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Theme Overview: Climate Change Economics

Jason F. Shogren

This thematic package in *Choices* celebrates the International Panel on Climate Change (IPCC) work, its Nobel prize and the significant contributions of agricultural and resources economists to the IPCC process and reports. These nine papers present work which overviews the major aspects of climate change and its implications for agriculture and natural resources written by people who have been intimately involved with the IPCC.

The researchers examine five major topics as they address climate change economics:

- Gerald North, a meteorologist, discusses the nature of projected climate change. North led a recent National Academy panel on climate change and has been an IPCC reviewer and provider of information.
- John Antle considers the relationship between climate change and agriculture; Rich Adams and Dannele Peck explore the implications of climate change and water. Antle and Adams were both IPCC lead authors.
- Steve Rose and Bruce McCarl consider the implications of emissions prospects for climate change and agricultural adaptation needs; both researchers were lead authors.
- Uwe Schneider and Pushpan Kumar examine the significance of emissions mitigation possibilities broadly; Cees Van Kooten addresses sequestration; Brent Sohngen focuses on deforestation; and Bruce McCarl on biofuels. Schneider was an IPCC contributing author and the rest lead authors.
- Gilbert Metcalf and John Reilly evaluate alternative policy approaches to climate protection; Reilly was an IPCC lead author.

After North sets the stage, the rest of the papers present the case that economics can make good climate change policy better, and can prevent bad policy from getting worse. Each paper addresses in its own way the three key ways economics can improve climate change policy. First, economics asks climate policymakers to distinguish a stock from a flow pollutant, and its relationship to damaged ecosystem services. Stock pollution is concentration -- the accumulated carbon in the atmosphere, like water in a bathtub. Flow pollution is emissions -- the annual rate of emission, like water flowing into the tub. Because risk comes from the total stock of carbon, policies should focus on projected concentration levels. Greenhouse gases remain in the atmosphere decades before they dissipate, so different rates of emission could generate the same concentrations by a given year. Policymakers have options about the concentration target to select and how fast they hit a given target.

Second, economists stress that alternative policy options should account for the carbon stock and flow relationship, the global public good, and flexibility to find low cost risk reduction mechanisms. The stock-flow recognition is important because a least-cost path starts slowly with a more rapid rate of emission reductions after several decades. This would allow for a natural rate of capital depreciation and the replacement of high-carbon energy sources (e.g., coal) for low carbon sources like wind and solar. The public good nature of climate change implies it is total global carbon that matters. This means that international cooperation is the key for effective abatement. Flexible economic incentive systems are needed for cost-effective strategies, usually advocated in the form of carbon taxes or carbon emission trading. Carbon taxes fix the cost of carbon, and allow the quantity of emissions to be determined by the private sector. Emission trading fixes the quantity of emissions and allows people to trade emission permits at a price set by the market.

Third, economics is needed to calculate the benefits and costs of action or inaction in climate policy. The research advocates efficiency in climate policy—society should assess both the benefits and costs of alternative climate policy options because all resources are scarce, whether they are human, physical, or natural. The benefit side should measure the gains from fewer emissions or by enhancing the capacity for adaptation or both; the cost side should estimate what society forgoes to pursue climate protection. The benefits and costs of international cooperation depend on the subjective/objective risk of a catastrophe, the degree of flexibility, and the origins of technological advance. If one believes catastrophe is not imminent, emission reductions can take a slower path toward stabilization. Regardless of the path, the degree of flexibility to follow this path affects costs. Flexibility is determined by the emission trading system, number of nations participating, and whether carbon sinks are included. Finally, the costs also depend on assumptions about the creation, adoption, and diffusion of new low-carbon technologies.

So take a few minutes to read this issue and help celebrate the role that AAEA agricultural and resource economists have and will continue to play in the IPCC's Nobel Peace Prize winning mission to better understand the risks created by climate change. And perhaps even more importantly think about how you can get involved in the IPCC's next Assessment Report process. The IPCC needs all the expertise we can provide.

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Future Climate of the Continental United States

Gerald R. North

JEL Classification: Q54

Agriculture will be influenced by future climate changes. In order to see these influences and examine their implications one must obtain a climate change projection. Climate change projections can be obtained from Global Climate Models (GCMs) run under scenarios that are forced by the drivers of the climate system. This paper will give a very brief summary of the GCMs and scenarios then present projections for the next half-century.

Climate Models and Their Reliability

The construction of global climate models (GCMs) began in the mid-seventies in parallel with the invention and proliferation of high-speed computers as well as the deployment of global observing systems such as satellite and measurements made directly in the atmosphere or ocean. The GCM is a physically-based numerical simulation model that includes the conservation of mass and water as well as momentum and energy. The dynamics of the oceans are coupled into the process. These models have descended from the numerical weather forecast models that date back to the 1950s.

Changes in climate are described statistically. For present purposes we are interested in the statistics of such quantities as temperatures and precipitation over large regions. The most important descriptive statistics include mean values averaged over say a decade and fluctuation indicators such as the variance and some extreme values. Some other specialized statistics include the frequency and intensity of hurricanes, El Nino events, etc.

Climate models strive to produce these statistics over historical periods when being validated and in the future under alternative scenarios for projections. The scenarios represent factors or "forcings" that affect climate. The most important climate forcing is the temporal evolution of the so-called greenhouse gases (GHGs) such as carbon dioxide, methane, nitrous oxide and many others. Concentrations of these GHGs have been observed directly for half a century, and measurements can be taken back 650,000 years by measuring the amount trapped in air bubbles in polar ice. Other important forcings include dust left high in the atmosphere and lasting a few years following some volcanic eruptions, changing sun brightness and aerosols (tiny particles floating in the air, some manmade).

Once a forcing scenario (e.g., steadily increasing carbon dioxide) is prescribed in the model simulation, feedbacks come into play to amplify or diminish the climate response. Globally the largest feedback is due to the response of water vapor to surface warming. When the surface warms, more water vapor evaporates and works its way high in the atmosphere and this forces even more climate change. The water vapor feedback roughly doubles the response to the forcings mentioned above. Other feedbacks include

- Ice/snow cover (albedo) effect, which makes the planet less reflective as it warms, thereby enhancing the warming.
- Clouds, which might amplify or diminish climate effects and pose possibly the largest uncertainties in current GCMs.

About 20 GCM modeling groups around the world simulate the climate response to various forcing scenarios for the reports produced every five years by the Intergovernmental Panel on Climate Change (IPCC). The GCMs unanimously agree that increases in GHG emissions have led to a steady increase in global temperatures. Comparing projections suggests that if carbon dioxide were doubled global level temperatures would increase by about 3 deg C (5.4 deg F) with a range across the models of about plus/minus 50%. At current rates of carbon dioxide emission increase (0.5% per year), the doubling will occur in 140 years. When other greenhouse gases are included the effective doubling occurs in about 70 years.

Across the GCM projections several important robust and relevant features emerge:

1) Global average temperatures increase with land areas leading ocean areas.
2) There is more warming toward the poles and less in the tropical areas.
3) Sea Level will increase by some 0.30 to 0.50 meters if there is no appreciable melting of the ice sheets on Greenland or the West Antarctic Peninsula.
4) Globally precipitation increases, but less than would be suggested by the rate of increase in atmospheric water content (relative humidity stays close to constant).
5) Most of the increases in precipitation are in the middle latitudes such as the northern tier of the contiguous United States, especially the Northeast. In the Continental United States expect more precipitation north of the Gulf of Mexico, less to the west of it.
6) Regions where the climate is considered 'tropical' will expand polewards with accompanying changes precipitation patterns (more on this later).
7) Mountain snow packs will shrink and last a shorter time into the spring leading to changes in river flows. Snow cover on grazing lands will begin later and melt earlier than at present.

How much faith should we put in these projections? Most outspoken criticisms of the model simulations seem to be based on other than scientific arguments. In the end we are forced to rely on expert assessments. In such a context the U.S. National Academy of Sciences has published many assessment reports in which the mainstream assertions in the last paragraph are endorsed. The most publicized and recent expert assessment comes from the 2007 IPCC's Fourth Assessment Report, abbreviated as the AR-4. The climate science component of AR-4 (Working Group I), made use of the 20 or so GCMs in assembling projections.

Climate Forcing Scenarios

In the AR-4 Working Group II Report Chapter 2, the IPCC discusses future scenarios. All scenarios reflect future population projections. Some scenarios consider paths that emphasize centralized planning and cooperation, while others take the way of regional differentiation. A variety of such scenarios are then used to generate future trends for greenhouse gas emissions and other human-originated forcings. These are then used in GCM simulations for the Twenty First Century. One important result is that through the year 2030 the simulated results are insensitive to which scenario is employed; but after that the results for different scenarios begin to diverge. Mean warming for the globe by 2090-2099 relative to 1980-1999 is projected to be 1.8, 2.8, and 3.4°C for three representative scenarios (B1, A1B, and A2).

- The B1 scenario is characterized by population leveling at 2050, a world economy that is service and information based, with clean technology.
- A1B contains a market oriented, rapidly growing economy with the same population path as B1 while technology employs well balanced sources of energy.
- A2 includes a population continuously increasing along with an economy that is regionally oriented and lowest in per capita growth with a technology that evolves the slowest with the most fragmented development.

Across these scenarios A2 is the most pessimistic and B1 the most optimistic in terms of heating due to greenhouse gas emissions. Since these three scenarios are fairly representative of the spread of global outcomes at the end of the century, we adopt them as our choices for investigating the regional rates of change over the next century.

Future Climate Projections for the Continental US

Following AR-4, Working Group II we divide the Contiguous US into regions as shown in Figure 1.

Figure 1. The regions used in describing climate change rates over the next century (adapted from AR-4, Working Group II, Chapter 2). (Published with the permission of the Intergovernmental Panel on Climate Change, see Carter et al., 2007)

Temperature Change (deg C per century) same as deg F per fifty years.

	DJF	MAM	JJA	SON
Western N. Amer.(WNA)	4 to 6	2 to 7	3 to 8.5	2 to 7.5
Central N. Amer. (CAN)	4 to 6	2 to 8	3 to 7	2.5 to 8
Central America (CAM)	1.7 to 4.5	2 to 4.5	2 to 5.0	2.5 to 5.0

Precipitation Change (% per century) half it per fifty years.

	DJF	MAM	JJA	SON
Western N. Amer.(WNA)	-5 to 20	-5 to +15	-15 to +10	-30 to +10
Central N. Amer. (CAN)	-10 to 10	-5 to +15	-20 to +10	-30 to +5
Central America (CAM)	-75 to -15	-60 to +15	-55 to +15	-35 to +20

The trends in temperature and precipitation and precipitation for different seasons are shown in the table (taken from figures in AR-4, Working Group II, Chapter 2:)

Recent research (Seager et al., 2007) completed too late to be included in the AR-4 suggests that the U.S. Southwest using the same AR-4 models will be particularly dryer perhaps to the extent that normal precipitation minus evaporation might compare with the record droughts of the 1930s and 1950s.

Summary

We can summarize the results most relevant to U.S. agriculturalists via the following statements. It is very likely that the Continental United States will be 30C (5.40F) warmer plus or minus 1.50C (2.70F). There are likely to be more heat waves with more mid-latitude drying in summer and an increased risk of prolonged droughts (and their consequences, fires, etc.). Precipitation in the United States will be mixed: a) the Eastern Sector will likely have more rain than now because mid-latitude storm tracks are likely to edge northwards. b) The Southwest is likely to be much drier as the storm tracks move northwards and the tropical summers experienced in that region are likely to be longer. Most models suggest that the multi-year swings of wet and dry periods will be more pronounced than those of today's climate. Sea level will rise a foot or two under the conservative assumptions that melting of the big ice sheets on Greenland and Antarctica does not accelerate catastrophically.

