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Theme Overview: Revisiting the Evidence and Potential Solutions on Climate Change

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JEL Classifications: Q1, Q5, Q54
Keywords: Adaptation, Climate change, Food Security, IPCC, Mitigation

An 2008, a *Choices* issue theme examined climate change just after the release of the 2007 Intergovernmental Panel on Climate Change (IPCC) report series. The last few years have seen the release of another round of IPCC reports along with the National Climate Assessment, reports from the National Academies and several other climate change assessments throughout the world. These reports and the literature more generally contain substantially more evidence on climate change effects and impacts and we have seen additional policy attention devoted to ways to mitigate and adapt to the risks. Thus, this *Choices* theme revisits the issue and, in doing so, the articles address some of the controversies, imperatives and unmet expectations that have arisen in the last decade plus the challenges that lie ahead.

The connection between climate change and agriculture is multifaceted. A major assertion in the 2014 IPCC and National Assessment reports is that climate change is already affecting agricultural productivity and adaptation is occurring in response. Evidence suggests that these effects are spatially heterogeneous and are likely to intensify in the next century. Furthermore, adaptation has evolved to be a much more prominent theme than in the past, with extensive coverage by the National Academy and prominent coverage in IPCC, 2014. Moreover, the reports again define a role for agriculture in greenhouse gas (GHG) mitigation. Through all this, there remains debate and substantial research on the nature, scale, and severity of future climate change, means of adaption into the future, and potential mitigation actions.

Articles in this Theme:

The articles in this thematic package address key dimensions of the effects, adaptation and mitigation facets of the climate change and agriculture issue:

- The projected impact of climate change on agricultural productivity and food security in domestic and international settings
- The motivation for adaptation efforts along with potential strategies and roles of public versus private entities

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Prospects for and policy towards an agricultural role in climate change mitigation

In the first article on the climate effects facet, Elodie Blanc and John Reilly review the latest climate change impact assessments on crop productivity in the United States. Their findings suggest that under current agricultural practices, a lower future yield trajectory is expected for the major crops grown in the United States, but that adaptation strategies can alleviate these negative impacts. The second article, by John Antle, takes a global view of food security as a potential form of climate change vulnerability. Antle discusses how climate change acceleration, together with population growth, economic growth, and other forms of environmental degradation, could create high hurdles to food access for the world's population. He argues that, despite these concerns, we know quite little about the likely impacts of climate change on food security. His article explains the apparent gap in our understanding of climate-related food security, why current modeling efforts do not adequately capture food security problems, and how future research can address these knowledge and application gaps.

The next two articles turn attention primarily to the adaptation challenge. Steven Rose reviews evidence and projections that indicate the global emissions rise and climate change will likely continue for some time, even with mitigation efforts being undertaken arguing that this will make inevitable the need for adaptation. Rose argues that agriculturalists are already well-versed in adapting practices to trend changes in technology and markets, and thus climate adaptation is not a completely foreign concept. However, adaptation to climate change will require investments in capacity for research, outreach and information decision, as well as the institutions to support these activities. Bruce McCarl builds on those by Rose and Blanc and Reilly and highlights the significance of the challenge facing agriculture. Drawing on data from the IPCC assessment report, he argues that the agricultural sector needs to prepare for two phases of climate change—one between now and 2040 that is more or less "dialed in" at about 1° C, and the post-2040 phase that could range from 2-6° based on the mitigation actions taken from this point forward. McCarl identifies about a dozen categories of adaptation, from standard changes in farm management practices to large scale changes, such as purposeful relocation of entire ecosystems, with roles for the public and private sectors. He highlights the current status of adaptation and areas for concern, attitudinal and economic hurdles to ramped up adaptation measures, and the need to intelligently link adaptation and mitigation.

The mitigation facet of this collection looks beyond specific practices, as that was well covered in the 2008 and earlier *Choices* theme issues and in other reports (McCarl and Schneider, 2000; Murray et al., 2005; IPCC, 2014). Specifically, the theme mitigation articles cover the evolution of mitigation policy over the last several years and expectations moving forward. Brian Murray recalls the pronouncements and speculation from the last decade that the inevitable emergence of carbon markets in the United States would drive substantial participation from the agricultural sector in GHG mitigation. He describes why these market forces did not materialize at the level anticipated. Reasons range from the political failure of a national, economy wide, cap-and-trade program, to the minor role of agriculture in the carbon markets that do exist, to the unforeseen costs of undertaking and aggregating mitigation measures in the sector. He describes a possible future path where agricultural mitigation could ramp up as part of the broader use of carbon markets that is now actually being observed, coupled with targeted public and private sector programs. Jan Lewandrowski and Kathryn Zook look at policy directions examining recent experiences and future pathways for complementary targeted programs. These efforts include the expansion or refocusing of traditional government conservation and bioenergy programs to target mitigation, assistance in the development of private sector initiatives such as supply chain imperatives for sustainably produced foods, and the use of economic incentives for the provision of a wide range of ecosystem services, including carbon sequestration and other forms of agricultural GHG mitigation.

Naturally this special theme issue cannot cover all aspects of climate change and agriculture, coverage of which has consumed thousands of pages of assessment reports, regularly published journals, special issues, books and individual papers. The bibliography below contains references that provide a much more comprehensive treatment.

For More Information

Choices. 2008. Theme on Climate Change Economics. Available online: http://www.choicesmagazine.org/2008-1/theme/index.htm.

Intergovernmental Panel on Climate Change. 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2013. Available online: http://www.ipcc.ch/report/ar5/wg1/.

Intergovernmental Panel on Climate Change. 2014. Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. Available online: http://www.ipcc.ch/report/ar5/wg3/.

Intergovernmental Panel on Climate Change. 2014. Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. Available online: http://www.ipcc.ch/report/ar5/wg2/.

McCarl, B.A. and U.A. Schneider. 1999 "Curbing Greenhouse Gases: Agriculture's Role", *Choices*, First Quarter, 9-12. Available online: http://ageconsearch.umn.edu/handle/131673.Murray, B.C., B.L. Sohngen, A.J. Sommer, B.M. Depro, K.M. Jones, B.A. McCarl, D. Gillig, B. DeAngelo, and K. Andrasko. 2005. EPA-R-05-006. "Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture." Washington, DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs. Available online: http://www.epa.gov/climate/climatechange/Downloads/ccs/ghg_mitigation_forestry_ag_2005.pdf.

National Climate Assessment. U.S. Global Change Research Program Washington, DC: National Research Council of the National Academies. The National Academies Press. Available online: http://nca2014.globalchange.gov/report.

National Research Council. 2011. America's Climate Choices Washington, DC: National Research Council of the National Academies. The National Academies Press. Available online: http://www.nap.edu/catalog/12781/americas-climate-choices.

National Research Council. 2010. America's Climate Choices: Adapting to the Impacts of Climate Change. National Academies, Washington, DC. Available online: http://www.nap.edu/catalog/12783/adapting-to-the-impacts-of-climate-change.

National Research Council. 2010. America's Climate Choices: Advancing the Science of Climate Change. National Academies, Washington, DC. Available online: http://www.nap.edu/catalog/12782/advancing-the-science-of-climate-change.

National Research Council. 2010. America's Climate Choices: Limiting the Magnitude of Future Climate Change. National Academies, Washington, DC. Available online: http://www.nap.edu/catalog/12785/limiting-the-magnitude-of-future-climate-change.

National Research Council. 2010. America's Climate Choices: Informing an Effective Response to Climate Change. National Academies, Washington, DC. Available online: http://www.nap.edu/catalog/12784/informing-an-effective-response-to-climate-change.

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Climate Change, Vulnerability and Food Insecurity

John M. Antle

Keywords: Climate change, Food insecurity, Vulnerability
JEL Classifications: O1, Q1

Achieving and maintaining food security for all of humanity appears to be an important but daunting global challenge in the face of population growth, economic growth, environmental degradation and accelerating climate change. Indeed, much lip service is given to the risks posed by climate change to food security in the scientific literature and the popular press (Wheeler and Braun, 2013).

Despite this "conventional wisdom," our understanding of the likely impacts of climate change on food security is very limited. Indeed, the most recent assessment report by the Intergovernmental Panel on Climate Change concludes, "All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability (high confidence)". But the report then observes, "There remains limited quantitative understanding of how non-production elements of food security will be affected, and of the adaptation possibilities in these domains" (Challinor et al., 2014).

Two reasons for this gap in our understanding are that, first, food security is difficult to define and measure. This is true currently, and these challenges are much greater when attempting to project food security under uncertain future socio-economic conditions. Second, the economic impact assessment models used to project future agricultural production and food consumption are not well-suited to the task of projecting impacts on food security. These limitations extend to assessing other aspects of economic or environmental vulnerability, as well.

Quantifying Food Insecurity

Food insecurity can be considered a type of vulnerability, that is, the risk of not having adequate food. Nutritional experts would extend the concept to nutritional security, going beyond the consideration of available calories to consider a broader set of nutrients available from food. These concepts can be defined at various scales: an individual person may be at risk of not having enough food to eat today or an entire country may be at risk of not having enough food for its population over a year or a decade. Different kinds of data and models are needed to quantify food insecurity at each of these scales.

Food security is difficult to quantify due to both conceptual and measurement issues (Barrett, 2010). Food security is conventionally defined in terms of availability, access and utilization of food, and the stability of these elements over time. It is evident that except in situations of subsistence agriculture, there is a very weak link between the production of agricultural commodities and the utilization of food by a household or an individual, because consumption of food in the household is separated from commodity production by a long chain of transportation, storage, processing, marketing, food preparation and utilization (Figure 1). Various quantifiable factors are used as food security indicators, including subjective feelings of hunger and objective measures of consumption or outcomes such as physical condition or health. All of these pose substantial data challenges as well as measurement problems.

Another major challenge to making future projections of food security is that scientific models (global climate,

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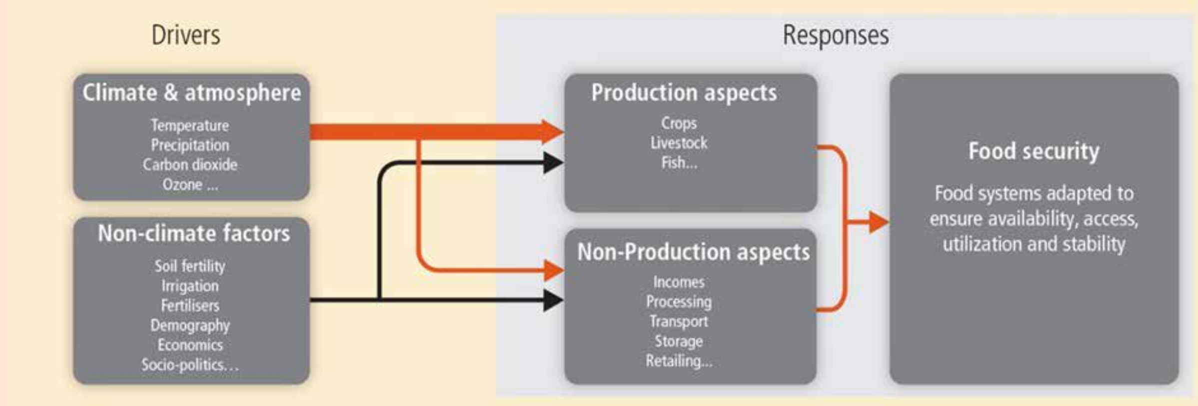
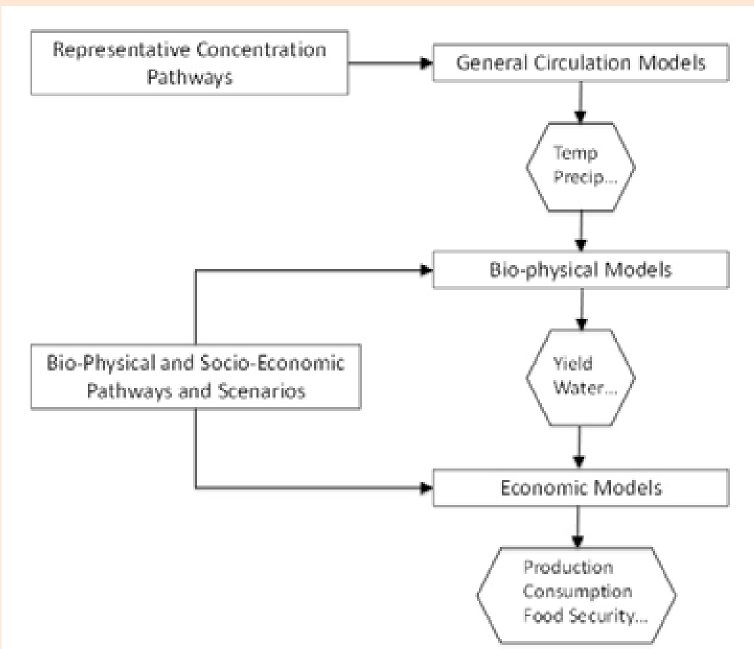
Figure 1. Drivers and Responses of Food Security



Source: Porter et al., 2014.

