inclusion of CO_2 fertilization, however, lowered these losses substantially with welfare losses ranging from $0.1 billion to $61.2 billion. When modest adaptation responses were factored in as well, these losses either became gains, or were further mitigated, depending on climate change scenario. A main conclusion of this study is that the change in a country's economic welfare due to climate change depends, in large part, on whether the country is an exporter or importer of agricultural commodities, and on the direction of domestic crop yield effects. Countries with substantial agricultural exports may gain from climate change if world prices rise as a result. Exporting countries that experience yield losses may actually have improved welfare if the increase in welfare due to increased export revenue more than offsets domestic losses in welfare due to higher prices. The authors also find that developing countries are generally worse off than developed countries due to climate change. For example, under no adaptation and no CO_2 fertilization, developing countries, in the aggregate, experience losses in economic welfare ranging from $89.6 to $173.1 billion, depending on climate scenario, which compares to losses of $13.4 to $17.6 billion for OECD countries. With CO_2 fertilization and moderate adaptation, developing countries experience losses in economic welfare ranging from $1.2 to $26.3 billion depending on climate change scenario, while developed countries have changes in welfare ranging from a $8.2 billion increase to a $11.4 decrease. The worst case scenario of no adaptation and no CO_2 fertilization would cause serious problems for developing countries in terms of malnutrition and starvation. However, the authors believe that the worst case scenario should be considered as the extreme bounds on potential negative impacts.

Rosenberg, N.J. "Adaptation of Agriculture to Climate Change." Climatic Change. 21(August 1992):385-405.

The author provides an overview of issues related to agricultural adaptation to climate change. It is argued that we currently lack adequate information on the direct physical and biological impacts on plants and animals, as well as the indirect effects on agriculture's resource base of water, soils, and genetics. Yet, there is still a benefit of studying a "realistic" range of climate change scenarios (from a variety of methods, e.g., general circulation models, paleo-climatic reconstruction, and historic weather records) and how they impact agriculture's resource base. The author points out several weaknesses in previous research, including: important spatial and temporal variations are ignored by examining uniform changes in temperature and precipitation over a large region imposed by general circulation model grid size; many studies have examined climate change impacts by imposing a changed climate onto today's world, which is inappropriate since the world will be different once we realize the changed climate; the complexity of agricultural systems and the linkages with the rest of the economy are often ignored; and the full range of possible adaptation strategies have not been explored, including autonomous adaptation (can be done within existing institutions) and institutional adaptations (requiring modification or replacement of existing institutions or policies). Next, the author discusses several possible adaptation strategies for agriculture, including longer season plant varieties, breeding new varieties in response to new climates, development of heat and drought resistant strains for major crop species, greater emphasis on moisture conserving tillage methods, improvements in irrigation efficiency, use of biotechnology to cope with climate change, and a switch from harvesting grain to harvesting edible bio-mass.

Rosenzweig, C., M.L. Parry, G. Fischer, and K. Frohberg. "Climate Change and World Food Supply." Research Report No. 3. Environmental Change Unit, University of Oxford, 1993.

This report is a summary of a three year study examining the potential impacts of global climate change on crop yields, agricultural production , food supply, prices, and the number of people at risk of hunger at the world level. The authors use the results of three general circulation models (Goddard Institute of Space Studies-GISS, Princeton Geophysical Fluid Dynamics Laboratory-GFDL, and the UK Meteorological Office-UKMO models) to construct three climate change scenarios due to a doubling of atmospheric concentrations of CO_2. To quantify potential impacts on crop yields, values for climatic variables from the general circulation model are used in crop yield simulation models in 18 countries for wheat, rice, maize, and sorghum. The yield simulations are run with and without a direct CO_2 fertilizer effect taken into account. Crop yield effects are then aggregated to national yield changes and used as inputs into a world food trade model to simulate economic effects. The study also includes several adaptation scenarios including no adaptation, and moderate and high levels of adaptation to climate change over time. In addition, there are also several scenarios based on differing economic growth levels, degrees of world trade liberalization, and rates of population growth. The results indicate that global grain production would fall by up to 5% under moderate farm-level adaptation, which is one of the more realistic scenarios. Climate change would worsen disparities between developed and developing countries, primarily since developed countries have more resources to adapt. Because the study predicts higher grain prices and reduced production, the number of people at risk of hunger would increase under climate change, even in the high adaptation scenarios. Various versions of this study can also be found in the following sources:

> Rosenzweig, C., and D. Hillel. "Agriculture in a Greenhouse World." National Geographic Research and Exploration. 9(1993):208-21.
>
> Rosenzweig, C. and M.L. Parry. "Potential Impacts of Climate Change on World Food Supply: A Summary of a Recent International Study." In Agricultural Dimensions of Global Climate Change. eds. H.M. Kaiser and T.E. Drennen, Chapter 5. St. Lucie Press: Florida, 1993.

Ruttan, Vernon W., ed. Sustainable Agriculture and the Environment: Perspectives on Growth and Constraints. Boulder: Westview Press, 1992.

This book summarizes a series of discussions related to the implications of global change for priorities on agricultural research in the 21st century. These discussions were held with a group of experts from the biological and social sciences at the Humphrey Institute of the University of Minnesota on November 27 and 28, 1989. Rather than a formal paper for each chapter, the chapters in this book are transcribings of the discussions that took place on a variety of topics, with each chapter having a discussion leader. A large part of this book is devoted to climate change issues. The first topic deals with what is actually known about climate change. The second topic discusses the impact of climate change on agriculture and natural resources. The third topic examines the implications of uncertainty due to global change for agricultural research priorities.