For More Information

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Climate Change and Agriculture: Economic Impacts

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JEL Classifications: Q1,Q2,Q3,Q4

Agriculture is arguably the most important sector of the economy that is highly dependent on climate. A large body of scientific data and models have been developed to predict the impacts of the contemporary and future climate. Since the first IPCC Assessment Report was published in 1990, substantial efforts have been directed toward understanding climate change impacts on agricultural systems. The resulting advances in our understanding of climate impacts have come from the collection of better data, the development of new methods and models, and the observation of actual changes in climate and its impacts. Such knowledge is critical as we contemplate the design of technologies and policies to mitigate climate change and facilitate adaptation to the changes that now appear inevitable in the next several decades and beyond.

This article briefly summarizes some of the key findings from the research on agricultural impacts of climate change, based on the recent IPCC Assessment Reports published in 2001 and 2007, and other recent work such as the recent U.S. assessment published in 2002 and the Council for Science and Technology report in 2004. In the remainder of this article, I discuss the substantial uncertainties that remain about actual and potential impacts of climate change on agriculture and its economic consequences. The paper concludes with some observations about linkages from impacts to policy.

The Current State of Knowledge

Early research on agricultural impacts led to some rather dire predictions of adverse impacts of climate change on food production, and the public perception that climate change may lead to global food shortages continues today. Although state-of-the-art at the time, the early predictions involved relatively simple data and methods, typically estimating the effects of increases in average annual temperature on yields of a limited number of crops at a limited number of locations, and extrapolating the typically negative effects to large regions.

With advances in data and models, most assessments of the impacts of climate change on agriculture predict that the world's ability to feed itself is not threatened by climate change. The most recent IPCC report on Impacts and Adaptation finds that climate change is likely to have both positive and negative impacts on agriculture, depending on the region and the type of agriculture. Overall, the report predicts that during the present century there will be a "marginal increase in the number of people at risk of hunger due to climate change." (Easterling et al. 2007, p. 275). However, research also shows that this finding should not lead to complacency, as analysis also suggests that some of the poorest and most vulnerable regions of the world are likely to be impacted negatively, and in some cases, severely.

One of the most important advances made in response to these early studies was to recognize that economic agents – in this case, farmers and the various private and public institutions that support agriculture – would adapt to climate changes in ways that would tend to mitigate negative impacts and take advantage of positive impacts. Another important advance in research was to recognize that there would be substantially different local, regional and global impacts. As data and modeling capability has improved, it has become increasingly clear that there are likely to be substantial adverse changes in some particularly vulnerable regions, such as in the semi-arid tropics, but there is also likely to be positive changes in the highland tropics and in temperate regions (Parry et al 2004). As a result, the adverse effects in some regions are likely to be reduced through international trade with other regions that have been positively impacted. Collectively the regional and global impacts are not likely to be large, and may even prove to be positive.

Impacts at the farm level include changes in crop and livestock productivity, which in turn will lead to changes in the most profitable production systems at a given location. Research suggests that in highly productive regions, such as the U.S. Corn Belt, the most profitable production system may not change much, but in transitional areas such as the "ecotone" between the Corn Belt and the Wheat Belt, substantial shifts in crop and livestock mix, in productivity, and in profitability may occur. Such changes may be positive, for example if higher temperatures in the northern Great Plains were to be associated with increased precipitation, so that corn and soybeans could replace the wheat and pasture that presently predominate. Such changes also could be negative, e.g., if already marginal crop and pastureland in the southern Great Plains 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 CO2 on crop yields. Some estimates suggest that higher CO2 levels could increase crop productivity substantially, by 50% or more, although these effects are likely to be constrained by other factors such as water and soil nutrients, particularly in the developing countries.

In the case of the United States agriculture, aggregate economic impacts of climate change are not expected to be large, although there will be important regional differences. Recent studies estimate that crop yield changes will tend to be positive, with some almost doubling, but most increasing in the range of 10% to 40% during this century. Regionally, the northeast, south and southwest benefit the least, and the upper Midwest and coastal Northwest benefit the most. In contrast, livestock production is expected to be reduced by 5-7% due to higher average temperatures. Economic impacts associated with agriculture in the United States appear to be positive overall, with estimates ranging from an annual loss of $0.25 billion to a gain of about $5 billion, depending on the climate scenario used, with consumers generally gaining from the increased productivity and producers generally losing. The regional distribution of producer losses tends to mirror the productivity impacts, with the Corn Belt, the Northeast and south and southwest having the largest losses (McCarl 2008).

The most vulnerable regions of the world are undoubtedly in the tropics, particularly the semi-arid regions where higher temperatures and reduction in rainfall and increases in rainfall variability could have substantially negative impacts, and in coastal areas that are likely to be flooded due to sea level rise. These impacts are likely to be most severe in isolated regions where transportation costs are high, incomes are extremely low, and most rural households are highly dependent on agriculture for their livelihoods and for their food. These adverse impacts are predicted to be most severe in parts of sub-Saharan Africa, and other isolated areas in southwestern and south Asia. Low-lying areas in south Asia, Indonesia, and other poor coastal regions are also likely to be severely impacted due to their vulnerability to sea level rise and a limited ability to adapt by moving to higher ground or making investments to protect vulnerable areas. As a result, the risk of malnutrition and hunger in the developing world, particularly in the highly vulnerable regions, is predicted to increase during this century (Parry et al. 2004).

Uncertainties

Despite the substantial advances in understanding of climate change and its agricultural impacts, many uncertainties remain. Of particular concern are some of the limitations of the general circulation models used to simulate climate changes, and the way those limitations may affect the predicted impacts of climate change on agriculture. Some of these limitations suggest that the generally optimistic predictions outlined above for the temperate regions of the world, may be too sanguine.

On the supply side, a critical limitation of GCMs is their ability to predict changes in climate with the spatial resolution needed to model impacts on agricultural productivity. As discussed in the companion article in this issue by Adams and Peck, changes in water availability are especially difficult to predict, particularly on the site-specific basis needed to quantify agricultural yield impacts. A related uncertainty concerns impacts on pests which are also highly sensitive to site-specific environmental conditions, and are not well-represented in the models used to predict yield effects.

Another key uncertainty that affects impacts on all biological processes, including agriculture, is the rate of climate change. The higher the rate of climate change, the higher will be rates of obsolescence of all types of capital, both produced and natural, and thus the greater will be the costs of adaptation be for farmers, the private sector providing technology and inputs to farmers, and for government institutions responsible for infrastructure and policy. A related, critical supply-side uncertainty is how technology will evolve so as to reduce impacts and facilitate adaptation. In the past, it has taken about 15 years to develop a new crop variety. A key question is whether biotechnology will speed adaptation and reduce vulnerability to drought, extreme temperatures and pests.

Another uncertainty on the supply side is the environmental consequences of adapting to climate change. One example is the increased pressures on water resources in arid regions. Another example could be the increase in population density and agricultural intensity in highland tropical areas where soils are often fragile and vulnerable to degradation.

On the demand side, impacts of changes in consumer incomes and in market infrastructure will be critical but highly uncertain factors. Given the predicted modest impacts of climate change on global food supply, the rate of economic growth is likely to be a key determinant of people's vulnerability to climate change. If the recent high rates of economic growth in many developing regions continues, vulnerability to the impacts of climate change will be modest. However, those regions that are not participating in this growth, such as parts of sub-Saharan Africa and isolated mountain regions in central Asia and Latin America, are at risk of greater vulnerability if local food production decreases and becomes more variable.

Conclusions and Policy Implications

While it is clear that climate change will affect agriculture in important ways, the evidence from the past several decades of research suggests that the aggregate impacts will be relatively small, but there will be important regional impacts, particularly in the poorest, most vulnerable parts of the tropics. Given the growing evidence that climate changes are taking place and that there will be substantial impacts on agriculture, there is a clear and compelling need for agriculture to adapt as discussed in the companion paper by Rose and McCarl in this issue of *Choices*. In addition, evidence suggests that agriculture could play an important role in mitigating greenhouse gas emissions as discussed by Schneider and Kumar. Thus, two key policy questions are related to the roles the public sector should play in facilitating adaptation and mitigation as discussed in Metcalf and Reilly.

To the extent that change is relatively gradual, all indications are that farmers in the industrialized countries such as the United States will be able to adapt through farm-level changes in crop selection, crop management, and appropriate capital investments. Likewise, the private sector technology supply industry should be able to effectively anticipate and plan for needed adaptations of crops, livestock, machinery and related capital equipment. One area where there is a clear need for public sector involvement is in public infrastructure, particularly ports and related transport facilities that may be adversely impacted by sea-level rise and changes in the geographic distribution of production. The more rapid climate change is, however, the more likely that there will be a need for public investment in adaptation research to complement private sector investments.

In the developing countries, there are many reasons why farmers and institutions supporting the agricultural sector will be less able to adapt to climate change than farmers and the food industry in the industrialized world, particularly in the poorest and most vulnerable areas. On the research side, the existence of climate change reinforces the already compelling case that can be made for public sector investment in agricultural research and outreach, for investment in physical infrastructure and human capital, and for strengthening both private and public institutions that support agriculture and rural development. General economic development will also play an important role by providing farmers and rural households with sources of income that are less dependent on climate than agricultural sources of income.

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Effects of Climate Change on Water Resources

Richard M. Adams and Dannele E. Peck

JEL Classifications: Q25,Q54

Climate change will affect water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation. This paper provides an overview of the projected physical and economic effects of climate change on water resources in North America (with a focus on water shortages), and a brief discussion of potential means to mitigate adverse consequences. More detailed information on this complex topic may be found in Adams and Peck (forthcoming) and in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4).

Global Climate Change and Precipitation

Models of climate change (GCMs) predict U.S. annual-mean temperatures to generally rise by 2° C to 3° C over the next 100 years, with greater increases in northern regions (5° C), and northern Alaska (10° C). Numerous other climatic effects are also expected. For example, U.S. precipitation, which increased by 5 to 10% over the 20th century, is predicted to continue to increase overall. More specifically, an ensemble of GCMs predicts a 20% increase for northern North America, a 15% increase in winter precipitation for northwestern regions, and a general increase in winter precipitation for central and eastern regions. Despite predictions of increased precipitation in most regions, net decreases in water availability are expected in those areas, due to offsetting increases in evaporation. A 20% decrease in summer precipitation, for example, is projected for southwestern regions, and a general decrease in summer precipitation is projected for southern areas. Although projected regional impacts of climate change are highly variable between models, the above impacts are consistent across models.

Global Climate Change and Water Resources

Additional effects of global climate change that have important implications for water resources include increased evaporation rates, a higher proportion of precipitation received as rain, rather than snow, earlier and shorter runoff seasons, increased water temperatures, and decreased water quality in both inland and coastal areas. The physical and economic consequences of each of these effects are discussed below.

Increased evaporation rates are expected to reduce water supplies in many regions. The greatest deficits are expected to occur in the summer, leading to decreased soil moisture levels and more frequent and severe agricultural drought. More frequent and severe droughts arising from climate change will have serious management implications for water resource users. Agricultural producers and urban areas are particularly vulnerable, as evidenced by recent prolonged droughts in the western and southern United States, which are estimated to have caused over $6 billion in damages to the agricultural and municipal sectors. Such droughts also impose costs in terms of wildfires, both in terms of control costs and lost timber and related resources.

Water users will eventually adapt to more frequent and severe droughts, in part by shifting limited water supplies towards higher-value uses. Such shifts could be from low- to high-value crops, or from agricultural and industrial to environmental and municipal uses. A period of delay is likely, however, because gradual changes in the frequency and severity of drought will be difficult to distinguish from normal inter-annual variations in precipitation. Economic losses will be larger during this period of delay, as compared to a world with instantaneous adjustment, but preemptive adaptation could also be costly given the uncertainty surrounding future climate.

Rising surface temperatures are expected to increase the proportion of winter precipitation received as rain, with a declining proportion arriving in the form of snow. Snow pack levels are also expected to form later in the winter, accumulate in smaller quantities, and melt earlier in the season, leading to reduced summer flows. Such shifts in the form and timing of precipitation and runoff, specifically in snow-fed basins, are likely to cause more frequent summer droughts. Research shows that these changes are already taking place in the western United States. Changes in snow pack and runoff are of concern to water managers in a number of settings, including hydropower generation, irrigated agriculture, urban water supply, flood protection and commercial and recreational fishing. Timing of runoff will affect the value of hydropower potential in some basins if peak water run-off occurs during nonpeak electricity demand. Energy shortages and resulting energy price increases will provide incentives to expand reservoir capacities or develop alternative energy sources.