Figure 2. Integrated Assessment Framework for Agricultural and Food System Impact Assessments



Source: Wallach et al. 2015.

biophysical, and economic) are lacking for many of the food security outcomes that are identified in the scientific literature, although progress in modeling both nutritional and health outcomes and linking them to economic models is being made (Hawkesworth, Dagour, and Johnston 2010).

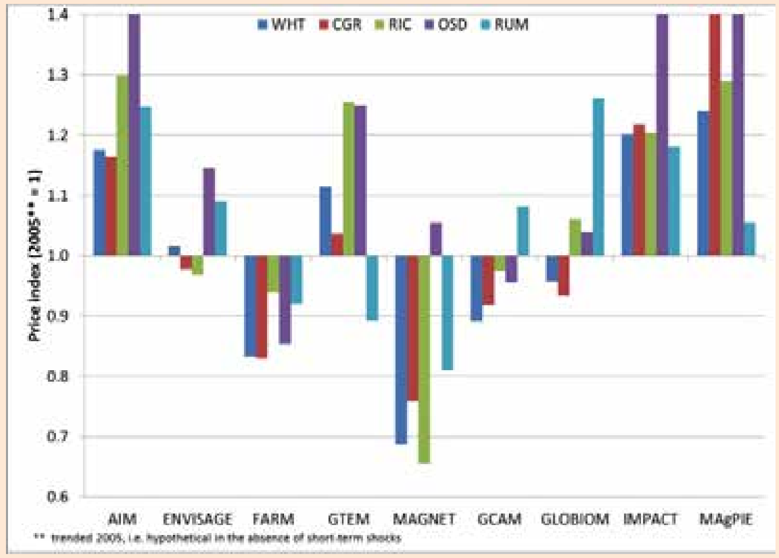
Quantifying Impacts of Climate Change on Agriculture and Food Systems

Figure 1 shows that the link from climate to food security involves a complex set of interacting systems. The main tools for projecting impacts of climate change on agriculture and food systems are models that represent some but not all of the components in Figure 2. Nelson et al., (2014) provide an overview of nine of the major modeling systems used for global agricultural assessments. In these assessments, climate projections from global climate models are used by biophysical models to simulate productivity effects of climate change as "shocks" or changes in exogenous conditions. These productivity impacts are then used as inputs to economic models that simulate equilibrium economic outcomes. Some economic models directly incorporate climate variables, thus bypassing the use of bio-physical simulation models. Each of the model components in Figure 2 are implemented using corresponding pathways and scenarios that define inputs into the models that represent the key non-climate future conditions. These factors define the socio-economic setting in which the analysis is couched and thus can strongly influence the outcomes of the analysis.

Global Model Projections and Uncertainties

In collaboration with the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-sectoral Impact Model Intercomparison Project (ISI-MIP), a group of nine major modeling teams completed the first global agricultural economic model intercomparison of climate change impacts in which all of the models used a standard set of scenarios linked to one emissions scenario and two socio-economic scenarios (Nelson et al., 2014; von Lampe et al., 2014). Importantly, these scenarios did not embody effects of increasing carbon dioxide (CO2) concentrations on crop yields, and used climate projections based on (RCP) 8.5, so in these dimensions they can be viewed as relatively pessimistic scenarios. However, these scenarios did incorporate a relatively optimistic set of projected crop yield growth rates to represent the impacts of ongoing productivity improvements, ranging from 1- 2.5% for major crops (wheat, coarse grains, rice, sugar, and oilseed) across the major regions of the world (von Lampe et al. 2014), so in this regard the scenarios can be viewed as somewhat optimistic.

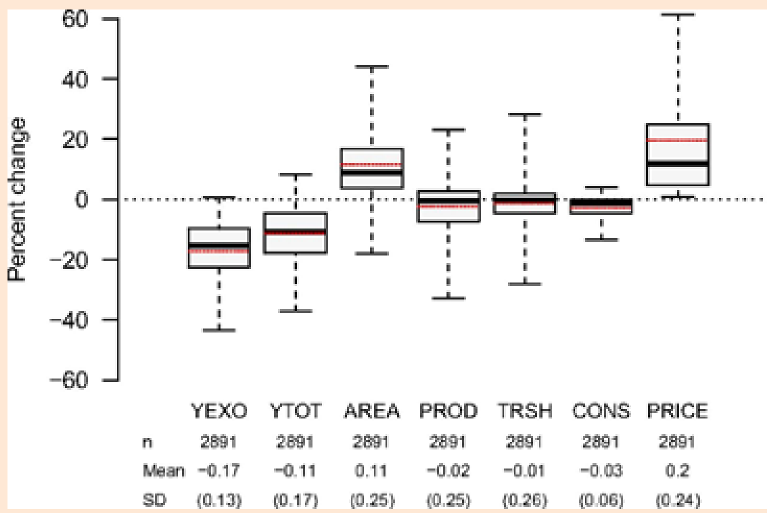
Figure 3. AgMIP Global Agricultural Economic Model Intercomparison, Projected Changes in Commodity Prices in 2050 without Climate Change



Note: WHT = wheat, CGR = coarse grains, RIC = rice, OSD = oil seeds, RUM = ruminant animal products
Source: Nelson et al., 2014.

Key findings of the AgMIP global agricultural model inter-comparison are summarized in Figures 3 and 4 (Nelson et al., 2014; von Lampe et al., 2014). Figure 3 presents price projections for five agricultural commodity groups (wheat, coarse grains, rice, oil seeds, and ruminant meat) for 2050 without climate change, but including other factors such as income growth, population growth, and trends in agricultural productivity. This figure shows how differently the nine models perform in terms of projecting future economic outcomes such as prices. The figure shows that some models project agricultural commodity prices could be up to 40% higher in the future relative to those observed today without climate change, while others show prices falling as much as 70%. Obviously, these findings indicate a high degree of uncertainty in these model projections, distinct from climate change effects, but they serve as a useful baseline for understanding potential changes due to climate change.

Figure 4. Ranges of Key Crop and Economic Model Results



Note: YEXO = yield effect of climate change without technical or economic adaptation, YTOT = realized yields with after management adaptation, AREA = agricultural area in production, PROD = total production, TRSH = net imports relative to domestic production, CONS = consumption, PRICE = prices Source: Nelson et al., 2014.

Projected crop yields are generally lower in most parts of the world with climate change, particularly in the latter half of this century, in the tropics, and under high emissions scenarios (Porter et al., 2014). Figure 4 summarizes the projected results for the impacts of climate change, using the nine global economic models in the AgMIP inter-comparison study. The lower yields are reflected in higher prices for most agricultural commodities, but the size of this effect varies widely across the models, and ranges from 0-20% for most models. Most models project some increases in land area under production, but little impact on trade or consumption.

Using Aggregate Model Projections to Assess Food Insecurity

In addition to the uncertainty in future price projections, another striking result from the model simulations presented above is that consumption is very stable, apparently because price increases stimulate production responses and trade. But how these changes would impact vulnerable populations—namely, the rural and urban poor—or how they would affect food access, availability, and utilization within countries or at the household level, cannot be ascertained from this data.

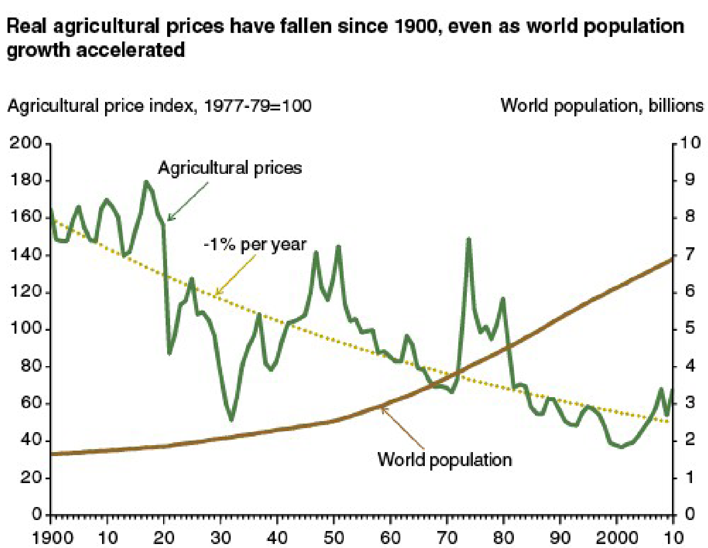
Several studies have attempted to bridge this analytical gap in global-scale models. One approach is to develop statistical links between projected changes in production or consumption to food security indicators. For example, Fischer et al., (2005) utilized the correlation between the share of undernourished in the population—as defined by the Food and Agriculture Organization (FAO)—and the ratio of average national food supply (including imports), relative to aggregate national food requirements, to assess the impacts of climate change on food security. Based on this relationship, and using a set of socio-economic scenarios, Fischer et al., (2005) projected an increase in the number of people "at risk of hunger," with their study projecting that an additional 175 million people could be undernourished in 2080 because of climate change. It is a projected 2.6% of the overall population of food insecure countries in 2080. Yet, this type of indicator is also highly aggregated and implies that undernourishment is only a problem of food availability. Moreover, this approach does not account for factors affecting food access, utilization, and stability within countries, and it must be assumed that the historical correlation between undernourished and food availability is stable over long periods of time.

Another example of an indicator used for economic outcomes on health and nutrition is the study by Nelson et al., (2010), which used per capita calorie availability from cereals and meat at the national level, and an index of child malnutrition. The percentage of malnourished children under the age of 5 was estimated using average per capita calorie consumption, assuming that other factors (life expectancy, maternal education, and clean water access) are constant in over time.

