Testimony of:

John M. Antle
Professor of Agricultural Economics and Economics
Montana State University, Bozeman MT
Courtesy Professor of Agricultural and Resource Economics
Oregon State University, Corvallis, OR
University Fellow, Resources for the Future, Wash. D.C.

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Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to appear today to testify about the potential impacts of climate change on the farm sector. My name is John M. Antle and I am a Professor of Agricultural Economics and Economics at Montana State University in Bozeman, Montana. I also am a Courtesy Professor of Agricultural and Resource Economics at Oregon State University, and a University Fellow at Resources for the Future in Washington, D.C. I was first involved with research on the economic impacts of climate change while serving as a Senior Economist for the President's Council of Economic Advisers in 1990, and since then have conducted research on climate change impacts and greenhouse gas mitigation in the United States and in other regions of the world. I have also served as a Lead Author and Contributing Author to the Third and Fourth Assessment Reports published by the Intergovernmental Panel on Climate Change.

My testimony today is a brief summary of a longer publication that may be of interest to this Committee, available on the world-wide web (www.rff.org/News/Features/Pages/Climate-Change-Forcing-Farmers-to-Adapt.aspx**)**. That study reviews recent research on economic impacts of climate change, and discusses implications for U.S. agriculture's potential to adapt to climate change. That report was prepared for a research program at Resources for the Future – a non-partisan research organization in Washington, D.C. – on adaptation to climate change in agriculture and other sectors of the U.S. economy (http://www.rfforg/News/ClimateAdaptation/Pages/domestic_home.aspx).

The following are the main points I would like to emphasize:

- **Agriculture and the food system are likely to be impacted substantially by climate change and by policies designed to mitigate the effects of greenhouse gas emissions.** While these sectors are dynamic and have demonstrated capability to adapt to change, the economic impacts of climate change on agriculture and the food system are likely to be substantial. There are many important unanswered questions about the ability of agriculture and the food system to adapt to climate change. There are also important, unresolved questions about the effects of policies designed to reduce greenhouse gas emissions.

- **Studies of CC impacts have likely underestimated the impacts of climate change on agriculture and the food industry, and thus have underestimated the importance of possible adaptations in mitigating the effects of climate change.** Climate impact assessments of agriculture have been limited in scope and relevance because of limitations of the data and models used. For example, studies of production agriculture have not adequately accounted for impacts of pests and diseases on crops, and have not adequately addressed impacts on important climate-sensitive sectors such as specialty crops, horticulture, livestock, poultry and rangelands. The impacts of climate change on transportation infrastructure and the food processing industry, and the effects of greenhouse gas mitigation policies, also have not been studied adequately.
- **There is a need for a comprehensive assessment of the effects of existing and likely future policies on agricultural adaptation to climate chane.** Many existing policies are likely to affect the ability of U.S. agriculture and food sector to adapt to climate change. These include:
  - *Agricultural subsidy and trade policies* which reduce flexibility and have unintended consequences for global markets.
  - *Production and income insurance policies and disaster assistance.* While providing some protection against climate variability and extreme events, to some extent these policies also may reduce the incentive for farmers and ranchers to take adaptive actions.
  - *Policies encouraging soil and water conservation and provision of ecosystem services.* These policies protect water quality and enhance ecosystem services such as wildlife habitat, but also may reduce flexibility to respond to climate change by reducing the ability to adapt land use and to respond to extreme events.
  - *Environmental policies and agricultural land use regulation*, such as regulations for location and disposal of waste from confined animal production facilities, are likely to affect the costs of adaptation.
  - *Tax policies* affect agriculture in many ways, and could be used to facilitate adaptation, for example, through favorable treatment of capital depreciation and investments needed to offset greenhouse gas emissions.
  - *Energy policies and greenhouse gas mitigation policies* are likely to have many impacts on agriculture as a consumer and as a producer of energy. Development of new bio-energy production systems and greenhouse gas

offset policies may benefit agriculture and facilitate adaptation. The increased cost of fossil fuels associated with greenhouse gas mitigation policies will adversely affect incomes of farmers in the near term, in the longer term it will have the benefit of encouraging adaptation.