If the runoff season occurs primarily in winter and early spring, rather than late spring and summer, water availability for summer-irrigated crops will decline, and water shortages will occur earlier in the growing season, particularly in watersheds that lack large reservoirs. Agricultural producers, in response to reduced water supplies and crop yields, will adjust their crop mix. Producers in irrigated regions might reduce total planted acreage, or deficit-irrigate more acres, to concentrate limited water supplies on their most valuable crops (e.g. onions and potatoes, rather than wheat and alfalfa). Producers in rain-fed regions might shift to crop species and varieties with shorter growing season requirements or greater drought tolerance, such as winter grains.

Cropping practices are likely to shift as well, perhaps towards reduced- or no-till technologies, which enhance water infiltration and conserve soil moisture, or towards irrigation technologies that are more efficient at the farm level (although not necessarily at the basin level). Producers may begin to supplement dwindling surface water supplies with groundwater resources, a response that has already been observed in many drought-stricken areas. These adjustments will mitigate a portion of private economic losses. They will also affect environmental quality, although the expected direction is more difficult to predict.

A shift in stream hydrographs to more winter flow may also disrupt the life cycle of cold water fish species, such as salmon, which depend on late spring flows to "flush" young salmon to the ocean, and on summer flows to moderate water temperatures. Unless winter runoff is captured and stored for late spring or summer use, fewer salmon smolt will survive migration and more frequent fish kills will occur from lethal stream water temperatures. Such environmental impacts will intensify debates about consumptive versus instream water uses, such as those ongoing in the Klamath and Platte River Basins.

Climate change is expected to affect water quality in both inland and coastal areas. Specifically, precipitation is expected to occur more frequently via high-intensity rainfall events, causing increased runoff and erosion. More sediments and chemical runoff will therefore be transported into streams and groundwater systems, impairing water quality. Water quality may be further impaired if decreases in water supply cause nutrients and contaminants to become more concentrated. Rising air and water temperatures will also impact water quality by increasing primary production, organic matter decomposition, and nutrient cycling rates in lakes and streams, resulting in lower dissolved oxygen levels. Lakes and wetlands associated with return flows from irrigated agriculture are of particular concern. This suite of water quality effects will increase the number of water bodies in violation of today's water quality standards, worsen the quality of water bodies that are currently in violation, and ultimately increase the cost of meeting current water quality goals for both consumptive and environmental purposes.

Rising sea levels could also reduce water quality and availability in coastal areas. Recent projections of sea-level rise by the end of the 21st century range from 19 to 58 cm. A more dramatic increase in sea-level, on the order of meters rather than centimeters, is possible, but most scientists consider it a low probability risk. For example, complete melting of the Greenland Ice Sheet or West Antarctic Ice Sheet would trigger such a large rise. Rising sea levels could affect groundwater quality directly via saltwater intrusion. Radical changes to the freshwater hydrology of coastal areas, caused by saltwater intrusion, would threaten many coastal regions' freshwater supplies.

Rising sea levels could also affect water availability in coastal areas indirectly by causing water tables in groundwater aquifers to rise, which could increase surface runoff at the expense of aquifer recharge. Water shortages will cause the price of water to rise, through monthly water bills or one-time connection fees for new homes and businesses. A sufficiently large price increase could affect the extent and pattern of urban growth throughout the United States. Costly water supply projects, such as desalination plants, pipelines, and dams will also become more economically attractive.

One final and important effect of the water resource impacts discussed above is the potential for more frequent and intense interstate and international water allocation conflicts. Water markets have the potential to prevent or diffuse such conflicts; however, the assignment of water rights to establish the market can create more conflict than it diffuses.

Coping With Changing Water Resources

Although subject to uncertainty, forecasts of climatic change offer a glimpse into possible future water resource impacts and challenges. Predicted impacts vary by region, but include increased temperatures and evaporation rates; higher proportions of winter precipitation arriving as rain, not snow; earlier and more severe summer drought, and decreased water quality. Water shortages, which currently result in substantial economics losses, will be more common in many regions because of these impacts. Such economic losses, which occur across a range of sectors, from agriculture to energy and recreation, have profound effects on local communities. More frequent shortages imply increased costs to society, although adaptation by water users will mitigate some portion of these costs.

Water resource users can reduce the negative effects of water shortages through a number of strategies. These include revising water storage and release programs for reservoirs, adopting crops and cropping practices that are robust over a wider spectrum of water availability, expanding and adjusting crop insurance programs (such as the Multi-Peril Crop Insurance program's Prevented Planting Provision), adjusting water prices to encourage conservation and the expansion of water supply infrastructure, and supporting water transfer opportunities. Damage from drought-induced wildfires can be minimized by using long range soil moisture forecasts to pre-position fire suppression resources and in the longer term, by changing land-use regulations to restrict development in areas facing increased fire risk.

The ability to anticipate and efficiently prepare for future water resource management challenges is currently limited, in part, by imprecise regional climate change models and long-term weather forecasts. Uncertainty about future climate conditions makes it more difficult to optimally prepare for and adapt to associated changes in water resource availability and quality. Imagine, for example, trying to prepare optimally for a water shortage when you are uncertain of when it will occur, how severe it will be, or how long it will persist. It may be tempting to make management plans based on the worst-case scenario; however, the opportunity cost of this "safety-first" approach can be high if the worst-case does not occur. Imperfect information ultimately increases the magnitude of economic losses (or reduce the magnitude of any potential economic gains) attributable to water resource changes.

Improvements in climate projections and long-term weather forecasts, such as forecasts based on the El Niño-Southern Oscillation phenomenon (ENSO), offer potential for reducing economic losses (or increasing economic gains) associated with climate change. More specifically, improvements in the ability to detect water shortages farther in advance, to more precisely forecast their location, intensity, and duration, and to use such forecasts to inform management strategies would enhance water users' confidence in regional forecasts, and their ability to efficiently prepare for and adapt to future water resource management challenges.

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Greenhouse Gas Emissions, Stabilization and the Inevitability of Adaptation: Challenges for U.S. Agriculture

Steven K. Rose and Bruce A. McCarl

JEL Classifications:Q1,Q54,Q58

The Intergovernmental Panel on Climate Change (IPCC) reports that climate change has occurred and is going to continue, driven by both past and future greenhouse gas (GHG) emissions. Mankind's emissions have grown by 70% from 1970 to 2004, and they are projected to increase by an additional 25% to 90% by 2030. GHG emissions have global and long-run atmospheric effects lasting decades to centuries, depending on the specific gas. The net climate forcing of GHGs has grown from preindustrial (circa 1850) levels of about 275 parts per million (ppm) carbon dioxide (CO2) equivalent to about 375 ppm today, and projected socioeconomic practices and growth could result in levels of 600 to 1550 ppm by 2100 (IPCC WGIII, 2007). Based on this data, the IPCC projects global average temperature increases of 1.1 to 6.4 degrees Celsius by 2090-2099 compared to 1980-1999 levels (IPCC WGI, 2007), with increases in CO2 concentrations the main driver, but other substances contributing as well.

Changing climate implies localized changes in temperatures, precipitation, extreme weather, and the potential for extreme events that could affect agriculture globally. U.S.farmers, for example, could experience longer growing seasons, increased frequency of heavy rainfall, reduced snowpack with consequences for water supplies, enhanced crop growth due to elevated atmospheric CO2, and increased frequency of droughts, pests, and crop and livestock heat stress. As found in the U.S.National assessment (Reilly et al., 2003), the net effect could be increased production that benefits consumers while putting downward pressure on farm incomes in the near-term as prices fall. However, larger changes in climate could result in negative effects and different distributional outcomes (for elaboration, see the papers in this issue by North; Antle; and Adams and Peck).

There are three broad approaches for managing climate change—

- Avoiding it, via mitigation of GHG emissions, i.e., reducing net GHG emissions, including increasing carbon sequestration (as discussed in the companion paper by Schneider and Kumar).
- Adapting to it, by learning to produce under a changed climate.
- Geoengineering that reduces warming by, for example, placing shields in space to reduce incoming solar radiation. Geoengineering approaches are extreme technological options that are typically presented in the context of preventing eminent catastrophic climate change impacts.

This paper discusses issues involved with GHG mitigation and climate change adaptation (see Keith, 2005, for a discussion of geoengineering).

Climate Stabilization

Substantial action is required to stabilize climate (IPCC WGIII, 2007; Clarke et al., 2007). For example, the IPCC indicates that stabilization at any level eventually requires net anthropogenic emissions to fall to very low levels, well below those of today (Table 1). Anthropogenic emissions can continue to rise with terrestrial and ocean carbon sequestration processes offsetting some emissions; however, eventually anthropogenic emissions must decline for stabilization, such that there are negative total net emissions (i.e., anthropogenic plus natural emissions minus sequestration is less than zero). The lower the stabilization target, the more anthropogenic emissions must decline to lower atmospheric concentrations of greenhouse gases. In addition, for achieving the lowest stabilization targets, given likely near-term projected emissions, it appears unlikely that we can avoid initially exceeding (or overshooting) the long-run stabilization level before declining to the prescribed stabilization target with rapid decreases in emissions.

The scenarios in Table 1 provide useful information on differences in emissions reduction timing and stringency for different targets. In general, the scenarios identify the lowest cost pathways for stabilization, but not the only pathways, given assumptions about future society, resource availability, and the climate and carbon systems. For example, under the most stringent stabilization targets (levels below 490 ppm, which would occur after 2100), CO2 emissions decline before 2015 and fall to below 50% of today's emissions by 2050. For somewhat higher stabilization levels (below 590 ppm), global CO2 emissions peak in the next 20 years (2010 –2030), followed by a return to 2000 levels by 2040. For higher stabilization levels (e.g., below 710 ppm), CO2 emissions peak around 2040.

The Inevitability of Adaptation

Society could decide to reduce GHG emissions in order to stabilize the climate. However, the climate will not respond immediately. The long atmospheric lifetimes of GHGs creates inertia in the climate system, which implies that it will take time for the climate to stabilize once atmospheric greenhouse gas concentrations stabilize. Even if atmospheric concentrations of GHGs could somehow be suddenly held constant, we would still be committed to global warming. For instance, if concentrations had been fixed at 2000 levels, the IPCC projects global average temperature would increase 0.3 to 0.9 degrees Celsius by 2090-2099 relative to 1980-1999, resulting largely from inertia in the ocean uptake of heat (IPCC WGI, 2007). Furthermore, given projected socioeconomic growth and sluggishness in shifting the energy system, the economic system is unlikely to be able to respond immediately.

Because of inertia in the climate and economic systems, adaptation by agriculture and forestry to some degree of climate change is inevitable. Climate change will certainly continue for some time regardless of the severity of action that is undertaken. How much agriculture and forestry will need to adapt depends on the level of mitigation, anticipated potential local climate change, capacity to adapt, and relative impacts on other regions.

Adaptation and Agriculture

Adaptation is nothing new for agriculture. Adaptation to climate, environmental, policy, and economic factors is a fundamental and ongoing agricultural sector activity. Production is highly dependent upon these factors, which vary substantially over space and time both in terms of long term characteristics and shorter run inter annual variability. As a result, managers have adapted existing production patterns and practices to regional climatic differences to the point where agriculture in Florida is quite different from that in Minnesota.

Observed regional differences in production such as these illustrate both the ability to produce under alterative climates, and the different sets of adaptation options that will be available—where Minnesota corn may expand North and Florida farmers may adopt crops more amendable to warmer conditions.