Based on this methodology, Nelson et al., (2010) found that climate change could result in price increases for the most important agricultural crops—rice, wheat, maize, and soybeans—and that higher feed prices will result in higher meat prices (the model used in this study is the IMPACT model which predicts higher baseline prices, and thus higher prices with climate change, see Figure 3). These price increases were projected to reduce the growth in meat consumption slightly and cause a more substantial fall in cereals consumption. Calorie availability in 2050 was projected to decline relative to 2000 levels throughout the developing world. By 2050, the decline in calorie availability will increase child malnutrition by 20% relative to a world with no climate change, and offset much of the improvement in child malnourishment levels that could occur without climate change.

This study shows how some aspects of food security can be elaborated, yet serious limitations associated with aggregate data and untested assumptions remain.

Figure 5. Long-run trend in real agricultural commodity prices



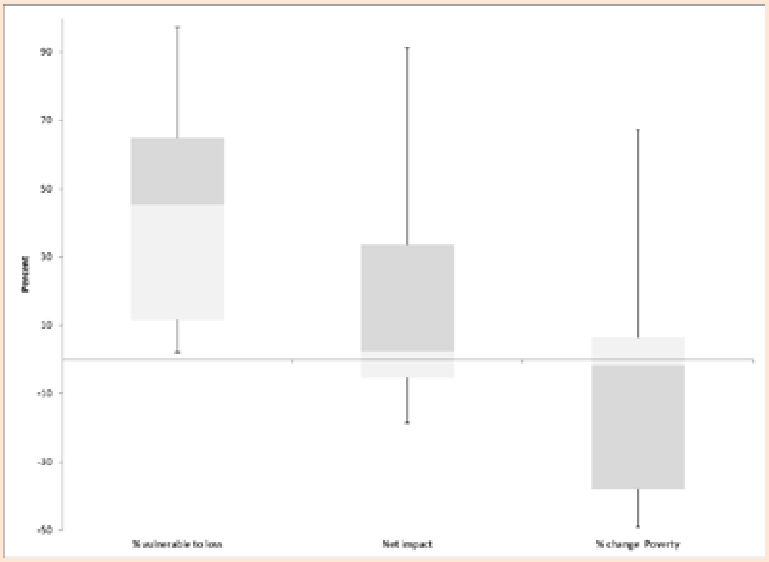
Source: USDA, Economic Research Service using Fuglie, Wang, and Ball (2012). Depicted in the chart is the Grilli-Yang agricultural price index adjusted for inflation by the U.S. Gross Domestic Product implicit price index. The Grilli-Yang price index is a composite of 18 crop and livestock prices, each weighted by its share of global agricultural trade (Pfaffenzeller et al., 2007). World population estimates are from the United Nations.

Prices, Price Instability, and Model Uncertainty

As the previously cited study suggests, a major factor in food security is the cost and availability of nutritious food, particularly for the poor who spend a large share of their income on basic food commodities.

We know that historically, agricultural commodity prices have declined in "real" terms for the past century or more, reflecting the fact that global agricultural production has increased at a faster rate than global demand, despite

Figure 6. Climate Change Impacts from AgMIP Regional Studies in Africa and South Asia Under Future Socio-Economics Conditions with Higher Agricultural Productivity and Higher Agricultural Prices, without Adaptation



Note: Vulnerability to loss and net impact are percent of farm income. Poverty is defined as the head-count ratio at a $1.25/person/day poverty line.

Source: Author's calculations based on data in Rosenzweig and Hillel (2015), various chapters.

population growth (Figure 5). A major question for the 21st Century is whether this long-term trend in prices is being reversed by the combined effects of demand growth, environmental degradation, reductions in productivity growth, and climate change. These considerations underscore the importance of the uncertainty in the baseline future price projections evidenced in Figure 3. Indeed, combining the data for prices in Figures 3 and 4, we have a remarkable implication: even though the global models generally project that climate change will tend to have a positive effects on future pries, it is possible that the downward effect of productivity increases could be larger, so that on net, future prices could be lower. We cannot say from these models whether one of the key factors for future food insecurity—food prices—will be higher or lower, due to the baseline model uncertainty.

This uncertainty is reinforced by Figure 5 which shows that the recent increases in food commodity prices observed in 2008-2009 and 2012 are relatively small in historical terms, and cannot be interpreted as evidence that the historical trend is being reversed. Indeed, as of this writing, real commodity prices have fallen back to near-historically low levels in real terms.

Figure 5 also shows that agricultural commodity prices have been unstable historically along this downward trend. One possible impact of climate change is an increase in extreme high temperatures by historical standards, as mean temperatures increase. Another important limitation of the impact assessment models is that they lack the storage and other mechanisms related to short-term market dynamics to meaningfully represent short term price variability caused by weather or other short-term events.

Regional Modeling Approaches

Since one of the limitations of existing models is their high level of aggregation, an alternative approach is to link global or national models to nationally disaggregated data (Hertel, Burke, and Lobell, 2010). While a step in the right direction, such efforts thus far use data averaged over relatively long time periods (for example, a year) and are not capable of dealing with short-term variability, due to data and model limitations.

AgMIP has developed a coordinated global and regional approach to integrated assessment to quantify the economic vulnerability of farm households. With better data, this approach can be applied to seasonally disaggregated data, and can be linked to food security indicators, such as those available in the Living Standards Measurement Surveys conducted by the World Bank (Antle et al., 2015). In this approach, global model simulations, such as those discussed above, are used to generate price changes and then used as inputs into regional assessments. The regional models simulate outcomes such as the regional distribution of production and income, and poverty rates and food security indicators.

AgMIP organized regional research teams in Sub-Saharan Africa and South Asia to assess climate impacts and adaptation in mid-century, all following the methodological design described in Figure 5 (Rosenzweig and Hillel, 2015). The AgMIP regional studies produced a number of indicators that are related to economic vulnerability, but did not include food security indicators (Figure 6). The results show a wide range of vulnerability to loss of farm income, on average 50% of the population under future conditions, even though the net or aggregate impact tends to be near zero so somewhat positive. Thus, it is clear that vulnerability to losses cannot be inferred from aggregate or average impacts.

Towards a Better Understanding of Vulnerability and Food Insecurity

How climate change will affect various economic, environmental and social vulnerabilities, including food insecurity, are very difficult questions.[1] In the aggregate, food availability does not appear to be threatened by climate change in the high-income regions of the world such as the United States (see Blanc and Reilly, 2015, this *Choices* theme). Yet it is clear that there are indeed significant risks to food security for the most vulnerable populations, even in rich countries. Data from the United States show that many poor households lack the income and other resources needed to ensure access and effectively utilize food, where the percentage of the food insecure population rose from 11 to over 14% during the recent economic recession (Coleman-Jensen, Gregory, and Singh, 2013). Even more severe food insecurity consequences have been documented for extreme weather events in other parts of the world (Coghlan et al., 2014). But to assess future food insecurity, we would have to be able to project how changes in income, food availability, and socio-economic factors affecting utilization and stability change over long periods of time. The challenges are even greater in the low and middle-income regions of the world that are likely to develop rapidly over the next decades. One only has to consider the large positive changes that have occurred in China over the past two decades, and that are likely to occur in Africa and South Asia in future decades, to realize the magnitude of the challenge.

What we do know is that our current methods of assessing vulnerability and food insecurity could be improved, through investments in better data and models. The data presented in Figure 6 demonstrate that economic vulnerability to climate change cannot be inferred from aggregate impacts, and this is likely to be even more true of food insecurity. This evidence suggests that better assessments of vulnerability and food insecurity will require better disaggregate data and corresponding models. Current efforts are underway by AgMIP in collaboration with the Center for Integrated Modeling of Sustainable Nutrition Security, and other organizations, to define a set of metrics for "sustainable nutrition security" and to improve data and models to quantify those metrics. These are positive steps towards achieving a better understanding of the risks to food security posed by climate change.

For More Information

Antle, J. M., R.O. Valdivia, K.J. Boote, S. Janssen, J.W. Jones, C.H. Porter, C. Rosenzweig, A.C. Ruane, and P.J. Thorburn. 2015. AgMIP's Trans-Disciplinary Agricultural Systems Approach to Regional Integrated Assessment of Climate Impact, Vulnerability and Adaptation. C. Rosenzweig and D. Hillel, eds. *Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments, Part 1.* London: Imperial College Press.

Acharya, T., J Fanzo, D. Gustafson, J. Ingram, and B. Schneeman. 2014. Assessing Sustainable Nutrition Security: The Role of Food Systems. ILSI Research Foundation, Center for Integrated Modeling of Sustainable Agriculture and Nutrition Security. Washington, DC. Accessible online: http://www.ilsi.org/ResearchFoundation/CIMSANS/Documents/CIMSANS-Sustainable-Nutrition-Security-FINAL%2030may2014.pdf.

Barrett, C. 2010. Measuring Food Insecurity. *Science.* 12 February: 825-828.

Challinor, A., K. Cochrane, M. Howden, M.M. Iqbal, D. Lobell, M.I. Travasso, N. Chhetri, K. Garrett, J. Ingram, L. Lipper, N. McCarthy, J. McGrath, D. Smith, P. Thornton, J. Watson, and L. Ziska (2013) "Food security and food production systems." In K.H. P. Aggarwal ed. *Climate change 2014: Impacts, adaptation, and vulnerability: Contribution of working group 2 to the fifth assessment report of the intergovernmental panel on climate change.* Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

Coghlan, C., M. Muzammil, J. Ingram, J. Vervoort, F. Otto, and R. James. 2014. A Sign of Things to Come? Examing Four Major Climate Related Disasters, 2010-2013, and Their Impacts on Food Security. Oxfam Resarch Report. https://www.oxfam.org/en/research/sign-things-come. Accessed April 9, 2015.

Coleman-Jensen, A., C. Gregory and A. Singh. 2013. Household Food Security in the United States in 2013. USDA Economic Research Report No. (ERR-173) 41 pp, September 2014.

Fuglie, K.O., S. L. Wang, and V.E. Ball (eds.). 2012. *Productivity Growth in Agriculture: An International Perspective.* CAB International, Oxfordshire, UK.

Hawkesworth S., A. D. Dangour, D. Johnston, K. Lock, N. Poole, J. Rushton, R. Uauy, and J. Waage. 2010. Feeding the World Healthily: The Challenge of Measuring the Effects of Agriculture on Health. Philos Trans R Soc Lond B Biol Sci 2010; 365: 3083–97.

Hertel, T. W., M. B. Burke, and D. B. Lobell. 2010. The Poverty Implications of Climate-Induced Crop Yield Changes by 2030. *Global Environmental Change, 20,* 577–585.

Nelson, G. C., H. Valin, R.D. Sands, P. Havlik, H. Ahammad, D. Deryng, J. Elliott, S. Fujimori, T. Hasegawa, E. Heyhoe, P. Kyle, M. Von Lampe, H. Lotze-Campen, D. Mason d'Croz, H. van Meijl, D. van der Mensbrugghe, C. Müller, A. Popp, R. Robertson, S. Robinson, E. Schmid, C. Schmitz, A. Tabeau, and D. Willenbockel. 2014. Climate Change Effects on Agriculture: Economic Responses to Bio-Physical Shocks. Proceedings of the National Academy of Sciences of the United States. 111(9): 3274–3279

Nelson, Gerald C., Mark W. Rosegrant, Amanda Palazzo, Ian Gray,Christina Ingersoll, Richard Robertson, Simla Tokgoz, Tingju Zhu, Timothy B. Sulser, Claudia Ringler, Siwa Msangi, and Liangzhi You. 2010. Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options. Washington, D.C.: International Food Policy Research Institute. doi:10.2499/9780896291867

Parry, M., C. Rosenzweig, and M. Livermore. 2005. Climate Change, Global Food Supply and Risk of Hunger. *Philosophical Transactions of the Royal Society B, 360,* 2125–2138.

