CHOICES
The magazine of food, farm, and resource issues
A publication of the American Agricultural Economics Association

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

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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.

For More Information

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