Forces such as evolving pest resistance to treatment methods; invasive species; changing consumer dietary preferences; competition for water from municipal and industrial forces, and changes in government policies, have required long-run adaptation of enterprise mixes and agricultural practices, and illustrate agriculture's capacity to adapt to long-run forces. A changing climate is likely to be another long-run force that changes relative prices and the profitability of different agricultural products and practices.

Forces such as pest and disease outbreaks, El Niño Southern oscillation events, droughts, and extreme events, illustrate agriculture's ability to adapt to events that occur on short time scales. While climate change involves a likely long term trend towards warming, the pattern over time will include variability and extreme weather events to which agriculture will need to adapt.

Agricultural adaptation to climate change will generally take the form of one or more of the following activities:

- Shifts in management practices (e.g. earlier planting dates, longer or shorter maturing varieties, shifting pest treatment methods, and cooling provisions for livestock).
- Changes in enterprises employed at a particular site (e.g. altering crop mix to use more heat toler-

Table 1: IPCC Climate Stabilization Scenarios

Stabilization level (ppm CO2-eq)	Global mean temperature increase above preindustrial at equilibrium (°C)	Year CO_2 emissions peak	Reduction in year 2050 CO_2 emissions compared to 2000 (%)	Year CO_2 emissions return to year 2000 level*
445 – 490	2.0 – 2.4	2000 - 2015	-85 to -50	2000 - 2030
490 – 535	2.4 – 2.8	2000 - 2020	-60 to -30	2000 - 2050
535 – 590	2.8 – 3.2	2010 - 2030	-30 to +5	2020 - 2060
590 – 710	3.2 – 4.0	2020 - 2060	+10 to +60	2020 - >2100
710 – 855	4.0 – 4.9	2050 - 2080	+25 to +85	> 2090
855 – 1130	4.9 – 6.1	2060 - 2090	+90 to +140	> 2100

Source: IPCC WGIII (2007)

* This column was estimated from Figure 3.17 of IPCC WGIII (2007).

ant crops; using more heat tolerant livestock breeds, and land use change including the abandonment of some agricultural land and conversion of new land).
- Adoption of new technology involving direct capital investment and or practice improvements developed by agricultural research (e.g., developing new plant/animal species or varieties, genetic improvements, water retention or application efficiency enhancing practices, improved tillage, better fertilization techniques and management, and improved pest management).

Some of these adaptation strategies can be characterized as autonomous adaptation, where farmers' current capacity and knowledge allows for responses that abate or exploit impacts, e.g., crop selection and changes in fertilizer or water management practices. Some adaptation strategies can be characterized as nonautonomous, or planned, adaptation. Planned adaptation refers to institutional or policy actions that facilitate adaptation to climate change, e.g., subsidy programs, extension, infrastructure development, and R&D investment. In the agricultural sector, four principal mechanisms facilitate both autonomous and nonautonomous adaptation:

- Research, including research by governmental/international research organizations, universities, and private companies, that develops improved and innovative agricultural inputs and production practices.
- Extension/training/outreach that provides training and facilitate diffusion of agricultural technologies and practices. This includes county-level extension, company marketing, and localized training.
- Informal producer networks that allow producers to share information plus observe and adopt practices of others.
- Government policies that help manage commodity risk, regulate market access, and develop infrastructure (e.g., irrigation).

U.S. agricultural production has shown that it can successfully adapt to a broad range of climatic conditions—from the irrigated areas of the High Plains of Texas and the dryland areas in the Midwestern Corn Belt. These productive areas are supported by substantial local research and technology diffusion efforts plus investment in appropriate technologies.

Agricultural capacity to adapt in the future will be defined by public and private investments and developments in the above mechanisms, which in turn enable autonomous adjustment by farmers, and the level of local climate change. If GHG emissions follow what are reasonable baseline projections, agriculture will likely be confronted with more challenging adaptation circumstances of more rapid and substantial changes in climate, weather variability, water stress, pest management, and extreme weather. This will place increased demands on agricultural research, extension and infrastructure (McCarl, 2007).

Economic Returns to Adaptation

A number of studies have investigated the economic value and nature of adaptation practices. For example, Adams et al. (1999) show that adjustments to planting date and variety can significantly reduce the economic impact of climate change, and find that changes in crop mix can change the estimated impact of climate change from a net loss to a net gain. In recent analysis, Reilly et al. (2003) consider adaptation to be an important element of U.S. agriculture's response to and net outcome from changes in climate. Reilly et al. consider a fairly comprehensive set of adaptation strategies (planting dates, shift in varieties, change in crop type, migration of production, irrigation, and input use) under different physical constraints (e.g., water and grazing/pasture supplies) and global market conditions. Finally, Seo and Mendelsohn (2007) show that adaptation in livestock production is worthwhile and likely.

These sorts of studies illustrate the benefits of adaptation, as well as the economic value of having and/or improving adaptive capacity to avoid or exploit climate change impacts. However, even with adaptation, individual farmers (in specific locations) may still be faced with less profitable production systems. The ability to adapt and minimize detrimental impacts will depend on the capacity to adapt and the level and rate of climate change. For additional discussion on adaptation in agriculture and reviews of the broader literature, see the IPCC's Working Group II report, Reilly et al. (2003), and Adams et al. (1999).

Challenges for Agriculture

The need for adaptation presents a number of challenges to the agricultural system, including the following:

- Climate change may eventually dampen crop and livestock yields and alter yield growth rates. Research investments may need to be increasingly devoted to maintaining productivity at a site rather than increasing productivity.
- Investments and capital intensive agricultural practices may need to spread to new locations. For example, climate conditions may increase the need for enhanced water management (i.e., irrigation) in areas where soil moisture is expected to decline due to increased temperature and or decreased rainfall. Such strategies may also be energy intensive and confronted with higher energy prices.
- Processing facilities may need to relocate with migrating cropping patterns.
- Extension activities may need to be broadened to include educational outreach and dissemination of adaptation strategies.
- Some currently productive areas

may become marginalized, thereby requiring broader economic adaptation, such as the development of other economic activities to support communities or the relocation of residents. While in other areas, there may be pressure to expand agriculture with consequences for conversion of natural areas or greater pressure on other environmental resources.

These challenges are likely to be greater for developing countries, as partially discussed in Antle's companion paper, where agriculture may be more susceptible to temperature and other climate changes, and institutions are lacking to support adaptation.

Climate change is inevitable and so will be the necessity for agriculture to adapt to climate change. The ability to adapt and minimize detrimental impacts will depend on the level of climate change and support for both autonomous and nonautonomous adaptation via research organizations, extension/training/outreach, informal producer networks, and government policies. Nonetheless, unique regional climate change and adaptation capabilities imply distributional implications. Some areas may become economically unproductive due to climate change, while some might adapt, and others might become productive for the first time.

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Greenhouse Gas Mitigation through Agriculture

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JEL Classifications: Q10,Q55,Q58

Greenhouse gas (GHG) emissions can be reduced or atmospheric GHGs sequestered to help reduce the future extent of climate change. Options to do this through agriculture have received increasing attention during the last decade. Some see agriculture as a potential low-cost provider of emission reductions in the near future with additional environmental and income distributional cobenefits. Others express concerns about agricultural mitigation efforts because of possible emission leakage and other environmental drawbacks. This article will not and cannot cover what is known about the whole gamut of the topic. Instead, it draws heavily on our experience and our role in the 2007 Intergovernmental Panel on Climate Change report on agriculture and mitigation (Smith et al. 2007). We focus on responses in the domain of technologies, economics, and subsequent impacts of agricultural mitigation covering mitigation strategies, mitigation potential, and possible externalities.

Mitigation Strategies

Agriculture produces primarily food and to a lesser extent fiber and other products. Emissions of GHG and sequestration[1] of carbon dioxide from agriculture are influenced by supply and demand for agricultural products, and farming technologies. Consequently, possible GHG emission mitigation options involve changes in these three aspects. However, given a growing and in part undernourished human population, global decreases in food supply are not desirable. Similarly, reductions in global fiber production would imply increased use of petroleum based, nonrenewable fiber sources and possibly increase emissions. The demand aspect for food relates to changes in human diets. Greenhouse gas emissions could be reduced by dietary shifts involving more local, more seasonal, less processed, and more vegetarian food. These options decrease emissions because they save energy used for transportation, processing, storage, and the metabolism of animals. To put the energy requirement of animal production in perspective, we computed land requirements per calorie by combining land requirements per kg food (Gerbens-Leenes et al. 2002) and nutritional energy contents in calories per kg food (FAO 2004). Results show that one thousand calories from beef, pork, wheat flour, and potatoes require about 9, 4, 0.4, and 0.3 square meters of land, respectively. However, these values should be interpreted with care because certain grasslands are only suitable for livestock and because proper human diets require more than carbohydrates. Diet changes could make a substantial contribution to greenhouse gas mitigation, especially in developed countries. In developing countries, such emission reductions are very unlikely because demand for livestock products grows as these countries become richer. And this trend might continue till 2050.

Most assessments of agricultural mitigation possibilities relate to changes in farming methods including a conversion from food production to alternative enterprises. The associated emission mitigation strategies are numerous and complex. Available direct options have been grouped into a) sinks or sequestration enhancements, b) emission reductions, and c) avoided emissions via replacement products or land use change prevention. Sinks can be interpreted as reversals of past agricultural emissions. They include carbon sequestration in soils and biomass achieved by changes in management or land use changes. Agricultural emission reductions comprise methane reductions from ruminant animals, manure, and rice fields; nitrous oxide emission reductions from fertilizer use and manure; and carbon diox-

1. *For more information on sequestration, see "A Perspective on Carbon Sequestration as a Strategy for Mitigating Climate Change" by G. Cornelis van Kooten in this issue.*

ide emission reductions from reduced fossil fuel combustion. Avoided emissions in other sectors include prevention of deforestation, substitution of biomass based energy for fossil fuel based energy or use of biomaterials to replace other emission intensive products. Energy replacement strategies generally distinguish biomass for direct combustion to generate electricity or heat and biofuel production replacing gasoline, diesel, and other transportation fuels. Biomaterial strategies comprise biopolymers, industrial plant oils, and plant based building materials. Biopolymers are substitutes for petrochemical polymers and can be processed into a wide range of plastic and packaging materials. Similarly, industrial plant oils can replace petroleum based lubricants. When used in non-confined outdoor settings, for example as chain saw lubricants, these biodegradable oils also reduce water pollution.

The societal desirability of possible agricultural options is strongly related to land scarcity and agricultural production intensities. Mitigation could be accomplished through intensification and extensification. Mitigation through intensification may increase emissions per hectare but could decrease total land requirements and therefore total agricultural emissions, although secondary environmental outcomes need to be considered. In addition, the released land can be used for greenhouse gas emission saving nonfood options. Mitigation through extensification involves a reduction in emissions per hectare. Total land requirements may increase slightly while still achieving a reduction in total greenhouse gas emissions.

Mitigation Potentials

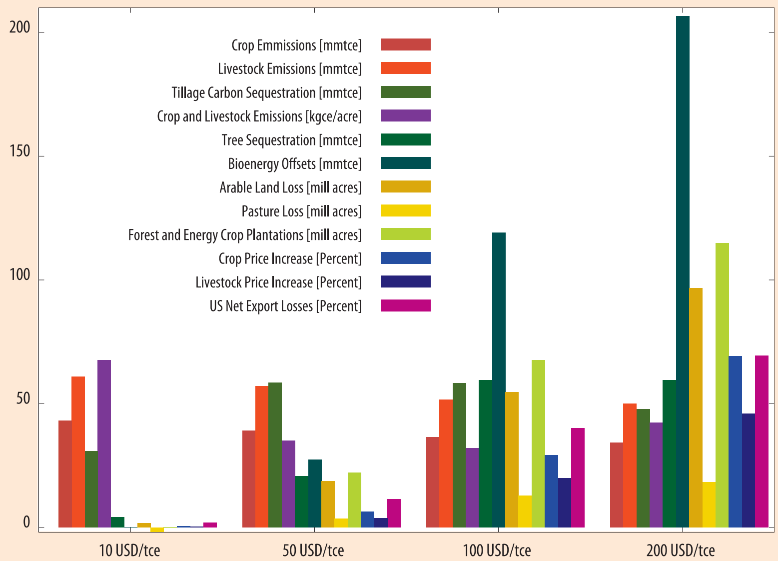
Now the question is what difference can agriculture make? Answers to this question usually involve measures of potential. The correct interpretation of such potentials, however, requires careful examination of the underlying data and methods. McCarl and Schneider (2001) found substantial differences between technical and economic potentials. Technical mitigation potentials give the greenhouse gas emission benefits from an exogenously specified change in technology. For example, one could assume that all cereal growers in the United States adopt zero tillage and compute the resulting carbon sequestration benefits as a measure of technical potential. Economic potentials specify the fraction of technical potentials that can be achieved at a certain economic incentive. For example, one could compute the likely carbon sequestration benefits in a scenario, where all U.S. cereal growers were offered a 20 USD per acre reward for using zero tillage. The resulting economic potential would then only include sequestration benefits from farms, where reduced tillage adoption would cost 20 USD per acre or less.