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S. M. Howden, M. M. Iqbal, D.B. Lobell, and M.I. Travasso. 2014. "Food Security and Food Production Systems." In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Available online: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap7_FINAL.pdf

Rosenzweig, C. and D. Hillel, eds. 2015. *Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments, Part 2.* London: Imperial College Press.

von Lampe, M., D. Willenbockel, H. Ahammad, E. Blanc, Y. Cai, K. Calvin, S. Fujimori, T. Hasegawa, P. Havlik, E. Heyhoe, P. Kyle, H. Lotze-Campen, D. Mason d'Croz, G. C. Nelson, R. D. Sands, C. Schmitz, A. Tabeau, H. Valin, D. van der Mensbrugghe, and H. van Meijl. 2014. Why do Global Long-term Scenarios for Agriculture Differ? An Overview of the AgMIP Global Economic Model Intercomparison. Agricultural Economics 45:3-20.

Wallach, D., L.O. Mearns, M. Rivington, J.M. Antle and A.C. Ruane. 2015. Uncertainty in Agricultural Impact Assessment. C. Rosenzweig and D. Hillel, eds. *Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments, Part 1.* London: Imperial College Press.

Wheeler, T. and J. von Braun. 2013. Climate Change Impacts on Global Food Security. Science 341:508-513.

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Climate Change Impacts on U.S. Crops

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JEL Classifications: Q54, Q10
Keywords: Crop Yields, Climate Change, Adaptation

The Intergovernmental Panel on Climate Change's (IPCC) the Fifth Assessment Report (AR5) (Romero-Lankao et al., 2014) found that climate change is responsible in part for historical yield increases in the United States thanks to increased precipitation. Since 1999, however, yield losses have been attributed to extreme weather events, such as heat waves, storms, and droughts and the IPCC concludes that in many crop growing regions of North America optimum temperatures have been reached and further warming would be detrimental to crop yields.

What to Expect in the Future?

Annual mean warming over most of North America is expected to exceed the expected global mean warming (1.1°C and 6.4°C by the end of the century), according to the IPCC. Regionally, annual mean precipitation is expected to increase in the Northeast of the United States and decrease in the Southwest. Along with these changes in mean conditions, an increase in the frequency of extreme weather events such as droughts, floods, and heat waves are also anticipated. These extreme events are also predicted to last longer and be more intense.

As a consequence of rising temperatures, decreasing precipitation and a greater frequency of extreme events, the IPCC projects a decline in net productivity of the major crops grown in North America by the end of the 21st century, although the scale of the impact depends on the climate models and scenarios considered. Overall, the decline is expected to be modest in the first half of the century but sharper toward 2100. The United Kingdom's Met Office's (2011) review of climate change impact studies concurs and finds that although the extent of the impact varies across studies due to differences in methodology and assumptions, the general consensus is that climate change will lower yields for the most important crops: maize, soybean, and wheat.

Several studies have focused on California, one of the United States' most productive regions, and project small changes in yields for the mid-century and declines between 9 and 29% by the end of the century, assuming no constraint on water availability. Viticulture would be the most affected due to a decrease in land suitability for grapes. Some regions in the North where water availability is not an issue are expected to benefit from climate change.

Main Drivers: Temperature and Precipitation

The IPCC discerned two main factors of yield declines: temperature and water availability. Temperature increases are expected to be responsible for declines in corn, soy, and cotton yields of between 30 and 82% by the end of the century. It would also reduce the quality of certain crops (for example, coffee and grapes). The detrimental effect of rising temperatures is only partially offset by precipitation increases. In regions where precipitation is expected to decrease, the negative impact of temperature increases on crop yields and quality is expected to be accentuated.

The Role of Extreme Weather Events

Crop yields will also be affected by extreme events such as extreme heat, heavy downpours, storms, and droughts. The largest risk of heat stress is expected to be in central-North

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America by 2070. When considering droughts and adaptive capacity, the northeastern and southeastern United States are expected to be the most vulnerable.

Water Resources for Irrigation

Most studies evaluating the effect of climate change on crop productivity consider either rainfed crops or assume that water availability for irrigation is not a constraint. However, several river basins in the United States are already subject to water stress and others are expected to be in the coming decades. Changes in rainfall and its intensity (increases in runoff intensity reduces the rainfall infiltration rate to the crop root zone) will affect the availability of water resources and, along with temperature changes will also affect crop water requirements. A recent United States Department of Agriculture (USDA) report (Walthall et al., 2012) considers the changes in relative crop returns between dryland and irrigated crops to reflect the sensitivity of yields to climatic factors. They expect continuing rainfed production in the northern regions, where rainfall increases are likely to increase soil moisture reserves. However, a decline in soil moisture in the southern regions, which would entail a decrease in dryland yields, would justify irrigation subject to water availability. Water availability is expected to be a constraint in the West and Southwest, with soil moisture decreases projected in the spring and summer under the worst case scenario. Water withdrawals are expected to exceed freshwater resources by 40% in the Great Plains, making it the most exposed region to water stress. In the West, summer and fall water availability are expected to be affected by earlier snowmelt and reduced snowpack, even if precipitation is unchanged.

Indirect Effects of Climate Change

In addition to influencing yields through climate change, increases in greenhouse gas (GHG) emissions will also impact crops via carbon dioxide (CO_2) fertilization effects. According to the U.S. Global Change Research Program (2009), higher CO_2 concentration would enhance crop yields but would also favor weeds. This would entail greater use of pesticides or hamper crop yield growth gains. Additionally, climate warming could also lead to a spatial shift of invasive weeds toward the north.

Climate change will also have direct and indirect effects on crop productivity via soil erosion via changes in rainfall, snowmelt and wind. By changing crop mixes and management practices (such as irrigation) in response to climate change, farmers will change the erosion rate. Excessive erosion rates entail losses of soil productivity, fertility, organic carbon, and nutrients. Walthall et al., (2012) report estimates soil carbon losses of between 33 and 274% by the mid-century compared to the 1990s in 10 out of 11 regions of the corn-belt when accounting for changes in biomass and planting, tillage, harvesting dates, and adaptive changes in crop mixes.

According to Walthall et al., (2012), climate change, and especially temperature change, would also have an impact on crops via 'biologically mediated services', such as animal pollination, which is responsible for 75% of the global food crop pollination. A study simulating the effect of warming on pollinator activity found that some species of bees will provide increased pollination services, while those of the honeybee, which is currently the main crop pollinator, will decrease. Overall, due to different responses to temperature changes of various bee types, the gain from some bee species would compensate the loss of services form another, except in systems where honey bees are the only pollinator.

Adaptation

The climate change impact projections on crop yields mentioned above correspond to simulations with no adaptation assumed. According to the IPCC, North America has the potential to offset yield reductions under 2oC warming thanks to adaptation strategies. For instance, spatial shifts of crop varieties are expected to reduce yield losses by between 6 to 14%. However, at 4oC warming, the effectiveness of adaptation strategies will be reduced and necessitate more drastic adaptation measures, such as livelihood and production diversification.

Adaptation Strategies

Farmers can adopt two main strategies to adapt to changes in climate: changes in management practices, and changes in the location of production. In term of management strategies, farmers can adopt crop varieties better suited to new climate conditions and diversify their production to reduce their vulnerability. They can also adopt sustainable agronomic practices, such as low-tillage, live mulching or cover crops, and adapt sowing and planting dates or improve crop rotations.

Subject to water resource limitations, farmers can also adapt their irrigation strategies by expanding irrigation to previously rainfed land, or replacing irritation systems with improved irrigation technologies with better conveyance and application efficiency. However, changes in irrigation strategies would entail a change in crop selection by favoring high value crops or less water intensive crops. At a large-scale, adaptation can take the form of spatial shift of production, with cropland shifting to areas with better climatic conditions or water availability for irrigation.

In addition to yield growth, the effect of climate change can be compensated by a growth in crop production which can be obtained either by increasing cultivated land expansion and intensification the use of cropland already in use.

Intensification can be achieved by, for instance, the densification of planting, which can make better use of the land already cultivated by improving soil fertility management; or with irrigation which enables farmers to crop land multiple times a year.

The IPCC also suggests greater institutional support to producers, which is currently deficient in some regions, to enhance adaptation. Changes could be made in water resource infrastructure and institutions to improve water allocation. The development and dissemination of daily and seasonal weather forecasts would also enable farmers to be better prepared.

The Role of Technology

Technology has played an important role in historical yield increases. The 'green revolution' brought major productivity improvements since the 1960s with the intensification of machinery and fertilizer use, and economies of scale. More recently, biotechnology techniques have been used to develop new plant varieties in order to increase yields, tackle pest and diseases issues, and improve resistance to abiotic stresses such as droughts and cold temperatures.

According to the FAO (2002), "even if no more new technologies become available, there is still scope for increasing crop yields in line with requirements". For instance, it estimates that the ratio of wheat yields could be at least doubled by increasing actual yields to maximum yields obtainable under current technologies.

Impact of Adaptation

The potential role of adaptation in alleviating the effect of climate change on crops has generated considerable debate. On the one hand, agriculture is very diverse and practiced across a wide range of climates, indicating that farmers can adapt to local conditions. Farmers also respond to prices, as evidenced by commodity price spikes over the past 50 to 100 years that have been met with a large supply response that have in turn resulted in decades of depressed prices and excess supply. Cross-sectional econometric analyses that Mendelsohn, Nordhaus, and Shaw (1994) termed the 'Ricardian' approach have found adaptation to be a powerful force. On the other hand, some scholars think that there is limited scope for adaptation. Using panel data, studies such as Schlenker and Roberts (2009) find limited past adaptation of seed varieties or management practices. They also attribute recent yield declines with extreme events in the United States. From that perspective, there is concern that there are extreme conditions that are intolerable to crops.

Agronomic process-based models of crop growth combined with market models of supply and demand are another approach to evaluate the scope for adaptation (Rosenzweig et al., 2013). Although agronomic models consider, in great detail, the effect of weather, soil quality, CO2, and ozone on crop growth, they have difficulty accounting for the influence of pests, disease, management strategies, and technological progress—which on principle econometric studies account for (Attavanich and McCarl, 2014). These studies tend to find that modeled adaptation substantially alleviate yield losses, leading to a production impact a fraction of the initial yield loss but at added cost (Reilly et al., 2007).

With northern regions of the United States likely to benefit from warmer temperatures, climate change may entail northward migration of cropping areas. Walthall et al., (2012) report cites findings that the spring wheat belt is expected to move north by more than 10 degrees into western Canada by 2050. Warming would also increase wheat cultivated areas and winter-sown spring wheat would become more suited to the southern United States.

Over the last 30 years, earlier corn and soybean planting dates and lengthening of the growing season have contributed to greater yields. This trend is attributed only in a small part to warming of the mid-west, the rest being enabled by new cold tolerant cultivars and the adoption of new plating equipment and conservation tillage, which reduced the preparation time required before planting.

In a meta-analysis of more than 1700 global climate change impact assessments, Challinor et al., (2014) find that simulated yields are increased by between 7 and 15% by crop-level adaptations. The study does not provide U.S. specific results, but shows that adaptation is expected to be more beneficial for wheat and rice than for maize. Out of the different adaptation strategies considered in the various studies (changes in planting dates, fertilizer application, irrigation, cultivars, and other agronomic adaptation), changes in crop varieties is found to be the most effective.