- **There is a potentially important role for the public sector to facilitate agricultural adaptation to climate change.** The substantial role that the public sector has played in making the complementary investments that led to the success of U.S. agriculture in the 20th century raises a number of questions about appropriate policies in the context of climate change. A key question for policy is whether climate change justifies an expanded role in these areas or whether markets can stimulate adequate responses to the adjustments that will be required as the climate changes. Examples of areas for public activity may be:
    - Estimation of adaptation costs and reassessment of impacts.
    - Breeding climate-resilient crop and livestock varieties.
    - Adaptation of confined livestock and poultry production to climate change and extremes, and development of resilient livestock waste management technologies.
    - Impact of climate change on insect pests, weeds and diseases and their management.
    - Effects of adaptation strategies on ecosystem services associated with agricultural lands.
    - Public information on long-term climate trends.
    - Assessing implications of energy policies and greenhouse gas mitigation policies for agriculture and the food sector.

Adaptation and Impact Assessment

Agricultural production and productivity depend on the genetic characteristics of crops and livestock, soils, climate, and the availability of needed nutrients and energy. Researchers use crop and livestock growth simulation models to analyze the possible impacts of climate change and increases in atmospheric carbon dioxide (CO_2) concentrations (known as *CO_2 fertilization*) on crop and livestock productivity. Temperature and precipitation, key drivers of agricultural production, operate on the highly site-specific and time-specific basis of the microclimate in which a plant or animal is located. Aspects of agriculture and food system impacted by climate change include:

- Soil and water resources
- Crop, livestock and poultry productivity
- Farm structure, income and financial condition
- Waste management for confined animal production facilities
- Ecosystem services from agricultural landscapes
- Food quality and safety

- Market infrastructure
- Food processing and distribution

Several methodologies have been used to estimate possible impacts of climate change on agriculture. Most studies use *integrated assessment* models, which combine process-based crop and livestock models that simulate the impacts of climate change on productivity with economic models that simulate the impacts of productivity changes on land use, crop management, and farm income. Some studies instead use statistical models based on historical data to estimate effects of temperature and rainfall on economic outcomes, and then use these models to simulate future impacts of climate change. Some of these integrated assessment models also link the farm management outcomes to environmental impact models to investigate impacts such as those on water use and quality, soil erosion, terrestrial carbon stocks, and biodiversity. The data presented here are derived from the recent U.S. assessment of climate change impacts on agriculture (Reilly et al. 2003), which used an integrated assessment model.

Research suggests that in highly productive regions, such as the U.S. Corn Belt, the most profitable production system may not change much; however, in transitional areas, such as the zone between the Corn Belt and the Wheat Belt, substantial shifts may occur in crop and livestock mix, in productivity, and in profitability. Such changes may be positive if, for example, higher temperatures in the northern Great Plains were accompanied by increased precipitation, so that corn and soybeans could replace the wheat and pasture that presently predominate. Such changes also could be negative if, for example, already marginal crop and pastureland in the southern Great Plains and southeast became warmer and drier. In addition to changes in temperature and precipitation, another key factor in agricultural productivity is the effect of elevated levels of atmospheric CO_2 on crop yields. Some studies suggest that higher CO_2 levels could increase the productivity of small-grain crops, hay, and pasture grasses by 50 percent or more in some areas (and much less so for corn), although these effects are likely to be constrained by other factors, such as water and soil nutrients. However, elevated CO_2 could also increase weed growth, and these adverse effects of climate change have not been incorporated into impact assessments.