In examining agricultural greenhouse gas mitigation potentials in the face of the thousands of existing estimates, we will briefly cover general principals since differences in regional conditions and the scopes of assessments will always occur. First, since the greenhouse gas concentration concern is global, so should be the estimate of mitigation potential. This is discussed in more detail in the next section under leakage. Second, emission reductions should consider food production implications. If current or higher levels of food quantity and quality are to be sustained, fewer emissions can be mitigated than if quantity and quality decline. Third, emission reduction potentials of different individual mitigation options are interdependent. Many –especially land based– mitigation options are mutually exclusive. If individual strategy assessments are added up, the total mitigation potential may be substantially overstated (Schneider and McCarl 2006). Fourth, the heterogeneity of agricultural mitigation options implies that different strategies may be preferred in different regions. Fifth, agricultural mitigation estimates should take into account the whole spectrum of greenhouse gases. This is especially true because some available strategies, while giving huge benefits with respect to one greenhouse gas, may increase emissions of another. Wetland restoration may sequester large amounts of carbon dioxide but at the same time increase methane emissions. Similarly, while energy crops have beneficial carbon offsets they can lead to undesirable increases in nitrous oxide emissions (Crutzen et al. 2008).

The above principals imply that realistic mitigation option assessments need to take into account a diverse range of implementation costs including a) direct strategy costs pertaining to changes in input use and maintenance costs, b) opportunity costs from the use of scarce resources, c) transaction costs for policy implementation, and d) external social costs and benefits. These costs may change over the amount of mitigation effort. If a large cultivated area would be afforested, agricultural commodity production would decrease and prices for associated commodities would go up making additional afforestation more expensive. Transaction costs need to be considered and relate to monitoring, verification, and enforcement. The costs of verification include the impacts of uncertainties and vulnerabilities. Uncertainties are particularly high for methane and nitrous oxide emissions. Sequestered carbon, on the other hand, is vulnerable because wildfires or management changes can rapidly release the amount that has been stored. Risk averse preferences imply that uncertain and vulnerable emission reductions have a lower value than certain and permanent emission reductions.

Figure 1 shows policy simulation results from the U.S. Agricultural Sector and Mitigation of Greenhouse Gas Model (ASMGHG, Schneider and McCarl 2006) to illustrate the

Figure 1. Summary of Mitigation Incentives Impacts on U.S. Agriculture



complexity of agricultural GHG mitigation potentials. For relatively low emission mitigation incentives in U.S. agriculture, tillage based carbon sequestration dominates other mitigation strategies. Above incentive levels of 100 USD per ton of carbon equivalent (tce), the largest contributions come from exclusive mitigation strategies such as afforestation and bioenergy production. When traditional crop and pasture areas decrease, prices for crop and livestock commodities go up. As a consequence, emission intensities of traditional crop and pasture areas may increase as observed between incentive levels of 100 and 200 USD per tce. Decreasing net exports of agricultural commodities imply increasing production and associated emissions outside the United States unless foreign regions are subject to similar or higher GHG mitigation incentives.

Mitigation Externalities

Policies that encourage agricultural mitigation efforts result in intended and unintended external effects. There are several categories of unintended effects, which are briefly described below.

Offsite unintended greenhouse gas emission - also called emission leakage. When a climate policy regulates emissions in some countries, emission intensive production and accompanying emissions may shift to other countries, thereby increasing their emissions (Searchinger et al. 2008). More generally, emission leakage can span across geography, time, greenhouse gases, or technologies. The magnitude of emission leakage depends both on the scope of a climate policy and on characteristics of the chosen mitigation strategies. In principal, if mitigation strategies are neutral to agricultural commodity supply, leakage is negligible. Examples of relatively neutral strategies include carbon sequestration via reduced tillage, moderate crop residue use for bio-energy generation, livestock manure management, use of low-emission fertilizers, and crop-demand based fertilization. Land intensive mitigation strategies, on the other hand, have a high leakage potential because these strategies decrease traditional agricultural commodity supply and provide incentives to expand agriculture elsewhere. Thus, high leakage potentials exist for afforestation of agricultural land, dedicated energy crop plantations and wetland restoration.

Nongreenhouse gas environmental side effects include impacts on soil, water, ecosystems and ecosystem services. Impacts may be beneficial or detrimental. Because soil quality correlates positively with humus levels, soil organic carbon enhancing mitigation strategies are typically beneficial. Restoration of degraded lands and wetlands are examples. On the other hand, if mitigation measures reduce the amount of organic or mineral fertilizer input, soil quality will decrease. Such measures include crop residue removal for bioenergy generation and manure digestion. Water quality can also be impacted. Higher soil organic carbon levels improve moisture and nutrient holding capacities and thus, decrease nutrient emissions into surface, sub-surface, and ground water along with irrigation requirements. Fertilizer based mitigation options, which aim at minimizing excess fertilizer, are likely to reduce water pollution. On the other hand, if tillage reductions increase herbicide applications, water quality will decrease. Finally, mitigation efforts through intensification could lead to soil salinity, water-logging and biodiversity suppressing mono cropping as has been experienced in many parts of the developing world with the green revolution. Collectively these undesirable ecological outcomes undermine agricultural sustainability and societal well being.

Synergies and trade-offs with ecosystems and their services. Mitigation impacts the condition and resilience of cultivated and downstream ecosystems which in turn decide the flow of the ecosystem services critical for agricultural inputs and outputs (Millennium Ecosystem Assessment 2005). Overall, whether ecosystem coeffects are positive or negative depends foremost on how mitigation influences the size of nature reserves. The establishment of permanent native forests or restorations of wetlands are beneficial. But replacement of rainforest with homogeneous energy crop or tree plantations is generally not desirable. If mitigation efforts reduce agricultural intensities on grasslands, pastures, and croplands, some on-site ecological benefits are possible. However, intensity reductions can increase land scarcity and thus increase pressure on nature reserves elsewhere.

Social welfare externalities related to food, water, energy, health, employment, extreme events, and landscape. Food security deceases if agricultural mitigation efforts a) consume land suitable for food production, i.e. via dedicated energy crop plantations, wetland restoration, or afforestation; or b) lead to a reduction in land productivity, i.e. via crop residue removal or livestock manure digestion thereby decreasing organic fertilizers. Synergies between mitigation and food supply are possible through soil carbon sequestration on degraded farmland or nutrient increasing fish production on waste or degraded lands. Changes in global food production patterns are also likely to affect food supply and prices in turn altering malnutrition and obesity with attendant health implications

Water availability. Land intensive mitigation strategies lead to increases in irrigation intensities for traditional crops (McCarl and Schneider 2001). In addition, negative water impacts are expected from large-scale energy crop plantations (Berndes 2002).

Broader societal side effects. Land use change may alter recreational opportunities and civil protection. For example, restored wetlands may increase flood protection. Increased nutrients may degrade water quality. Provision of water storage facilities in arid and semi arid areas can contribute towards bioremediation.

Important Issues

Society can reap benefits from agricultural GHG mitigation options but there are several important issues that arise such as: Which of the complex array of alternatives should be used given regional variations, and uncertainties? Alternatively, what mitigation strategies should not be adopted by agriculture? For those considering these questions, we offer general remarks.

1) The best mitigation strategy mix would minimize the social costs of emission mitigation per unit GHG reduction. In achieving this note that inefficiencies arise if a) technologies are regulated instead of emissions, b) noncarbon greenhouse gas effects are excluded, c) environmental and societal side effects are ignored, and d) uncertainties, vulnerabilities, and irreversibilities are not properly integrated.
2) The complexity of land use impacts on food, water, energy, climate, and ecosystems calls for integrated assessments. Otherwise, today's solution may become tomorrow's problem.
3) Agriculture has a limited potential to provide low cost emission reductions. Higher emission mitigation targets are land intensive and due to land scarcity lead to substantial increases of marginal mitigation costs.
4) Emission leakage leading to increased deforestation of native forests or destruction of wetlands or other valuable ecosystems could become a serious drawback to agricultural mitigation efforts particularly those involving land use change and commodity production reduction. Irreversible biodiversity losses coupled with positive overall net emissions of greenhouse gases would essentially imply an environmental loss-loss strategy. Such situations could arise with unconditional promotion of dedicated energy crops or large-scale afforestation programs replacing croplands. Similarly, on-site greenhouse gas emission reductions from low input cropping systems may be more than offset through emission leakage.
5) Measures, which relax land scarcity, decrease the potential for emission leakage and negative environmental side effects. Such measures include supply side restorations of degraded lands and emission friendly yield improvements, along with demand side promotion of energy friendly diets.
6) Cost must be considered as often technical potential is much higher than cost effective potential particularly when considering transactions (implementation) and externality costs.

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A Perspective on Carbon Sequestration as a Strategy for Mitigating Climate Change

G. Cornelis van Kooten

The 1997 Kyoto Protocol includes, as a strategy for mitigating climate change, the option of removing CO2 from the atmosphere through biological carbon sequestration. This includes activities such as tree planting and land disturbance reduction that are commonly grouped under the abbreviation LULUCF (Land Use, Land Use Change and Forestry). Perhaps surprisingly, in the decade since 1997, such schemes have not been widely or appropriately utilized. However, LULUCF activities should only be included in a climate mitigation strategy under very restrictive circumstances. The objective in this paper is to bring perspective to the role in mitigating climate change of carbon sequestration through land use and forestry projects.

While there is no doubt that growing plants and trees remove CO2 from the atmosphere and store it in biomass or soils, this does not translate into unmitigated support for LULUCF as a source of carbon credits. There are many problems with LULUCF-generated offset credits, including:

- Measurement, monitoring and verification are difficult and costly;
- Carbon is not stored indefinitely (terrestrial carbon sinks are ephemeral);
- The time path of carbon uptake and future release is not easy to estimate or evaluate;
- Many projects cannot be considered 'additional' and would likely be implemented in the absence of climate concerns; and
- Indirect carbon and other greenhouse gas effects (leakages) are generally ignored.

As a result, it is extremely difficult to demonstrate that terrestrial projects truly generate the carbon credits that are claimed.

Suspect Sequestration Claims

The claims made by many LULUCF projects are suspect. Yet, many schemes claim to generate biologically-based carbon offset credits, including:

- In Australia for $40, Greenfleet will plant trees that "... will absorb the greenhouse gases that your car produces".
- In Scotland, Trees for Life uses the idea of a carbon footprint to solicit donations for tree planting: it offers "... you the chance to make a real difference and become Carbon Conscious."
- The Haida-Gwaii First Nation in British Columbia, Canada, intends to remove alder "growing in an unnatural manner" and replace it with the original mixed conifer species of the climax rainforest, partly funding the project from the sale of carbon credits.
- The Little Red River Cree Nation located in Northern Alberta, Canada, wished to create carbon permits by delaying harvests of forests, but was turned down by the Canadian government.
- A community group in Powell River, British Columbia, hopes to obtain carbon credits to fund activities to prevent the harvest of coastal rainforest.