Some strategies of adaptation also have co-benefits. For instance, no-till practices help reduce soil erosion and runoff by increasing water infiltration and soil organic matter while also reducing GHG emissions. Growing legumes and managing weeds on pastures is also a good way of improving productivity while sequestering carbon in soils. Crop diversification also alleviates the impact of climate change and reduces market shocks.

Limits to Adaptation

As the main limit to adaptation, Walthall et al., (2012) report highlights ecological constraints such as water quality and quantity and pollution, and social barriers such as the perceived need for adaptation, which is influenced by finances, political ideas, culture, and religious ideologies. Alternatively, some mechanisms could have unintended negative effect on adaptation. For instance, subsidized crop insurance and disaster assistance may limit the adaptation response such as diversification, at added costs to these programs. Another concern related to agriculture and climate change is that biofuels and reforestation as mitigation strategy would compete with traditional agriculture for land, possibly having a greater impact on markets than the direct influence of climate (Reilly et al., 2012).

U.S. Exports at Risk

Productivity of the major crops in the United States is expected to be affected by climate change. Although the United States has no food security issues, it is a major exporter of food crops and a decrease in crop yields could have serious implications for global food security. Adaptation has the potential to alleviate these yield losses, but ultimately, as stated by USDA in Walthall, et al. (2012): "the vulnerability of agriculture to climatic change is strongly dependent on the responses taken by humans to moderate the effects of climate change."

For More Information

Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, L.H. Ziska. 2012. "Climate Change and Agriculture in the United States: Effects and Adaptation." In *USDA Technical Bulletin* 1935.

Attavanich, W., and B. A. McCarl. 2014. "How Is Co2 Affecting Yields and Technological Progress? A Statistical Analysis." [In English]. *Climatic Change* 124, no. 4 : 747-62.

Challinor, A. J., J. Watson, D. B. Lobell, S. M. Howden, D. R. Smith, and N. Chhetri. 2014. "A Meta-Analysis of Crop Yield under Climate Change and Adaptation." *Nature Climate Change* 4, no. 4: 287-91.

FAO. 2002. "World Agriculture: Towards 2015/2030. Summary Report." Food and Agriculture Organization of the United Nations.

Mendelsohn, R., W. Nordhaus, and D. Shaw. 1994. "The Impact of Global Warming on Agriculture: A Ricardian Analysis." *American Economic Review* 84: 753-71.

Reilly, J., S. Paltsev, B. Felzer, X. Wang, D. Kicklighter, J. Melillo, R. Prinn, M. Sarofim, and C. Wang. 2007. "Global Economic Effects of Changes in Crops, Pasture, and Forests Due to Changing Climate, Carbon Dioxide, and Ozone." *Energy Policy* 35, no. 11: 5370-83.

Reilly, J.M., J. Melillo, Y. Cai, D. Kicklighter, A. Gurgel, S. Paltsev, T. Cronin, A. Sokolov, and A. Schlosser. 2012. "Using Land to Mitigate Climate Change: Hitting the Target, Recognizing the Trade-Offs." *Environmental Science and Technology* 46, no. 11: 5672-79.

Romero-Lankao, P., J. B. Smith, D. J. Davidson, N. S. Diffenbaugh, P. L. Kinney, P. Kirshen, P. Kovacs, and L. Villers-Ruiz. 2014."North America." Chap. 26 In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change*, edited by V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, *et al.*, 1439-98. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Rosenzweig, C., J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. Thorburn, J. M. Antle, *et al.* 2013."The Agricultural Model Intercomparison and Improvement Project (Agmip): Protocols and Pilot Studies." *Agricultural and Forest Meteorology* 170: 166-82.

Schlenker, W. and M. J. Roberts. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences of the United States of America* 106, no. 37: 15594-98.

United Kingdom Met Office. 2011. "Climate: Observations, Projections and Impacts."

United States Global Change Research Program. 2009. "Global Climate Change Impacts in the United States."

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The Inevitability of Climate Adaptation in U.S. Agriculture

Steven K. Rose

JEL Classifications: Q00, Q18, Q54, Q56, Q58
Keywords: Adaptation, Agriculture, Climate change, Economics

Globally, greenhouse gas (GHG) emissions have risen and are likely to continue to rise into the immediate future. As a result, the Intergovernmental Panel on Climate Change (IPCC) and the U.S. National Climate Assessment (NCA) expect climate change to continue, producing higher temperatures and changes in precipitation and extreme weather. Even under aggressive GHG reduction scenarios, some level of climate change is still expected.

Rose (2015) makes an argument for the inevitability of climate change. There are also magnitude and timing arguments that can be made (McCarl, Norton and Wu, 2015; IPCC, 2014) In particular, the IPCC future projections (IPCC, 2013) are summarized in Figure 1 and show temperature change under four alternative emission scenarios (called Representative Concentration Pathways, or RCPs). IPCC (2014) considered these projections and formed alternative futures as represented by the vertical lines and arrows that appear in the Figure.

A changing climate implies changing conditions for agricultural production in States, with among other things shifts in growing seasons, seasonal temperature extremes, precipitation patterns, and weather events. Midwestern farmers in the United States, for instance, could eventually experience annual average temperatures 10˚F higher than today with 30 to 50 additional frost free days and 0 to 9 additional consecutive dry days a year. The changes will vary from place to place across the United States and across countries, altering relative crop and livestock production possibilities. The net effect, however, at least in the near future, could be increases in agricultural production that benefit consumers but decrease producer revenue. Over the longer-run, climate change could be potentially damaging on net, as more extreme environmental changes increasingly stress agricultural production systems.

The state implications of climate change for agriculture will depend on the level of climate change and the ability to adapt. How society evolves and to what degree it manages the climate through GHG mitigation policies and/or geo-engineering solutions will determine the level of climate change. Geo-engineering strategies manage the earth's radiative balance with extreme technological solutions such as injecting aerosols into the upper atmosphere, placing shields in space to reduce incoming solar radiation, or sucking carbon dioxide (CO_2) directly out of the atmosphere. Adaptation, on the other hand, manages the climate change that occurs and maximizes returns in the new environment. Adaptation, however, is constrained by current knowledge, technology, markets, institutions, infrastructure, and policies. Planning decisions today will shape these dimensions and shape agriculture's ability to adapt in the future.

Emissions

Globally, GHG emissions have risen from 27 billion metric tons of CO_2 equivalents ($GtCO_2$-eq) in 1970 to 49 $GtCO_2$-eq today (in 2010). Future GHG emissions are uncertain and depend on population and economic growth, energy markets, technology, and climate policy. Scenarios of potential futures without additional policies to manage climate change indicate that GHG emissions could reach 58 to 96 $GtCO_2$-eq by 2050 and rise or fall beyond 2050 to 46 to 136 $GtCO_2$-eq by 2100 (Table 1). When there is a

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Table 1: Future Global Atmospheric Concentrations, GHG Emissions Changes and Temperature Changes*

Type of scenario	Concentrations in 2100 (CO_2-eq ppm)	CO_2-eq emissions		Change in CO_2-eq emissions relative to 2010		Change in global average annual temperature by 2100 (˚F)
		2050	2100	2050	2100	
Baseline futures	> 1000	74 to 96	85 to 136	52 to 95%	74 to 178%	3.9 to 12.9
	720 to 1000	58 to 75	46 to 84	18 to 54%	-7 to 72%	2.7 to 9.3
Climate policy futures	650 to 720	44 to 57	23 to 39	-11 to 17%	-54 to -21%	2.3 to 7.0
	580 to 650	30 to 61	-17 to 25	-38 to 24%	-134 to -50%	1.6 to 6.5
	530 to 580	26 to 52	-41 to 20	-47 to 7%	-183 to -59%	1.4 to 5.4
	480 to 530	21 to 37	-7 to 13	-57 to -25%	-114 to -73%	1.1 to 4.8
	430 to 480	14 to 29	-9 to 11	-72 to -41%	-118 to -78%	0.7 to 3.9

*Note: 5th to 95th percentile results shown for temperature changes, and temperature changes are relative to 1986-2005.

Source: IPCC WGIII (2014).

global climate change reduction goal, projected emissions range from 14 to 61 $GtCO_2$-eq in 2050 and negative 41 to positive 39 $GtCO_2$-eq in 2100, depending on the stringency of the goal. Negative emissions reflect the deployment of technologies that on net remove and store CO_2 from the atmosphere. Projections for the most stringent climate goals have emissions of 14 to 29 $GtCO_2$-eq in 2050, which is 41% to 72% below today's emissions. The most aggressive climate objectives of course have the highest projected economic costs and require a significant degree of international coordination in controlling emissions.

Inevitability of Adaptation

Even with the most stringent emissions futures, atmospheric concentrations of GHGs increase (Table 1). Concentrations increase with additional emissions despite future annual emissions lower than today because GHGs accumulate in the atmosphere. The long atmospheric lifetimes of GHGs mean that concentrations in the atmosphere today include emissions from previous decades and centuries, where the atmospheric lifetime depends on the type of GHG. Only when annual emissions are below the rate of natural and man-made withdrawal will concentrations decline.

Rising concentrations will increasingly prevent outbound radiation from escaping into space, and the resulting trapped energy contributes to climate change, including changes in average global temperature, the most publically prominent climate change indicator. By 2100, global average temperature could be anywhere from 0.7 to 12.9˚F warmer than today according to the IPCC (Table 1). Even with the lowest GHG emissions futures, global average temperatures are projected to rise by 0.7 to 3.9˚F by 2100. Some level of future climate change is therefore inevitable.

U.S. Climate Change and Agriculture

Climate change represents far more than just changes in temperature, with changes expected in a broad set of variables relevant to agriculture—temperature, precipitation, CO_2 levels, extreme weather, and potential extreme events. Also, climate change will vary by country, potentially favoring some countries and disadvantaging others. Climate changes would also vary dramatically within the United States—north to south and east to west. U.S. farmers, for example, could experience increases in average annual temperatures locally of 3 to 15˚F by the end of the century depending on future global emissions and a farmer's particular location, with warming greatest in more northern and inland states, including the Midwest and the Great Plains (Figure 1). For some U.S. farmers, climate change could imply longer growing seasons and earlier planting dates with enhanced crop growth due to elevated atmospheric CO_2 levels. But, climate change could also imply increases in consecutive dry days and the number of hot days each year, and increases in the frequency of heavy rainfall, extreme heat and severe drought, as well as increased frequency of weeds, diseases, and pests, crop and livestock heat stress, and reduced snowpack with water supply consequences.

Adaptation in Agriculture

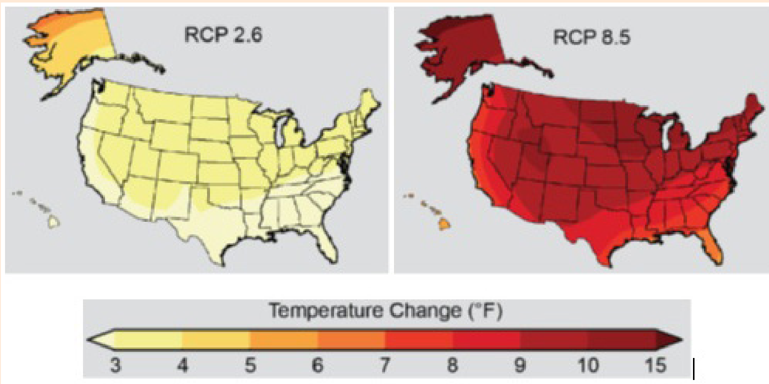
Adaptation is nothing new for agriculture. U.S. Farmers are adept at adapting to dynamic market conditions, weather, new technologies and knowledge, and policies. We see adaptation in year to year strategies to manage risks and exploit opportunities, and across states in differences in production systems suited to local productivity and economic conditions. Adaptation is evident in the expansion of corn production in response to renewable fuels policy, as well as the differences we observe in the agricultural output of California, Wisconsin, Texas, and New York.