According to the U.S. assessment study, the aggregate economic impacts of climate change on U.S. agriculture are estimated to be very small, on the order of a few billion dollars (compared to a total U.S. consumer and producer value of $1.2 trillion). This positive outcome is due to positive benefits to consumers that outweigh negative impacts on producers. Impacts on producers differ regionally, and the regional distribution of producer losses tends to mirror the productivity impacts, with the Corn Belt, Northeast, South, and Southwest having the largest losses and the northern areas gaining. The overall producer impacts are estimated to range from –4 to –13 percent of producer returns, depending on which climate model is used. Some statistical modeling studies have produced estimates of much smaller impacts on U.S. agriculture. For example, the study by Deschenes and Greenstone (2007) finds positive impacts on the order of 3 to 6 percent of the value of agricultural land and cannot reject the hypothesis of a zero effect.

Limitations of Integrated Assessment and Statistical Models

There are a number of significant limitations to integrated assessment models, as well as the statistical models, as discussed in detail in Antle (2009). One critical limitation of these modeling studies is the difficulty in quantifying the costs of adaptation. Whereas these studies have attempted to quantify the impacts of climate change on physical quantities of production and their economic value, few, if any, studies have attempted to quantify the costs of adapting to climate change. These costs would include adaptations to production agriculture, including additional research and development of crop and animal varieties, and changes in or relocation of capital investments such as crop storage infrastructure, confined animal facilities and waste management investments. If the rate of climate change were relatively high, implying that the costs of adaptation were also relatively high, then the net benefits of adaptation would also be lower, and less adaptation would occur. Consequently, contrary to many economists' arguments that adaptation is likely to offset much of the adverse impacts of climate change, it may be that if the costs of adaptation are high, the impact estimates assuming little adaptation may be closer to actual outcomes than the estimates that ignore adaptation costs.

In addition to their inherent model limitations, the impact assessments cited above do not consider many of the potential impacts of climate change on the food transportation, processing, and distribution sectors mentioned above. In particular, none of the impact assessments has considered the costs of relocating input distribution systems, crop storage and processing, or animal production, waste management, slaughter and processing facilities. Only recently have some studies begun to assess impacts of proposed GHG mitigation policies on production agriculture or on input production and distribution, output transport, or food processing and distribution systems. Recent experience with higher fossil fuel costs suggests that these impacts may be more important for farmers and food consumers than the impacts of climate on productivity. Thus, by largely ignoring possible impacts of future climate change mitigation policies, the impact assessments carried out thus far may have missed some of the most important long-term implications of climate change.

Policy Issues

The evidence on likely impacts of climate change on agriculture and the food sector suggest two aspects of policy that need to be evaluated. First, many existing policies affect agriculture and the food sector, and many of these policies are likely to affect adaptation. Climate change is not likely to be the focus of many of these policies, but it does make sense for policy design to take adaptation into consideration. Second, there may be a role for public policy in facilitating adaptation of agriculture and the food sector.

Policy Design and Adaptation

As yet there has not been any systematic effort to evaluate the effects of these existing policies on adaptation. Some examples of existing policies and their possible effects on adaptation are described here.

Agricultural subsidy and trade policies. Agricultural subsidy programs for major commodity crops such as wheat, corn, rice, and cotton, as well as trade policies such as the import quota on sugar, were established in the 1930s and continue today. The structure of these programs has changed over time, but a common feature is that they reduce flexibility by encouraging farmers to grow subsidized crops rather than adapting to changing conditions, including climate. In addition, because the United States produces a large share of many of these commodities, these policies have the unintended consequence of distorting global markets and discouraging an efficient allocation of resources in other parts of the world.

Production and income insurance policies and disaster assistance. There is a long history of both private and public crop and insurance schemes for agriculture and disaster relief programs. The most recent farm policy legislation, enacted in 2008, continued existing crop insurance subsidies, introduced a new revenue insurance program, and established a permanent disaster assistance program. These types of publicly subsidized crop and income insurance could be one way to address increasing climate variability and climate extremes associate with climate change. Whether this is an appropriate policy response to climate change is an open question that deserves further study. In any case, it is clear that public subsidies for crop or revenue insurance and disaster assistance, like other types of agricultural subsidies, will have the effect of reducing the incentive for farmers and ranchers to avoid adverse impacts of climate change through adaptation.