There is nothing objectionable about the forgoing projects, except that, when it comes to claims that climate-mitigating offset credits are being created, these and many other projects are suspect. In some cases, the carbon credit angle is largely a marketing technique to solicit funds for a project that would proceed in any event.

Even Clean Development Mechanism (CDM) forestry activities are suspect. The first approved CDM tree-planting project establishes 2,000 ha of multiple-use forests on degraded lands in China. The CDM report indicates the project would sequester 773,842 tCO2 over the 30-year project life, but there is no information about the timing of CO2 uptake and its possible eventual release. Unless one knows how long CO2 stays out of the atmosphere, it is impossible to determine how many carbon credits are produced. Yet Spain and Italy will each claim a share of the project's 'credits'.

Some Terrestrial Carbon Sequestration Costs

Over the past decade, I investigated data on carbon uptake and costs from several hundred biological sequestration projects or proposals. Activities included soil conservation (e.g., conservation and zero tillage, reduced summer fallow), switches from annual crops to perennial ones (e.g., forages), tree planting schemes (plantations on denuded forestland and agricultural land), deforestation prevention, and forest management (enhanced silviculture). The vast majority of studies and project documents fail to identify how long carbon is sequestered, whether the activity would have taken place in the absence of concerns about global warming, and the leakages that the project induces. For example, sequestered carbon in soils as a result of tillage change, reduced fallow or land use conversion would be released very quickly once the prior practice is reinstated. Nor is the time path of carbon accumulation specified. And many studies ignore the increased emissions of CO2 or equivalent gases related to the increased use of chemicals brought about by practices to enhance soil organic carbon – leakages are ignored.

It is very difficult to appropriately credit terrestrial carbon activities. For the vast majority of biological sequestration projects the future path of carbon uptake and release is generally unknown and unknowable. There is always a risk that carbon will be released due to unforeseen hazards, such as fire and erosion; and the ability to measure/monitor actual rates of sequestration and associated leakages is inadequate. As a result, the transaction costs associated with the creation of credits via terrestrial sequestration activities are high, militating against the use of sequestration in carbon trading.

Consider conservation tillage. A study by West and Marland (2002) found that reduced tillage did not lower atmospheric CO2, because the carbon stored in soil organic matter is offset by the CO2 and other greenhouse gasses released by increased production, transportation and application of chemicals. Given the risk that carbon stored in soils is released when land use or management conditions change, reduced tillage may actually increase overall CO2 emissions.

Conversion to zero tillage is a more promising enterprise. Nonetheless, it is not uniformly true that zero tillage sequesters more carbon than conventional tillage, since less residue is available for conversion to soil organic carbon in arid regions (Manley et al. 2005), which affects the costs of creating carbon credits. Some cost estimates are provided in Table 1, and these omit the possible increased emissions related to greater chemical use and the transaction costs associated with measurement and monitoring. Even so, given that utility companies are banking on carbon credits costing no more than $20 per metric ton of CO2 as reported in The Economist (2007), the cost of generating carbon credits by changing agronomic practices is not very competitive, except perhaps in the U.S. South.

Furthermore such practices may not be additional – farmers have increasingly adopted conservation tillage practices, including no-till cropping, without requiring side payments for carbon uptake.

Table 1. Cost of Creating Carbon Credits via Zero Tillage Agriculture, $ per metric ton of CO2

Region	Wheat	Other Crops
U.S. South	$3 to $4	$½ to $1
Prairies	$105 to >$500	$41 to $57
U.S. Corn Belt	$39 to $51	$23 to $24

Source: Adapted from Manley et al. (2005)

Given that agricultural carbon uptake activities are particularly ephemeral, what about forest activities? Again, forest carbon sinks are not the answer. If anything, they are a distraction and even a means of unloading climate mitigation onto a future generation. First off, as I have shown elsewhere (van Kooten 2008), it is nearly impossible to determine how many carbon credits are actually created due to issues regarding the timing of CO2 uptake and release, measurement, leakage, etc. Second, measurement, monitoring and verification are difficult and increase transaction costs, although these are typically ignored partly because they are difficult to determine.

An indication of the potential marginal costs of forestry based carbon credits is provided in Table 2, which is based on 68 studies with costs again ignoring transaction costs. For the most part, forest activities are more costly than $20 per t CO2, except for tree planting in many tropical regions, some boreal activities and some U.S. projects. The opportunity cost of land is generally too high. This holds even when account is taken of carbon stored in wood products. The only exception occurs when trees are harvested and burned in place of fossil fuels to generate electricity, and even then not in all locations.

Future Commitments

Finally, while a country can use carbon sequestration credits to achieve some proportion of its current Kyoto emissions-reduction target, this may create problems for the future if the country remains committed to long-term climate mitigation. Suppose a country is committed, in a future commitment period (a second period is currently being negotiated), to reduce emissions beyond what it committed to for 2008-2012. It must then meet the new target plus any shortfall from the first commitment period; in particular, it still needs to reduce emissions by the amount covered in 2008-2012 by biological sink activities. But there is more: the country is also technically liable for carbon stored in the nonpermanent terrestrial sink.

Table 2. Marginal Costs of Creating Carbon Offset Credits through Forestry Activities, Various Forestry Activities and Regions, $ per metric ton of CO2

Global	$25-29	Tropics (CDM Projects)	$0-4
Planting	$0-1	Planting & opportunity cost of land	$0-7
Planting & opportunity cost of land	$22-33	Planting, opportunity cost of land & fuel substitution	$0-23
Planting, opportunity cost of land & fuel substitution	$0-49	Forest management & opportunity cost of land	$34-63
Forest management	$1-89	Forest management, opportunity cost of land & fuel substitution	$0-50
Forest management & opportunity cost of land	$60-118	Conservation	$0-103
Forest management, opportunity cost of land & fuel substitution	$48-77	Conservation & opportunity cost of land	$26-136
Forest conservation	$2-158		
Forest conservation & opportunity cost of land	$47-195		
Europe	**$140-184**	**Boreal Region**	**$9-110**
Planting & opportunity cost of land	$158-185	Planting & opportunity cost of land	$5-128
Planting, opportunity cost of land & fuel substitution	$115-187	Planting, opportunity cost of land & fuel substitution	$1-90
Forest management & opportunity cost of land	$198-274	Forest management & opportunity cost of land	$46-210
Forest management, opportunity cost of land & fuel substitution	$203-219	Forest management, opportunity cost of land & fuel substitution	$44-108

Source: Adapted from van Kooten and Sohngen (2007)

Consider the example of a country that agreed to reduce emissions in the first (2008-2012) period by 6% and then commits to reduce them by a further 6% in a second period, for an overall reduction of 12% from the 1990 baseline emissions. Suppose that, in the first period, it reduced emissions by 4%, while relying on forest sinks to cover the remainder. For the second period, therefore, it must reduce emissions by 8% rather than 6% in order to meet the 12% target. Furthermore, if and inevitably when the terrestrial sink releases its carbon to the atmosphere, the country must also cover that loss (which amounts to 2%), implying that it must really reduce emissions by 10%. This temporal shifting in the emissions-reduction burden caused by reliance on carbon sinks is therefore likely to result in an onerous obligation for future generations.

Concluding Observations

All things considered, I concur with Julianna Priskin who states that those who intend to be "carbon neutral travelers need to be well-informed about carbon credits that finance tree plantations. ... The singular action of tree planting will not solve climate change problems ... notably because it does not lead to a reduction of fossil fuel reliance." The same applies to other biological sequestration, particularly agricultural activities.

Are we then left with no role whatsoever for terrestrial carbon sequestration? On the contrary, plants remove CO2 from the atmosphere, while providing a host of other benefits. Thus it makes sense to implement certain environmentally sound sequestration activities. However, I see no role for biological sequestration in a carbon trading scheme given the impermanence, volatility and onerous transaction costs related to duration, measurement and monitoring.

One possible solution, however, is to provide a predetermined schedule of carbon storage for sequestration alternatives and base subsidies and penalties on this schedule. A subsidy is provided while the sequestration activity continues and a penalty assessed when land use reverts to the prior practice. Actual carbon flux need not be monitored or verified as carbon flux would be determined by the pre-determined schedule, with the value of carbon determined in the emissions trading market. The only relevant transaction costs relate to the establishment of a contract on the property that covers future landowner liability for carbon stored. However, I believe that few would undertake such an agreement since the benefit to landowners will likely be too small, and the risk that carbon prices and resultant liabilities will increase over time too large.

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Paying for Avoided Deforestation – Should We Do It?

Brent Sohngen

JEL Classification Codes: Q23,Q56,Q57

Carbon Emissions from Deforestation

Deforestation remains one of the largest sources of global CO2 emissions, constituting around 17% of total emissions (Figure 1; Intergovernmental Panel on Climate Change, 2007a). When forests are converted to agriculture, most of the carbon in biomass is emitted into the atmosphere either through active burning, or through decay. Deforestation is rather common today in tropical regions (Brazil, Africa, Southeast Asia) and results mainly from expansion of agricultural land, including the development of feedstocks for bioenergy.

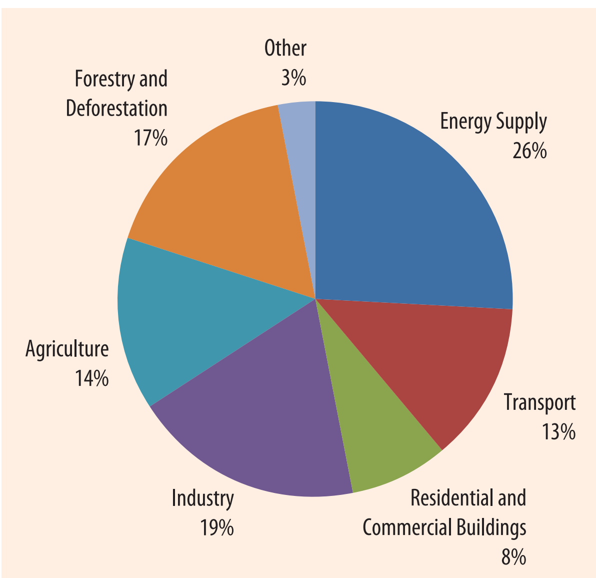

Figure 1. Proportion of global carbon emission from various sources (Intergovernmental Panel on Climate Change, 2007a)

According to the Intergovernmental Panel on Climate Change (2007b), reductions in deforestation could have important near-term greenhouse gas impacts and they could reduce the overall costs of avoiding climate change. The role of deforestation in future climate policy has become a prominent policy issue. At the recent Bali international climate change meetings, countries (including the United States) agreed to keep the question of deforestation on the table during the debate about future policy after the Kyoto Protocol.

This article discusses and examines arguments in favor and against the use of credits from reductions in deforestation in climate policy. While reductions in deforestation are an area of intense negotiation in international policy, they could easily become an area of concern domestically if the U.S. moves toward stronger climate policy. Several current legislative proposals explicitly consider importation of international carbon credits, some of which could arise from reductions in deforestation.

Arguments Against Credits from Reductions in Deforestation

There are a number of arguments against using carbon credits derived from reductions in deforestation. Perhaps the most important relates to economic growth. In many regions (e.g., Brazil), agricultural land expansion is considered an important driver of future prosperity. Standing tropical forests do not provide consistent annual income flows, while livestock or crops (including biofuels) generally do. Many developing countries have been reluctant to take on GHG emission caps in their industrial sectors due to growth concerns, and some may be similarly reticent to take on targets for reductions in deforestation.

Second, many governments and stakeholders believe reductions in deforestation would be difficult to contract, measure, and monitor. Despite all the advances in satellite and other technologies, it remains no small task to build measurement systems that track land-use. It is even more difficult to measure the carbon content in forests, particularly remotely. Even if tracking systems can be put in place, designing contracts that affect land use is complex. Consider for example the "urban sprawl" discussion about controlling land use that has occurred in the last decade. While some large U.S. Department of Agriculture programs were implemented, it has not always been clear that land use change actually slowed as a result of the programs.