Also, climate change is but one of many long-run forces shaping agriculture production. Technology, infrastructure, and policies (conservation, farm, energy, and trade) can shape U.S. agriculture for decades. Climate change will shape long-run agriculture with gradual shifts in temperature and precipitation. However, there are dimensions to climate change that may require more significant adaptation such as changes in the variability of weather and extreme weather events like droughts.

In general, there are three types of potential on-farm adaptation responses:

Adjusting management practices:

Figure 1: U.S. Temperature Change for a High (RCP 8.5) and Low (RCP 2.6) Global Emissions Future*



*Note: With respect to Table 1, RCP 8.5 and RCP 2.6 fall in the >1000 and 430-480 CO2-eq ppm 2100 concentration levels respectively. Values are changes between average annual temperatures for 2071-2099 relative to 1970-1999.

Source: NCA CH2 (2015).

continuing with the same production activity but adjusting inputs in response to the changing climate, such as shifting planting dates, increasing irrigation, or cooling livestock.

Changing production systems: shifting to an alternative, but existing, cropping or livestock system, e.g., altering crop or livestock mix, shifting rotations, abandoning or converting land.

Adopting new technology: adopting new technology developed for new climate conditions, e.g., new drought tolerant plant varieties, better water retention management strategies, or improved fertilizer or pest management.

Farmers already have the capacity to adapt to some climate change with a variety of response options at their disposal. Current knowledge, technology, markets, institutions, infrastructure, and policies give them the capacity and flexibility to make adjustments and adapt to new circumstances. However, adaptation potential is constrained by current capability in each of the above dimensions. Planning and investments, public and private, can increase farmers' adaptive capacity through:

Research – developing improved climate resilient practices, inputs, and technologies.

Extension and outreach – providing training and sharing of new knowledge (techniques and technologies).

Information networks – facilitating the informal direct exchange of practices and experiences and nurturing of new ideas amongst farmers.

Government policies – developing institutions, infrastructure, and market access, and helping to manage commodity risk.

Significant public and private sector planning and investments support today's farming, including substantial local research and outreach. U.S. agriculture's capacity to adapt to climate change in the future will be defined by today's planning and resulting developments for the potential climate challenges of tomorrow. Of course, the need to adapt will depend on future emissions and the corresponding shifts in potential temperature, precipitation, weather variability, and extreme events.

Economics of Adaptation

Farmers will adapt if it is valuable to do so, changing practices to avoid losses or pursue opportunities. Economic studies have explored past producer behavior to understand how farmers have responded to changing climatic conditions. This research has found farmers adjusting livestock species mix, numbers, and stocking rates, as well as shifting land between livestock and crop activities, all in response to changing average temperatures and precipitation (Seo and Mendelsohn, 2008a, 2008b; Mu and McCarl 2011). Economic modeling has also evaluated the potential future implications of climate change for U.S. farmers and consumers, finding adaptation to be a fundamental part of the story. Climate driven changes in planting dates, varieties, crop mix, land use, irrigation, and amendments reduce potential climate damages and may even result in net benefits (Adams et al., 1999; Reilly et al., 2003). Similarly, while crop, forage, and grazing yields could be significantly affected by a changing climate (with the potential for increased or decreased yields), changes in agricultural output are expected to be far less dramatic due to adaptation changes in inputs and land use (Reilly et al., 2007). Adaptation at a broader macroeconomic level is also expected with changes in agricultural trade patterns, regional food prices, regional food consumption, and non-agricultural consumption as resources shift between agriculture and non-agriculture sectors in the economy. Adaptation responses, from the farmer to the global economy, moderate the consequences of climate change. Economic studies like those mentioned above illustrate the value of past and future adaptation to agriculture.

Implicit in these studies is the capacity to adapt. Knowledge, technology, markets, infrastructure and policies define capacity and constrain the possibilities for adaptation. Planned improvements in these conditions can increase the capacity to further manage detrimental effects, as well as opportunities. Farmers will not be affected equally by climate change. Local climate change and adaption capacity will determine their situation.

Adaptation Challenges and Opportunities

Significant local changes in agricultural potential may result with climate change—changes that represent major shifts in production possibilities and profitability. Some existing crop and livestock lands may have significantly reduced productivity, while other lands become increasingly viable for agricultural production for the first time. Improving the capacity to adapt for these diverse circumstances will be a challenge. Research, education, and capital investments for maintaining existing production will be important, as will additional investments, market access, and policy planning to support and environmentally manage new agricultural systems and production locations. In addition, some communities may require economic support or re-training as agricultural production potential diminishes relative to other locations. Initiatives, like USDA's regional climate hubs, capacity building partnerships, and decision support-tool development, will contribute to the future climate resiliency of U.S. farmers and agriculture communities.

Some degree of climate change is expected to occur even under the most aggressive GHG emissions reduction scenarios. It is, therefore, likely inevitable that farmers will have to adapt to new temperature, precipitation, weather extreme, and extreme event conditions. The need to adapt will depend on the level of climate change. Farmers are adept at adapting to evolving conditions; however, future climate change could be significant. The ability to adapt depends on the state of knowledge, technology, markets, infrastructure and policies, and could be enhanced with adaptation planning in research, extension and outreach, information networks, and government programs and policies.

For more information

Adams, R.M., B.A. McCarl, K. Segerson, C. Rosenzweig, K.J. Bryant, B.L. Dixon, J.R. Conner, R.E. Evenson, and D.S. Ojima. 1999. "The Economic Effects of Climate Change on U.S. Agriculture," in *The Impact of Climate Change on U.S. Agriculture,* Edited by R. Mendelsohn and J. Newmann, Cambridge University Press, London, 18-54. Available online: http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/724.pdf.

Clarke L., K. Jiang, K. Akimoto, M. Babiker, G. Blanford, K. Fisher-Vanden, J.-C. Hourcade, V. Krey, E. Kriegler, A. Löschel, D. McCollum, S. Paltsev, S. Rose, P. R. Shukla, M. Tavoni, B. C. C. van der Zwaan, and D.P. van Vuuren. 2014. Assessing Transformation Pathways. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hatfield, J., G. Takle, R. Grotjahn, P. Holden, R. C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. Ch. 6: Agriculture. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 150-174. doi:10.7930/J02Z13FR.

Mu, J.H., B.A. McCarl. 2011. Adaptation to Climate Change: Land Use and Livestock Management Change in the U.S. Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Corpus Christi, TX, February 5-8, 2011.

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso. 2014. Food Security and Food Production Systems. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533.

Reilly, J., S. Paltsev, B. Felzer, X. Wang, D. Kicklighter, J. Melillo, R. Prinn, M. Sarofim, A. Sokolov, C. Wang. 2007. Global Economic Effects of Changes in Crops, Pasture, and Forests Due to Changing Climate, Carbon Dioxide, and Ozone. *Energy Policy* 35, 5370–5383.

Reilly, J., F. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, C. Izaurralde, S. Jagtap, J. Jones, L. Mearns, D.Ojima, E. Paul, K. Paustian, S. Riha, N. Rosenberg, and C. Rosenzweig, 2003. U.S. Agriculture and Climate Change: New Results, *Climatic Change* 57: 43–69.

Seo, N. and R. Mendelsohn. 2008a. Climate Change Impacts on Latin American Farmland Values: The Role of Farm Type. *Revista de Economia e Agronegocio* 6, 159-176.

Seo, N. and R. Mendelsohn. 2008b. Measuring Impacts and Adaptation to Climate Change: A Structural Ricardian Model of African Livestock Management. *Agricultural Economics* 38, 150-165.

USDA. 2014. *United States Department of Agriculture Climate Change Adaptation Plan*. (June). Available online: http://www.usda.gov/oce/climate_change/adaptation/adaptation_plan.htm.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Ch. 2: Our Changing Climate. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.

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Elaborations on Climate Adaptation in U.S. Agriculture

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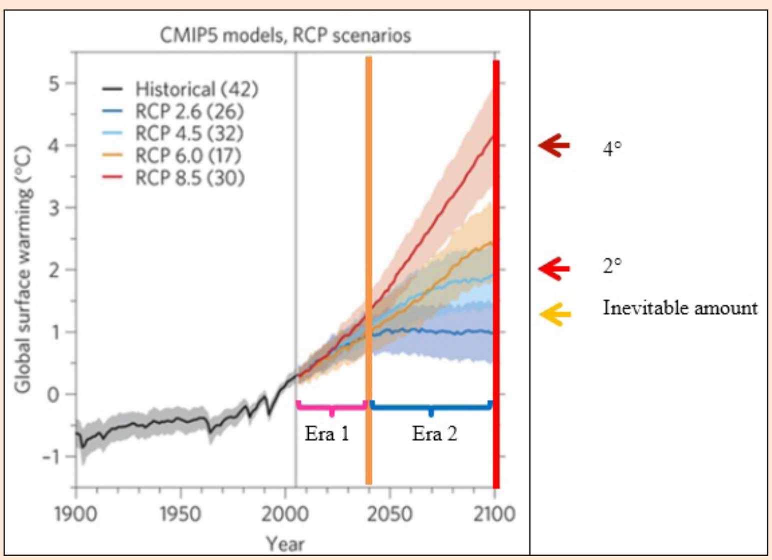
JEL Classifications: Q1, Q5
Keywords: Adaptation, Burden Sharing, Climate change, Limits, Public Role

Adaptation as defined in Intergovernmental Panel on Climate Change (IPCC), (2014) is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. Climate change is likely to be a large challenge for the agricultural sector and society over the next 25 years and requires a large amount of effort be directed to adaptation options.

Figure 1: IPCC Graph of Future Temperature Change under Alternative Emission Scenarios



Source: Adapted from Knutti and Sedláček, (2013) with the vertical lines, arrows and era markings added for exposition here.

More on Inevitability

Rose (2015) makes an argument for the inevitability of climate change. There are also magnitude and timing arguments that can be made (McCarl, Norton and Wu, 2015; IPCC, 2014) In particular, the IPCC future projections (IPCC, 2013) are summarized in Figure 1 and show temperature change under four alternative emission scenarios (called Representative Concentration Pathways, or RCPs). IPCC (2014) considered these projections and formed alternative futures as represented by the vertical lines and arrows that appear in the Figure.

Two eras of climate change are portrayed in Figure 1. Era 1 is the period between now and 2040 and Era 2 the time period between 2040 and 2100. Also note that the data in the black line represents actual historical observations to date showing past change in climate.

During era 1, the next 25 years, climate change follows one basic path regardless of mitigation effort with the amount of warming essentially the same across all emission scenarios at about 1°C for 2040. Agriculture will likely confront this inevitable amount of temperature change and must prepare to adapt to it. Beyond that the emission scenario results diverge depending on mitigation effort (where RCP8.5 has much less effort than say

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RCP4.5). Neglecting the unrealistic RCP2.6 case, the era 2 cases show a temperature change spanning between 2 and 4 °C. Thus the adaptation challenge—How can agriculture prepare itself for a 1°C change in the next 25 years and 2-4°C degrees by the end of the century?