Soil and water conservation policies and ecosystem services. Over time U.S. agricultural policies have shifted from commodity subsidies towards a variety of policies that provide subsidies to encourage protection of soil and water resources and the provision of ecosystem services. For example, the Conservation Reserve Program, established in 1986 legislation, has led to more than 30 million acres of land being taken out of crop production and put into grass and tree cover through cost-sharing of conservation investments and long-term contracts providing payments to maintain conserving practices. While these policies protect surface water quality from soil erosion and chemical runoff, and enhance a number of ecosystem services such as wildlife habitat, they also reduce flexibility to respond to changes in climate over time, by reducing the ability to adapt land use, and also reduce the ability to respond to extreme events. For example, according to CRP rules farmers are not allowed to use CRP lands for grazing or to harvest grasses as animal feed. As a result, when severe droughts reduce availability of livestock feed in pasture and rangeland farmers are not allowed to use CRP lands for livestock, even though in many places this could be done on a temporary basis without substantially impacting environmental benefits of the CRP. In some cases the Secretary of Agriculture can waive these rules to allow grazing. Changes in program design, such as more flexibility in administrative rules, and better targeting of the policies towards lands with high environmental value, could facilitate adaptation.

Environmental Policies and Agricultural Land Use. Many environmental policies affect agricultural land use and management. Policies governing the management and disposal of animal waster from confined animal feeding operations are an important example that has clear implications for adaptation. Both state and federal laws regulate the choice of sites and management of these facilities. Changes in average climate and climate extremes are likely to impact the viability of these operations in some locations, for example where waste ponds become vulnerable to extreme rainfall events and floods. Environmental regulations raise the cost of re-locating facilities and thus have the unintended consequence of discouraging spatial adaptation. Including benefits of climate adaptation in regulatory design could lead to policies that achieve the dual goals of environmental protection under current climate and the need for adaptation to future climate.

Tax Policies. A wide array of tax policies affect agriculture, including the taxation of income and the depreciation of assets. Tax rules could be utilized to facilitate adaptation in a variety of ways, for example, by accelerating the depreciation of assets, and by encouraging investments that reduce greenhouse base emissions. However, creating such policies for climate adaptation alone may prove difficult to implement, since many other types of economic and technological changes may also lead to capital obsolescence and it may not be desirable to give favorable tax treatment in all such cases.

Energy Policies. The increasing public interest in developing domestic sources of non-fossil based energy, including biofuels, has already resulted in significant policy developments, such as subsidies for corn ethanol, and is likely to have important implications for both food and fuels prices and for adaptation. Further developments in biofuels could further change the way land is used for food and fuel production and have implications for adaptation, and will be impacted by related energy policies, such as requirements for use of renewable energy. Development of other types of energy technologies, such as the use of animal waste for energy production, may have important impacts on the adaptability of these systems and the way they are regulated (see the preceding discussion of environmental regulation).

Greenhouse Gas Mitigation Policies. Policies that constrain greenhouse gas emissions have the potential to affect agricultural operations as both emitters and as suppliers of offsets to emissions, depending on how such policies are designed and implemented. For example, recent legislative proposals have imposed some limits on the use of offsets, but also have excluded agricultural operations from emissions caps. Moreover, because agriculture and the food system are relatively intensive fossil fuel users, any policy that effectively raises the cost of fossil fuels will have potentially important impacts on these industries.

Policies to Facilitate Adaptation

The record shows that U.S. agriculture's success in the 20th century was dependent on complementary investments in physical and human capital and agricultural research and extension, many of them publicly funded through institutions such as the land grant universities. Moreover, complementary policies have fostered the conservation of natural resources and the adoption of more sustainable management practices. This experience suggests that that the U.S. agricultural sector is capable of adapting to a wide range of conditions and adopting new technologies as they become available. As long as the rate of climate change is relatively slow and predictable, we can expect the same to be true with future climate change. However, important questions remain about how effectively the sector could adapt to rapid changes in average climate or increases in extreme events.