Questions about contracting for reductions in deforestation involve a host of additional issues, not least of which are baselines (e.g., identifying areas that will be deforested) and property rights. Baseline setting is a problematic contracting issue in part because it is difficult to determine how much and where deforestation will occur in a given country in the future without the policy to reduce deforestation. Economists are notorious for debating projections about any economic indicators, and land-use change is no different. In addition, countries themselves have strong incentives to overstate their baseline deforestation rates because the baseline establishes the number of credits that they ultimately can sell. From an economics and policy research perspective, baseline setting clearly deserves strong attention in the future if reductions in deforestation are to become a valid emission reduction mechanism.

Uncertain land tenure, or property rights, creates similar problems for contracting. In many regions where carbon credits from reduced deforestation may be developed and sold, land tenure is not completely secure. It is not clear how two parties can contract for anything if the seller cannot guarantee ownership. This "property right" problem with carbon differs from other commodities, such as timber, where "illegal" logs are routinely marketed. The specific location of carbon in trees matters for ensuring that payments get to the owners, and for verification. In illegal log markets, the location of the point of harvest does not matter, and uncertain tenure and lack of control over the resources likely serve to enhance the market for illegal logs (although they are not the only issues). A lack of control over land, or an inability to ensure that carbon remains on the land if contracted and sold, in contrast, creates inefficiencies in making payments for sequestered carbon.

Third, many environmental groups are concerned that allowing credits for reductions in deforestation could reduce carbon market prices and in turn, incentives to invest in energy saving technologies. Thus, while deforestation reductions would benefit the atmosphere and mitigate climate change, they would also cause us to put off other investments.

Arguments in Favor of Credits from Reductions in Deforestation

The most important argument in favor of credits from reductions in deforestation relates to costs. Most economic evidence suggests that policies including reductions in deforestation would be cost effective. The recent IPCC report suggested that up to 2 billion tons (1 ton = 1000 Mg or 1 metric tonne) of CO2 emissions could be reduced by avoiding deforestation for less than $20 per ton CO2 by 2030. This represents a substantial share of global emissions over the next 30 years and is much cheaper than a number of other estimates.

The implications of slowing deforestation this much, this cheaply, are fairly large. A study by Tavoni et al. (2007) combined a large-scale, integrated assessment model with a land-use model to examine the relative merits of undertaking forestry and energy actions to stabilize future concentrations of carbon in the atmosphere. Specifically, Tavoni et al. examined a 550 parts per million target, whereby emissions would have to be curtailed dramatically over the next several decades in order to hold concentrations below this level. This policy is roughly equivalent with allowing a doubling of carbon dioxide in the atmosphere relative to preindustrial concentrations, but not allowing emissions to increase concentrations beyond that point.

Tavoni et al. found that forestry actions, which include reductions in deforestation, could reduce costs of stabilizing concentrations by up to 50% compared to an energy-option only strategy. They show the "benefits" of including forestry in global stabilization policy are nearly three times the costs. In addition, there are a number of other environmental benefits, such as habitat, water quality, biological diversity, species preservation, etc. While it is difficult to quantify the value of these benefits, they are likely positive, and growing over time.

Implementation and Transaction Costs

Is it even realistic to expect that large areas of land could be enrolled or influenced by carbon policy? The program most often cited as an example of a successful land-use policy is the U.S. Conservation Reserve Program (CRP). Over a 25 year period, the CRP changed the use and management of over 36 million acres of land. In comparison Tavoni et al.'s results imply 47 million acres of U.S. land would need to be converted to forests by 2030. The climate program is clearly a large program, but perhaps not out of the question when compared to CRP.

Now, consider what the results in Tavoni et al. mean in South America. Between 2005 and 2030, the baseline model (without carbon incentives) in Tavoni et al. (2007) suggests that 201 million acres of tropical forestland will be lost in South America due to deforestation. With the carbon incentives of the stabilization policy, only 58.5 million acres would be deforested by 2030, for a net increase of 142.5 million acres. This change represents a 71% reduction in deforestation over the next 30 years. Is it feasible to carry out a program this large in South America? On average, there are 178 tons of CO_2 on each acre of standing tropical forests in South America. With this amount of carbon, the lump sum initial payment for land enrolled in a program to reduce deforestation would be $400 per acre for land enrolled in 2005 under the carbon prices described in Tavoni et al. Due to the projected rise in carbon values over time, land enrolled in 2030 would be paid $2800 per acre. While these payments are not likely to compete with the net returns from already accessed croplands (with average yields of 40 bushels per acre and net returns of $100-$150 per acre), they could be competitive in regions near the margin where active, and costly, land clearing is occurring.

On the other hand, to avoid such large deforestation levels, substantial costs of design, implementation, and enforcement would arise – e.g., transactions costs. There is some evidence on the magnitude of such costs. Sathaye and Antinori (2006), estimate implementation costs to be less than $1 per ton CO_2, but they consider projects that are much smaller than those that would need to be carried out under a stabilization policy.

A crude, but different, way of looking at the transaction costs is to consider the CRP budget. In 2004, the Farm Service Agency total budget was $25.5 billion. Of this $1.9 billion was spent in rental payments to farmers for CRP, and $1.3 billion in salaries and expenses across all programs. CRP rental payments were about 7% of the total budget. If one simply assumes that 7% of the salaries and expenses were used for the CRP, then implementation costs would be $92.8 million per year. For roughly 36 million acres this amounts to around $2.50 per acre per year. On average, afforested acres in the United States may be able to sequester 2.4 tons CO_2 per acre per year, suggesting administrative costs could be around $1 per ton CO_2 sequestered.

This is an admittedly "back-of-the-envelope" way to estimate institutional costs, but it nonetheless can be informative. Based on the results from Sathaye and Antinori (2006) and the calculations from the CRP in the United States, institutional costs do not appear to be all that large when compared to the types of carbon prices that might emerge with global policy. Further, CRP is a government program, and as such, one may expect that its administrative costs are larger than they would be with private party transactions. Of course, it is not at all obvious that the costs of implementing CRP in the US will be representative of implementation costs of similar programs in the developing world. Bureaucratic inefficiencies could drive these costs higher elsewhere (although wage differentials may limit this increase).

It is important to bear in mind that the discussion about implementation costs above focuses on a specific type of property right– namely, that landowners are considered sources of credits. Alternative approaches, however, are possible. For example, policy makers could tax emissions from deforestation rather than design systems to pay landowners to hold land in forests. Yield and other types of taxes are routinely implemented in many developed countries, so taxation systems are clearly feasible with potentially low transactions costs (self-reported in many cases – with high penalties for mistakes). Many countries, however, could find this policy difficult to implement politically and to enforce in practice.

Worth Considering

Will payments for reductions in deforestation be used in the future? Any policy that has a nearly 3-1 benefit cost ratio is worthy of consideration. While additional transactions costs ignored in this estimate will increase the costs, these do not appear overly burdensome. Further, the potential additional ecological benefits of preserving rainforests could be as compelling as climate change itself. Collectively it appears that additional work on policy design is needed if reduced deforestation programs were to be implemented efficiently. For example, the large literature on contracting with asymmetric information provides many good insights that could be used to help design monitoring and verification systems, or to help design payment vehicles.

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Bioenergy in a Greenhouse Mitigating World

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JEL Classifications: Q1,Q4,Q54

Agriculture may help mitigate climate change risks is by helping reduce greenhouse gas (GHG) emissions. One way of doing this is by providing substitute products that can replace fossil fuel intensive products or production processes. Production of biofeedstocks for bioenergy achieves this, where the biofeedstocks are traditional products, crop residues, wastes or processing byproducts. The forms of bioenergy include electrical power or liquid transportation fuels e.g. ethanol or biodiesel.

Employing agricultural products in such a way generally involves recycling of carbon dioxide (CO2), a greenhouse gas, because plant growth absorbs CO2 while combustion releases it. This is likely to mean that emission permits would not be needed for the CO2 emissions that arose when generating biofeedstock fired electricity or consuming liquid biofuels.

GHG permit prices could raise the market value of agricultural commodities as long as bioenergy use does not require acquisition or use of potentially costly/valuable emissions permits. Consequently, biofeedstocks may be a way that both: (a) energy firms can cost effectively reduce GHG liabilities and (b) agricultural producers gain agricultural income. But, before wholeheartedly embracing bioenergy as a GHG reducing force, one must fully consider the GHGs emitted when raising feedstocks, transporting them to a plant and transforming them into bioenergy. One must also consider the market effects and possible offsetting effects of production stimulated elsewhere. Two issues arise when taking on such a viewpoint

- What are the GHG offsets obtained when using particular forms of bioenergy and what does this mean for comparative economics of feedstocks?
- When bioenergy production reduces traditional commodity production does the market reaction of other producers reduce net GHG effects?

This paper briefly discusses these issues and is largely drawn from a longer version of the paper by McCarl (2008).

Lifecycle Accounting and Biofeedstock Economics

The net GHG contributions of a bioenergy production possibilities depend upon the amount of fossil fuel used in the project lifecycle from production until use including emissions generated when: (a) making production inputs, (b) producing the feedstock, (c) hauling it to a facility and (d) processing it into fuel or electricity. This contribution varies by feedstock, type of energy developed and region of the country since hauling costs depends on yield and density of production. Table 1 displays a consistent set of estimates across a number of possibilities for use of

- crop or cellulosic ethanol in place of gasoline,
- biodiesel in place of diesel and
- biofeedstock fueled electricity with sole firing and 5% cofiring

using data from regions commonly discussed as having high potential for feedstock production.

The data within Table 1 show the percentage direct reduction in carbon dioxide equivalent emissions.

The table shows for example that the percentage reduction in net GHG emissions when using corn-based ethanol is 17% relative to using gasoline. This means 83% of the potential emissions savings from replacing the gasoline are offset by the emissions from the use of fossil fuels in producing the corn, transporting it to the plant and transforming it into ethanol. We also see higher emission offset rates for electricity principally because the feedstock is burned with little transformative energy needed once it is at the generation site. Also cofiring generally has a higher degree of offsets because hauling distances are shorter as lower feedstock volumes are required and because of the

Feedstock Commodity being used	Form of Bioenergy being Produced				
	Liquid Fuels			Electricity	
	Crop Ethanol	Cellulosic Ethanol	Biodiesel	Co fire at 5 %	Fire with 100% biomass
Corn	17%				
Hard Red Winter Wheat	16%				
Sugarcane	65%				
Soybean Oil			95%		
Corn Oil			39%		
Switch Grass		57%		86%	75%
Corn Cropping Residue		70%		89%	80%
Wheat Cropping Residue		56%		93%	87%
Manure				99%	96%
Bagasse		96%		98%	96%
Lignin				91%	86%

Table 1. Percentage Offset of Net GHG Emissions from the Usage of a Biofeedstock.

hotter burning caused by the presence of coal which increases feedstock heat recovery.

Broadly across the table, we see

- Relatively lower rates for liquid fuels as opposed to electricity.
- The lowest liquid fuel offsets arising for grain based ethanol with relatively higher values from cellulosic ethanol and biodiesel from soybean oil.
- Results that reflect differential offset rates due to the differential use of
  - Emission intensive inputs in producing feedstocks (corn is a large fertilizer user).
  - Emission intensive transformation processes in making ethanol along with successively less so processes to make cellulosic ethanol, biodiesel and electricity.

Such results portend that economically if higher greenhouse gas prices were to arise that there would be a shift in production away from grain based ethanol toward cellulosic and a trend to move toward electricity. Analysis by McCarl and Reilly shows such trends.

Leakage – Offsets from Elsewhere

Beyond the direct GHG impacts of bioenergy there are offsite concerns. Namely, market forces such as today's high corn prices (rising principally because of the rapidly rising amount of corn being converted to ethanol) can cause net GHG emission reductions within one region to be offset by increased emissions from expanded production in other areas of the world or portions of the economy (Murray, McCarl and Lee; Lee et al; Fargione et al, Searchinger et al). Today it is common to hear about many forms of such offsets (typically called leakage in international GHG settings) being stimulated by high agricultural commodity prices including

- U.S. forested acres being harvested and converted to cropland,
- Possible reversion of Conservation Reserve Program lands into cropland or
- Expansions of crop acres in Brazil and Argentina at the expense of grasslands and rainforest (Lee et al, Searchinger et al) .