Nature of Possible Adaptations and Roles

Adaptations can involve actions that, following IPCC (2014), alter management, infrastructure, technology, information, education, institutions, norms, behavior, emergency response, and public assistance. There are also natural adaptations with, for example, birds, pests, and fish moving their geographic range, or ecosystems changing to accommodate an altered climate.

Some of these items have public good characteristics in that individuals will not readily invest in them as they cannot fully capture the benefits while others are beyond the capabilities of individuals or are much more expensive than an individual can afford—such as developing new crop varieties, building a sea wall, providing extension information, financing insurance (Mendelsohn, 2000). This introduces two forms of adaptation: private/autonomous and public, or also known as planned in the climate change literature. The private adaptations are those that individuals undertake in their own best interests while the planned are implemented by governments, Non-Governmental Organizations (NGOs) and others in the social interest. A list of possible adaptation categories with an indication of whether the actions will be public or private follows:

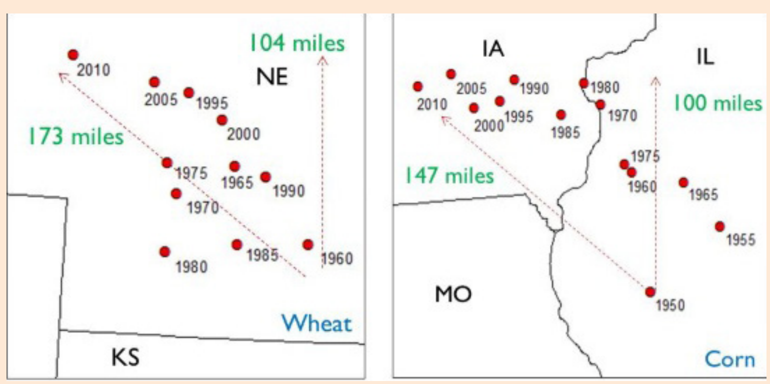
- Altered patterns of enterprise management, facility investment, enterprise choice, or resource use (mainly private).
- Direct capital investments in public infrastructure (for example, water management, roads—mainly public).
- Technology development through research (for example, development of crop varieties—private and public).
- Altered patterns of facility location for commodity movement and processing (mainly private).
- Creation and dissemination of adaptation information (through extension or other communication vehicles—mainly public).
- Education (for example, investment in adaptation ability— private and public).
- Redesign or development of adaptation institutions (for example, altered forms of insurance or extreme event early warning—private and public).
- Changes in norms and regulations to facilitate private actions (for example, altered building codes, technical standards, regulation of grids/networks/utilities, or environmental regulations—mainly public).
- Alterations in individual behavior (private, with possible public incentives)
- Altered emergency response procedures and crisis management (mainly public).
- Public assistance in implementing adaptation (providing loans or facilitating migration).
- Managing the unmanaged where unmanaged ecosystems have adaptation facilitated by management actions (for example, moving butterfly populations or sugar maple seeds—mainly public).

Adaptation and Agriculture: Status and Concerns

Agriculture is fundamentally an adaptation enterprise with different production systems arising geographically in response to local climate and other conditions. However, most of the adaptation actions that have arisen have been tailored to a stable, but variable, climate and have been in place for a substantial time period. Nevertheless, recent climate change related adaptations have been observed with changes in crop mix (Figure 2—Attavanich et al., 2011)—which is an update of Reilly et al., (2003), land use (Mu, McCarl, and Wein, 2013) and livestock breeds (Zhang, Hagerman, and McCarl, 2013) among many other items.

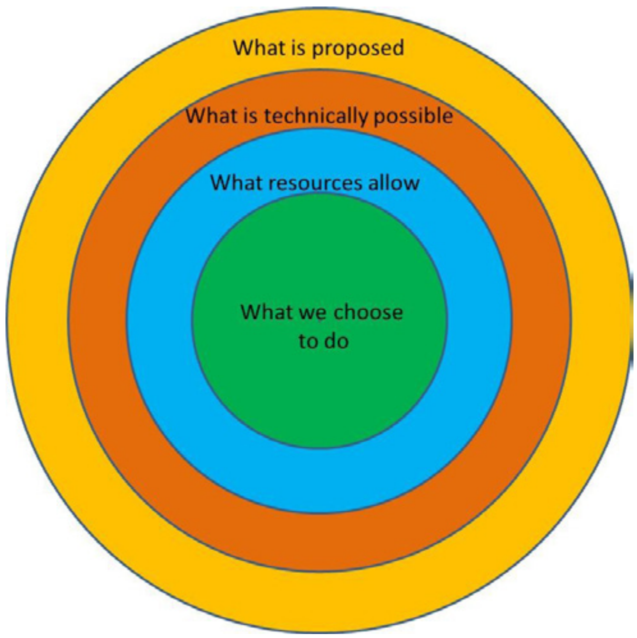
Climate change portends a need for more active, ongoing adaptation to maintain productivity as climate alterations occur. This implies a need for ongoing adaptation as a regular part of the enterprise and also raises several possibilities including:

Figure 2: Production-Weighted Centroid Location of U.S. Wheat and Corn Production in 1950–2010



Source: Based on historical data from Attavanich et al., 2011.

Figure 3: The Narrowing of Adaptation from the Space of All Possible Adaptations to What Will Be Done.



Source: Adapted from IPCC, 2014, Figure 17-1.

First, there are agricultural systems that currently have an adaptation deficit in that there are unused beneficial adaptations which could yield improved performance under current climate conditions. Economically such deficits are rational if the local costs of implementing an adaptation strategy considering scarce resources exceed its benefits.

Second, some adaptation actions may lead to maladaptation when their implementation worsens adaptation status of the parties undertaking the adaptation, parties elsewhere or parties in the future. For example, actions may be poorly designed where, abandoning a risk managing diversified agricultural system in favor of a growing single high valued crop may worsen performance in a variable climate (McDowell and Hess, 2012). Similarly, protecting one area from flooding may worsen it in other areas. Finally, current activities may enhance adaptation for short time but then worsen it in the future. For example, installing a sea wall that protects against a 100 centimeter sea level rise would encourage added investment in the protected area would certainly place more assets at risk when the sea level rise exceeds one meter. From an economic viewpoint maladaptation is not unexpected and one would consider whether the local gains to those adapting now exceed the losses to those whose adaptation is worsened with consideration of discounting.

Third, adaptation is likely to be less effective the more climate changes and the more invested in adaptation (Parry et al., 2013). Economically this implies diminishing marginal returns to climate investment.

Fourth, there will be residual damages as adaptation cannot economically or technically overcome all climate effects in a meaningful time period. This is especially true of irreversible effects like glacier melting or species extinction. From an economic viewpoint residual damages are rational when the marginal costs of reducing the damages exceeds the amount of the damages.

Fifth, adaptation activities are going to be highly localized with a no global prescriptions possible for adaptation to specific strategies but rather a tailoring of strategies to local conditions uniformly needed.

Limits and Attitudes

While many forms of adaptation are possible not all will ever be employed due to limits and attitudes. Following discussion in IPCC, 2014 chapter 17, a conceptual way of considering the causes of a gap between potential and implemented adaptations is portrayed in Figure 3.

The outside circle represents the full set of adaptation actions that are suggested. The second circle represents the subset of adaptation actions that are possible after considering technical and physical limits like water availability, the intractability of restoring outdoor temperatures, and limited technology availability. The third circle represents the subset of adaptation actions that are desirable considering limited financial, human, and infrastructure resources. The inner circle represents what will be done, taking into account decision maker objectives, attitudes, market failures, political, and institutional constraints. The area between the first and the last circles is residual damages, because adapting to them is impossible, too expensive, or not deemed desirable.

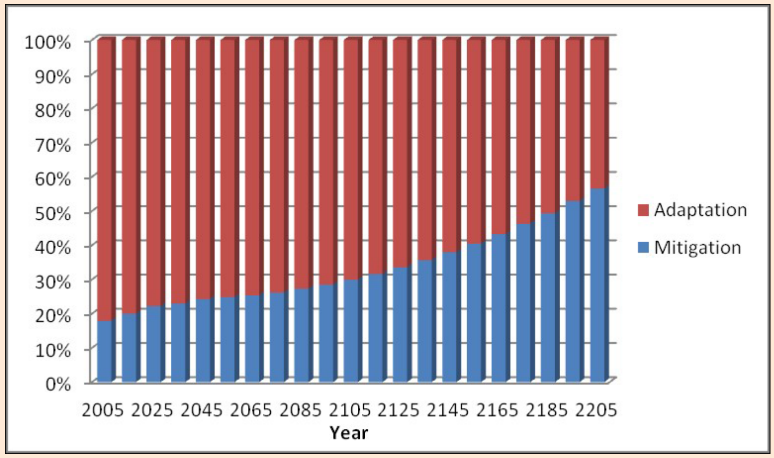
Total Costs and Burden of Adaptation

Globally, adaptation is likely to be a costly enterprise. The IPCC (2014) chapter 17 reviews the few available estimates of global costs and indicates that, for agriculture, they range from $7-8 billion U.S. Dollars (USD) per year with much of the cost in low income countries. On the other hand, global estimates of the expenditures in 2011 are estimated at $244 million USD (Elbehri et al., 2011) showing an underinvestment gap. Note these are crude estimates as discussed in IPCC, 2014 Chapter 17, but nevertheless, they show adaptation will be expensive and the adaptation deficit may well be growing. They also point out the need for global participation in adaptation financing particularly since it has been argued that the burden should be borne not only by those adapting but also by those emitting greenhouse gasses (GHG) who are also wealthier (Delink et al., 2009).

Mix of Adaptation and Mitigation

Climate change effects can be reduced through both mitigation and adaptation. The question is, what is the appropriate mix? The material above shows that mitigation—emission reduction—does not have major effects until post 2040 so adaptation is certainly appropriate today. However sole reliance on adaptation leads to diminishing returns and effectiveness. Furthermore, money spent on mitigation or adaptation precludes levels of investment in other items such as infrastructure or research and development plus trades off with consumption. Thus the issue is: What is the appropriate level of climate investment versus traditional consumption and investment considering the effects that climate change would have on well being? Wang and McCarl, (2013) studied this in a global modeling setting. They found that there was an optimum mix that included both adaptation and mitigation where adaptation constitutes more than 50% of the total climate related investments until 2200 but mitigation dominates thereafter (Figure 4). Naturally there are a lot of assumptions behind this and one should not rely on the quantitative results but it does show qualitatively that adaptation is dominant in the near term with mitigation taking over as the climate change gets larger.

Figure 4: Temporal Investment (percentage) of Adaptation and Mitigation in the Model with Both Adaptation and Mitigation Investment Allowed



Source: Wang and McCarl, (2013).

Concerns

Adaptation is clearly a principal and inevitable concern. Agricultural leaders and others need to prepare for a 1°C change in the next 25 years and 2-4°C degrees by the end of the century. Many strategies are possible and there is a strong need for both private implementation and public facilitation. Additionally, in cases, we may need to adapt systems that previously were unmanaged and natural. Clearly not all potential adaptations will be implemented with practicality, resources, attitudes, and objectives determining the mix put on the ground. Today adaptation appears to be the dominant short term strategy but investment is low relative to needs and an adaptation deficit is likely growing. The real issue is will we keep up with adaptation avoiding a large deficit and excessive residual damages plus avoid cases of gross maladaptation.

For More Information

Attavanich, W., B.A. McCarl, S.W. Fuller, D.V. Vedenov, and Z. Ahmedov. 2011. "The Effect of Climate Change on Transportation Flows and Inland Waterways Due to Climate-Induced Shifts in Crop Production Patterns." Presented at 2011 AAEA & NAREA Joint Annual Meeting in Pittsburgh..