The substantial role that the public sector has played in facilitating agricultural development raises a number of questions about appropriate policies in the context of climate change. The justification for public funding of infrastructure, research, and information systems was based on economies of scale as well as the public good aspect of basic research needed to develop agricultural technologies. Although a substantial public role remains in infrastructure, research, and outreach, it has diminished over time as private institutions have become increasingly capable of providing these services. A key question for policy is whether climate change justifies an expanded role in these areas or whether markets can stimulate adequate responses to the adjustments that will be required as the climate changes. Some examples of the key questions about adaptation and a possible role for public sector involvement follow:

- *Estimation of adaptation costs and reassessment of impacts.* As noted above, the impact assessments carried out thus far have largely ignored the costs of adaptation for the agricultural production sector and for the broader food industry. Besides biasing the conclusions of the impact assessments, data on costs of alternative adaptation strategies are needed to inform both private and public decision makers. Costs should be evaluated under alternative scenarios for the rate of climate change, climate variability, and the occurrence of extreme events. Thus far, most of the research effort has been devoted to the impact on grain crops. Much more research on impacts and costs of adaptation in other agricultural systems is needed, particularly for livestock and other economically important products, such as vegetable and fruit crops.
- *Identifying adaptation strategies and supporting basic research needed for development of adaptation technologies.*
    - Basic crop and animal research on vulnerability to extremes.
    - Breeding resilient crops and livestock varieties.
    - Research on effects of climate change on pests and diseases and their management.
    - Development of more resilient livestock waste management technologies, incorporation into biofuels production.
- *Identifying and estimating the vulnerability of ecosystem services to climate change and adaptive responses*. Agricultural land-use practices are known to have important impacts on the provision of ecosystem services. As yet, the impacts of climate change on ecosystem services have not been quantified systematically on

a regional or national basis. Research is needed to evaluate the effects of alternative adaptation strategies on ecosystem services.

- *Provision of public information about long-term climate trends and their economic implications.* There is a great deal of public information available on short-term weather forecasts, but there may be a need for more public awareness of long-term climate trends and forecasts. This information is a public good that may need to be supported with public funds.
- *Implications of climate change and mitigation policies for agriculture and the food sector.* As yet, virtually no research has been done on identifying and quantifying potential impacts or adaptation strategies for the food sector. Included in such an analysis would be costs of adapting the food distribution system to a warmer climate and potential impacts on the prevalence and control of food-borne pathogens. The dependence of this sector on fossil fuel–based energy also suggests that GHG mitigation policies could have substantial impacts on the national and global food system as it presently operates. As yet, none of these issues has been addressed in impact assessment studies.

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JOHN MICHAEL ANTLE

CURRENT POSITIONS:

Professor of Agricultural Economics and Economics, Montana State University, Bozeman
Professor of Agricultural and Resource Economics, Oregon State University (effective Sept. 2010)
University Fellow, Resources for the Future, Washington, D.C. USA

EDUCATION:

Ph.D., Economics, University of Chicago, 1980
M.A., Economics, University of Chicago, 1979
A.B., summa cum laude, Economics and Mathematics, Albion College, 1976

HONORS:

John Dillon Fellow, Australian Agricultural and Resource Economics Society, 2005
Distinguished Fellow, American Agricultural Economics Association, 2002
President, American Agricultural Economics Association, 1999-2000
Outstanding Journal Article Award, American Agricultural Economics Association, 1988
Gilbert F. White Fellowship, Resources for the Future, 1984-1985

PUBLIC POLICY AND PROFESSIONAL SERVICE:

Contributing Author, Fourth Assessment Report, IPCC, United Nations, 2006-2007
Lead Author, Third Assessment Report, IPCC, United Nations, 1999-2000
Member, Committee on the Human Dimensions of Global Change, NRC, 1997-2000
Member, Board on Agriculture, National Research Council, 1992-1997
Senior Economist, President's Council of Economic Advisors, 1989-1990

RESEARCH FUNDING:

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