Key factors in the size of this leakage as discussed in Fargione et al, McCarl and Murray, McCarl and Lee, include

- The amount that marketed production that is offset. Note use of residues and waste product feedstocks lower this while use of conventional commodities raises it.
- The land use that replacement acres come from and the embodied emissions. Large offsets occur when rainforest or forest or possibly CRP land is involved.
- The supply responsiveness of competitive areas.
- The market share of the country producing the bioenergy.

McCarl constructs leakage estimates based on a formula by Murray, McCarl and Lee show international leakage easily offsets nearly 50% of the domestic diverted production when GHG offsets per acre are equal and an even higher share of the net GHG gains if acres with higher emissions are involved. Along this line Searchinger et al show that when acres are directly replaced by rainforest reductions, that net GHG emissions would increase. Fargione et al point out the risks of emission increases varies under different land uses and feedstocks along with the desirability of using waste products.

It is also important to note that market forces may also cause reductions elsewhere where for example commodity price increases for feed may reduce livestock production and accompanying emissions as covered in McCarl.

Concluding Remarks

This paper discusses several major points relative to bioenergy and greenhouse gas offsets

- Not all bioenergy forms have equal direct greenhouse gas offset effects. Generally grain based ethanol provides the least offsets, then cellulosic, then biodiesel, and then electricity.
- Leakage created by market price induced replacement production overseas and domestically is an important factor and can offset domestic GHG emission reduction gains substantially. There is a high degree of uncertainly as to

the magnitude of the leakage but it is expected to be significant. Less leakage occurs when biofeedstocks are used which do not divert market production.

- Economically as GHG prices rise the more desirable bioenergy forms become bioelectricity and cellulosic ethanol.

From a policy perspective the arguments above indicate that bioenergy and greenhouse gasses are complexly intertwined and that current promotion of items like corn ethanol may not in fact be contributing much to greenhouse gas reductions. In fact, recent papers argue that this reliance may well be leading to net increases when the global consequences are considered. Certainly U.S. GHG reduction policies need to be carefully formulated as they can be ineffective, even having the opposite effect, if global and competing land use changes are not considered. Leakage, per unit GHG offset and market displacement appear to be lessened with reliance on residue and waste products in addition to emphasis on cellulosic ethanol and electricity.

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Policy Options for Controlling Greenhouse Gas Emissions: Implications for Agriculture

Gilbert E. Metcalf and John M. Reilly

JEL Classification: Q1, Q2, Q5, H2

Climate Change Legislation Picks Up Speed

The pace of activity around climate change legislation picked up noticeably in 2007. The increased focus brought new legislative proposals to reduce greenhouse gas emissions (GHGs). These bills include cap-and-trade systems, and carbon taxes[1] as well as energy bills that promote energy efficiency or renewables (Table 1). Many also include support for research and development for emission reducing alternatives.

The cap-and-trade bills generally engage agriculture through a credit system. As such, agriculture is not capped, but individual land owners can make the case that they have reduced emissions or increased carbon uptake and thus get credits. Entities under the cap can apply these credits and that creates sales possibilities.

The carbon tax bills generally defer decisions on how to include nonenergy emissions. For example the Larson bill, directs the Secretaries of Treasury and Energy to make recommendations within six months on non-carbon GHGs. We argue below that these activities can be brought into a carbon pricing system similarly to energy related emissions.

Market Based Incentives and Complementary and Competing Approaches

Economists widely favor market based incentives (e.g. carbon taxes or cap and trade systems) as they are generally more economically efficient than regulatory approaches. A carbon tax or the CO2 price that results from a cap and trade control system will raise fossil fuel costs and tip the balance toward less emission intensive fuels like renewables. An incentive-based program lets the market determine whether, when and how much renewable fuel should be used rather than setting a mandatory blending rate, portfolio standard, or production target.

Given that we wish to use a market-based approach, what are the important design features? The first important design issue is whether the system is imposed at upstream or downstream. Upstream refers to coal mines, natural gas, oil wells, refiners or import points for energy. Downstream refers to the end users of fossil fuels. In the case of energy-related CO2 and from an efficiency standpoint it does not, for the most part, matter where the price is imposed. This is simply a consequence of the general principle that the tax wherever it occurs will be passed though to consumers leading them to reduce energy use and, as a result, emissions.

From an administrative and regulatory cost viewpoint, however, it makes a difference where the price is imposed. The United States has roughly 1500 coal mines, 150 oil refineries and 200 natural gas pipeline locations meaning a small number of places the upstream tax would be levied. In contrast, a downstream system would require taxing millions of consumers, raising the administrative costs. Both would provide incentives to reduce energy use and lower associated emissions. For agriculture and land-use, upstream means applying the tax or cap and trade system on the owner of the land.

Second, it is important to make the system comprehensive. This means including as many GHGs and sectors as possible. This calls for agriculture to be included. A number of studies have found that by being comprehensive the cost of an abatement program is sharply reduced.

1. *Carbon taxes can apply to carbon emissions only or to a broader array of greenhouse gases. In this paper, we will use the term "carbon tax" to apply to a tax on some or all greenhouse gases.*

Bill	Primary Policy Instrument	Other Features	Agriculture Related Provisions
Lieberman-Warner December 2007	Cap and Trade	R&D Incentives, Energy Efficiency Standards	• Agriculture's energy-related emissions not covered • Credits for sequestration and other GHGs • Incentives for fuel from cellulosic biomass
Bingaman-Specter	Cap and Trade	R&D Incentives	• Because regulated upstream, covers energy-related emissions from agricultural sector • Credits for sequestration and other GHGs • Incentives for fuel from cellulosic biomass
Kerry-Snowe 2007	Cap and Trade	R&D Incentives, Renewable Portfolio Standards, Energy Efficiency Standards, Motor Vehicle Emission Standards, Gasoline Content Standards	• Breadth of sectoral coverage of the cap and trade left to the executive branch • Credits for sequestration • Renewable fuel required in gasoline • E-85 fuel pump expansion
Sanders-Boxer 2007	Cap and Trade	R&D Incentives, Renewable Portfolio Standards, Energy Efficiency Standards, Motor Vehicle Emission Standards, Gasoline Content Standards, Emission Standards for Electric Generation Units	• Breadth of sectoral coverage of the cap and trade left to the executive branch • Credits for sequestration • Renewable fuel required in gasoline
Waxman 2007	Cap and Trade	R&D Incentives, Renewable Portfolio Standards, Energy Efficiency Standards, Motor Vehicle Emission Standards	• Breadth of sectoral coverage of the cap and trade left to the executive branch •No provisions for agriculture
Udall-Petri 2006	Cap and Trade	R&D Incentives	• Because regulated upstream, covers energy-related emissions from agricultural sector • Credits for sequestration and other GHGs
Larson 2007	Carbon Tax	R&D Incentives	• Increased fuel prices create incentives for reduction of energy-related agricultural emissions • Credits for sequestration and other GHGs
Stark-McDermott 2007	Carbon Tax		• Increased fuel prices create incentives for reduction of energy-related agricultural emissions
Dingell Draft 2007	Carbon Tax + Gasoline Tax	R&D Incentives	• Increased fuel prices create incentives for reduction of energy-related agricultural emissions

Table 1: Congressional Climate Bills Featuring Incentive-based Mitigation Measures

Third, it is important to identify the real losers under any carbon pricing scheme[2]. The SO2 trading system and the EU Emissions Trading Scheme gave permits to the energy sector largely for free. However, the burden falls predominantly on final consumers, especially lower income ones. Revenues from auctioned allowances or a carbon tax can be used to relieve some of that burden.

Given this, what about the choice between cap and trade and a tax? Both have similar desirable characteristics in terms of economic efficiency in a certain world but differ under uncertainty. Under a cap and trade system the price is uncertain and variable whereas in the tax system the price is specified but the emissions reduction level is uncertain. Research shows that for greenhouse gas control eliminating uncertainty in the price has an economic advantage, tending to favor the tax approach. So-called hybrid systems where a cap and trade system is specified and then a price ceiling (safety valve) or price floor have been proposed to limit price variability, matching some of the properties of tax. While the difference between a cap and trade and a tax system has spurred a vigorous economics debate, the primary concern should be to undertake an incentive system that addresses the three issues above and is not cluttered with other measures that undermine its efficiency.

Many bills have a host of other provisions and the question is do these contribute to efficiency or undermine it? Some of these measures are complementary and some competitive. The complementary ones include information and labeling, research and development funding and reconsideration of public infrastructure funding such as for transportation. However, while experience with these approaches has shown some emissions reduction benefit, alone they are insufficient to significantly reduce emissions growth.

Competing programs are those that create mandates like fuel blending standards, renewable portfolio standards, or mandated efficiency standards. It may turn out that they are completely redundant as in the

2. *We set aside here the distributional implications of climate change itself.*

case of older lower renewable fuel standard that has been far surpassed by the market. However, if they are binding they lead to inflexibility in responding to a carbon price and thereby forcing more costly abatement options.

Agriculture in a Carbon Pricing System

With regard to agriculture and land use, a worrisome aspect of the proposed legislation is the unwillingness to cover land use emissions and other GHG emissions from agriculture on the same basis as other emissions. Economic agents causing greenhouse gas emissions should face a price for those emissions. Crediting systems in proposed legislation, while a step in the right direction, do not bring agricultural emissions fully into a cap and trade or tax system on the same basis as other emitting activities. They allow land owners to receive credits if they demonstrate abatement but if they simply choose to continue emitting they face no penalty.

Agricultural Emissions

Agriculture includes emissions from energy—that will be covered with an energy focused cap and trade system—but also a methane from livestock and rice and nitrous oxide resulting from fertilizer use. How should agriculture be treated? Bringing all or at least large sources under a cap and trade system would treat these symmetrically with energy related emissions.

Methane emissions from enteric fermentation, for example, contributed 112 million metric tons of CO2-equivalent emissions in 2005 or about 20 percent of total agriculture emissions. Large beef and dairy operations generate the bulk of these emissions. Treatment similar to that of energy suggests there should be a tax per head of cattle based on average emissions. Alterations of the animals' diets can change emissions. The government could give credits for diet induced reductions. The burden of proof of dietary change would be on the cattle feeders wishing to avoid the tax or to receive credits applicable to its cap.

Land Use

Land use and management of land can lead it to be either a source or a sink for greenhouse gases but approaches similar to those for other emissions can be applied to land-use with the land owner required to inventory carbon stock changes in order to sell the credits into the market, although such a program may be limited to land owners above a threshold to capture uses such as major forest operations with others allowed to opt in to the cap to avoid excessive management and monitoring costs associated with small sources. Such an approach is consistent with that proposed to deal with carbon capture and sequestration from power plants—where it is presumed that coal combustion leads to emissions unless CCS is demonstrated, and would thus provides similar treatment of emissions across sectors. Similarly, nitrous oxide presumed to be released from use of nitrogen fertilizer could be place under an upstream cap, with the presumed emissions depending on the form of nitrogen applied or where good practice demonstrated lower emissions a credit could be issued. Just as all carbon contained in fossil fuels is presumed to be released into the atmosphere (and thus priced) unless otherwise proven, agricultural emissions are presumed based on standard agricultural practices unless otherwise proven.

Ways Forward

It is desirable to implement incentive-based systems so as to stimulate industry to reduce emissions and innovate in reduction technology. Attention is also needed with regard to where to place regulation (upstream or downstream), comprehensiveness of treatment, and burden distribution. We reject the view that has been dominant in the literature to date that agriculture and land-use activities are somehow special and must be treated differently under a carbon pricing regime. Agricultural emissions should be fully included and activities that reduce emissions should be eligible for credits. Comprehensive inclusion is central to a viable, cost-effective, and efficient carbon pricing program.

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