Sonka, S.T., and P.J. Lamb. "On Climate Change and Economic Analysis." Climatic Change. 11(1987):291-311.

The authors propose a conceptual framework for examining the social impacts of climate change based on an evolving change in climate and societal adaptations to it. Appropriate economic analysis should include the potential response of society to climatic change, including physical responses in the form of altered production practices and development of new technologies, as well as institutional and public policy responses. In addition to changing cropping patterns, other forms of farm-level adaptation that should be considered include: use of different plant varieties, tillage systems, fertilization rates, and irrigation. There are many public policy responses, including disaster compensation and subsidized insurance, while institutional responses include technological research and development. All potential social responses should be included in impact analyses. The authors suggest that impact analysis should also incorporate population growth and other societal changes since climate change will be a long-term phenomenon. The article then discusses the value of using integrated models to study potential impacts. In terms of crop yield models, the authors contend that plant growth simulation models have several advantages to other models because: (1) the effect of a changing climate can be explicitly linked to crop responses since these models use daily weather data; (2) the effect of changing climate variability, as well as changes in averages can be assessed; (3) the yield implications of new plant varieties adopted in response to a new climate can be examined; and (4) the use of such simulation models allows for evaluating new technologies by defining the new technologies in terms of altered genetic coefficients in the model. The output of plant growth simulation models can be used as inputs in farm-level decision models, which may have several different objectives, e.g., maximize profit, or multiple goals. The next component of a unified model is the market level, where total supply and demand for each crop is estimated. This component is necessary so that the price effect of climate change can be estimated, which then feeds back into farm-level decision models. In addition, the authors discuss the role of markets as institutions (e.g., capitalism vs. centrally planned economies) should be reflected in the model. Obviously, model linkage will be important since no single model can satisfy every consideration the authors list in this article.

Summary

The purpose of this paper was to report and summarize recent research on the potential economic impacts of global climate change on agriculture. To that end, an annotative bibliography of articles was presented. For the most part, the articles summarized in this paper were published works in either books, or in academic journals. While the review is not all inclusive, this paper presented a sizable and representative survey of the literature on this topic.

It is very difficult to form generalizations from these economic analyses of agricultural impacts from climate change. This is due to differences in climate change scenarios, crop yield models, spatial coverage, economic models, and various assumptions made among studies. Nevertheless, there are several observations that most would probably agree with. These include the following:

1. Climate change will have distributional impacts, with developing countries generally worse off than developed countries. Poorer countries have less

resources to invest in adaptation strategies, and their agricultural research bases are inadequate to deal with a change in climate. Also, developing countries have substantially lower per capita income than developed countries, and are therefore much more at risk to starvation and malnutrition particularly if climate change leads to major increases in commodity prices.

2. The impact of climate change (under a doubling of atmospheric CO_2) on economic welfare in developed countries may generally be rather small compared to national income. Developed countries, which tend to have substantial agricultural research capacities, will likely be able to adapt quite successfully to climate change. Under most analyses that predict higher commodity prices due to climate change, losses in consumer surplus in developed countries are typically offset by gains in producer surplus. Thus, total welfare losses are relatively small compared with national income.

3. The economic effects of climate change will be very different than the physical effects, as has been empirically demonstrated in most studies (e.g., Adams et al.(1990), Kaiser et al. (1993), Reilly et al. (1993), Rosenzweig et al. (1993)). Generally speaking, the economic impacts will not be as severe as the yield impacts due to market adjustments. One of the main conclusions of a report by Tobey et al. (1992) is that climate change-induced welfare effects on individual countries will not only depend upon changes in domestic yields, but also on changes in world prices, and the country's relative strength as an exporter and importer. With even large negative yield effects, the interregional adjustments in the world market may cushion the impacts on economic welfare.

4. Climate change will be evolutionary and gradual, as opposed to instantaneous. In this context, there will be change in other important factors as well (population, income, barriers to trade, institutions, political regimes) which may

have equally, if not more important impacts on agricultural markets than the change in climate.

5. Farmers and agricultural institutions will not stand by and do nothing if climate change has negative impacts on agriculture. Farmers will adapt to climate change by changing what they grow and how they grow it as long as such responses are more profitable than no action. Likewise, climate change will also induce institutional change, from changes in agricultural policy to new water markets for allocating water to agriculture vs. non-agricultural uses.

6. Adverse impacts of climate change on a region's agricultural supply will generally increase producer surplus for farmers as a group, and decrease consumer surplus. This is due to the fact that agricultural commodities tend to have relatively price inelastic supply and demand. This means that the percentage decrease in supply due to climate change will be accompanied by a greater percentage increase in price. As a result, the impact on producer surplus due to decreases in supply will be more than offset by increases in prices.

7. The results of the studies reviewed generally suggest that crop prices will increase due to climate change. While predicted change in prices due to climate change vary from study to study (and within study), they tend to be higher for corn and soybeans than for wheat and other coarse grains. These price increases are due to declines in overall production, particularly in the mid-latitude countries like the U.S., European Community, and Canada.