Dellink, R., M. den Elzen, H. Aiking, E. Bergsma, F. Berkhout, T. Dekker, and J. Gupta. 2009. "Sharing the Burden of Financing Adaptation to Climate Change." *Global Environmental Change*, 19, 411-421.

Elbehri, A., A. Genest, and M. Burfisher. 2011. *Global Action on Climate Change in Agriculture: Linkages to Food Security, Markets and Trade Policies in Developing Countries.* Trade and Markets Division, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 82 pp.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC. 2014. *Climate Change 2014, Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

Knutti, R. and J. Sedláček, 2013. "Robustness and uncertainties in the new CMIP5 climate model projections." *Nature Climate Change* 3, 369–373.

McCarl, B.A., R.D. Norton, and X.M. Wu. 2014. *Assessing Climate Change Effects of IDB Projects: Concepts and Procedures*, Interamerican Development Bank.

Mendelsohn, R. 2000. "Efficient Adaptation to Climate Change." *Climatic Change* 45, 583-600.

McDowell, J.Z. and J.J. Hess. 2012. "Accessing Adaptation: Multiple Stressors on Livelihoods in the Bolivian Highlands Under a Changing Climate." *Global Environmental Change*, 22, 342-352.

Mu, J.E., B.A. McCarl, and A.M. Wein. 2013. "Adaptation to Climate Change: Changes in Farmland Use and Stocking Rate in the U.S." *Mitigation and Adaptation Strategies for Global Change*, 18, 713-730.

Parry, M., N. Arnell, P. Berry, D. Dodman, S. Fankhauser, C. Hope, S. Kovats, R. Nicholls, D. Satterthwaite, R. Tiffin, and T. Wheeler. 2009. *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates*. International Institute for Environment and Development (IIED) and Grantham Institute for Climate Change, London, UK, 111 pp.

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S. M. Howden, M. M. Iqbal, D.B. Lobell, and M.I. Travasso. 2014. "Food Security and Food Production Systems." In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Available online: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap7_FINAL.pdf

Reilly, J.M., F. Tubiello, B.A. McCarl, D.G. Abler, R. Darwin, K. Fuglie, S.E. Hollinger, R.C. Izaurralde, S. Jagtap, J.W. Jones, L.O. Mearns, D.S. Ojima, E.A. Paul, K. Paustian, S.J. Riha, N.J. Rosenberg, and C. Rosenzweig. 2003. "U.S. Agriculture and Climate Change: New Results." *Climatic Change,* 57, 43-69.

Rose, S.K. 2015. "The Inevitability of Climate Adaptation in U.S. Agriculture." *Choices Vol* 30 (2).

Wang, W.W., and B.A. McCarl. 2013. "Temporal Investment in Climate Change Adaptation and Mitigation." *Climate Change Economics*, 4.

Zhang, Y.W., A.D. Hagerman, and B.A. McCarl. 2013. "How Climate Factors Influence the Spatial Distribution of Texas Cattle Breeds." *Climatic Change*, 118, 183-195.

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Why Have Carbon Markets Not Delivered Agricultural Emission Reductions in the United States?

Brian C. Murray

JEL Classifications: Q18, Q54
Keywords: Climate change, Greenhouse gas mitigation, Carbon markets, Agriculture

Toward the end of the last decade, many believed domestic U.S. climate policy would stimulate strong action to reduce greenhouse gases (GHG) in agriculture and forestry (Metcalf and Reilly, 2008). This belief was rooted in the expectation that the U.S. Congress would pass, and the new president would sign into law, comprehensive "cap-and-trade" legislation to limit and reduce GHGs from most major emissions sources in the economy. Cap-and-trade is a market-based approach designed to meet an aggregate emissions limit by issuing "allowances" to emit and permitting regulated entities to trade allowances among themselves. This system establishes a market price for emissions and provides more flexibility and cost-effectiveness than a system with fixed emissions limits imposed on each source.

Studies conducted during last decade's policy debate showed that changes in agriculture, forestry, and land use (AFOLU) could produce economically attractive GHG reductions (mitigation) that would compete favorably with reductions from other sectors. One study showed enough mitigation potential from AFOLU to offset almost all of the emissions from the electric power sector—the nation's largest source of emissions—with high, but plausible economic incentive levels (Murray et al., 2005). With a powerful mandate to reduce emissions and an economic advantage in doing so, the reasoning followed that GHG mitigation would be the "agricultural commodity of the 21st century" (Reed, 2012).

As of 2015, things have not turned out this way. I offer several reasons why.

The Federal "Cap-and-Trade" Bill Never Materialized

In 2009, the U.S. House of Representatives narrowly passed (219-212) a comprehensive cap-and-trade bill introduced by Representative Henry Waxman (D-CA) and Representative Edward Markey (D-MA). The Waxman-Markey bill, officially The American Clean Energy and Security Act of 2009 (ACES)—H.R. 2454 of the 111th Congress—placed a cap on emissions from the electric power, industrial and transportation sectors, which together accounted for nearly 85% of all U.S. emissions. The initial cap was set to achieve relatively modest reductions at the time of inception in 2012, and then would be ratcheted down annually until an 83% reduction was achieved in 2050.

Agriculture and forest emissions were not directly regulated by the Waxman-Markey emissions cap, but actions to reduce emissions and enhance carbon sinks from these sectors could generate "offset" credits that could be sold to regulated sources in the capped sectors. The system provided agriculture and forestry with no obligation to reduce emissions, but a potentially strong incentive to voluntarily produce offsets. The U.S. Environmental Protection Agency's (EPA) advance economic modeling of the Waxman-Markey bill projected a very strong role played by domestic U.S. offsets, mostly from forestry and agriculture, in meeting the capped sector's compliance obligations, with up to 185 million tons of equivalent carbon dioxide (CO^2e) of reductions generated in 2020, accounting for about 20% of all domestic compliance in that year (U.S. EPA, 2009). Had these projections materialized, this clearly would have

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had a substantial impact on the way U.S. agricultural and forest lands were managed.

After passage in the house, the Waxman-Markey bill moved to the Senate, where it faced a tough battle for advancement, even with bipartisan co-sponsorship by Senators John Kerry (D-MA), Lindsey Graham (R-SC), and Joseph Lieberman (I-CT). By 2010, the U.S. and world's economy remained in very poor condition following the global financial and economic crisis of 2008-2009. Moreover, Congress and the administration had just engaged in a highly charged political battle over health care reform. Over the course of the year it became apparent that the 2010 mid-term elections would likely change the balance of power in Congress, which it did by delivering a House majority to the Republicans. These factors together combined to provide a roadblock to passage of any legislation as significant as a comprehensive cap-and-trade bill. That situation has not changed much since then.

Where Cap-and-Trade Programs do Exist, Agricultural Offsets Play a Minor Role

Although a federal cap-and-trade program did not materialize, the state and regional cap-and-trade programs in the United States have emerged in California and the northeastern United States to create a smaller and more fragmented market for carbon offsets. Although forest activities have featured prominently in these programs, changes in agricultural management have not.

California

California's statewide cap-and-trade program, used to meet part of its GHG reduction obligations under AB 32—Global Warming Solutions Act of 2006—places a cap on GHG emissions from the state's power, industrial, and transportation sectors. Regulated entities within those sectors can meet their compliance obligations in part through the use of offsets from uncapped sectors. Although offsets used in California can be generated outside the state, California currently restricts offsets to verified emission reductions from the following types of activity:

- Forest carbon—reforestation, improved forest management, avoided conversion, and urban forestry in the United States.
- Capturing and Destroying Methane from Manure Management Systems
- Mine methane capture
- Ozone depleting substances (ODS)

California also plans to add a category of offsets from international reduced emissions from deforestation and degradation (REDD) and rice methane capture. While the California offsets program allows virtually all forest carbon activities with mitigation potential, the same cannot be said of agriculture. Methane (CH^4) from livestock manure and rice are important sources, but they only account for 12% of all agricultural emissions in the United States. The other significant sources of emissions reduction potential in agriculture include nitrous oxides (N^2O) from fertilizer management and reduced enteric methane from livestock, which together accounts for 83%t of agricultural emissions. Thus, much of the mitigation potential from United States agriculture is left out of the mix in California. Moreover, only 8% of compliance obligations in California can be met by offsets of any type, further limiting the potential scale of agricultural mitigation.

Regional Greenhouse Gas Initiative (RGGI)

The RGGI program regulates emissions from electric power plants in nine northeastern states through a cap-and-trade program are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. Like California, RGGI allows offsets from uncapped sectors but in the case of RGGI, the offsets must be generated on projects within the RGGI region unless a Memorandum of Understanding (MOU) with an outside state is signed. And, like California, the only agricultural activity permitted as a RGGI offset is methane capture from manure management. Credits from forest carbon sequestration projects are allowed as offsets, as are those from projects to reduce landfill methane, sulfur hexafluoride (SF6), and CO^2 from energy efficiency improvements. Offsets are limited to comprise no more than 3.3% of a regulated entity's emissions compliance obligation. In practice, RGGI offsets have been very limited in use, in part because the RGGI carbon market price has been so low due to a variety of factors that have reduced allowance demand—the availability of low cost and lower-emitting natural gas, the economic recession since 2008-2009 (right at the time of RGGI's launch), and complementary environmental policies (Murray, Maniloff and Murray, 2014). However, in 2014 the RGGI cap has been tightened and carbon prices have risen substantially, from less than \$2/ton in 2013 to more than \$5/ton in early 2015. However, these prices are still on the low end of what it would likely take to induce much mitigation from agricultural and forest offsets.

Regulators' Caution?

Why is agricultural offset eligibility so limited in these regional programs? It may be due to an abundance of caution. First, significant concerns have been raised about offsets in general, in particular, whether they generate real emission reductions that are valid as credits against regulated emissions (Wara and Victor, 2008). Significant among these concerns is non-additionality—whether credits are granted for emission "reductions" that would have happened anyway through business as usual. There are also objections in some corners to the notion that entities in regulated sectors should not be able to "buy their way out" of reducing emissions by paying unregulated producers to do so, but these objections are more philosophical than technical.

Agriculture and forestry introduce their own special circumstances where offsets are concerned (Murray, Sohngen, and Ross, 2007). Regarding additionality, should a farmer earn offset credits for no-tillage agriculture or planting trees when that is the most profitable action to take anyway? Another consideration is non-permanencewhat if credits are granted for carbon sequestered in one year that is released to the atmosphere five years later in a fire? Agricultural emissions are also relatively difficult to measure, report, and verify, especially major sources like N2O from fertilizer use and CH4 from enteric fermentation in livestock. In fact, direct measurement is almost impossible at a reasonable cost, which often leaves measurement to take the form of calculations from a biophysical process model (for example, emission default factors from the Intergovernmental Panel on Climate Change). Taken together, these factors seem to have created an aversion by regulators to fully embrace agriculture as an offset activity. While some of these factors affect forestry as well—particularly non-permanence—the relative ease of measurement of above-ground forest carbon and the development of mechanisms to handle non-permanence, such as buffer accounts, seem to have enabled broader acceptance of forest offsets than those from agriculture.

Voluntary Markets Have Created Greater Room for Agricultural Offsets, but Uptake is Limited

California and RGGI create markets through regulatory action, but there is also a market driven by voluntary demand for carbon offsets. Most voluntary offsets in the United States fall under one of three protocols: (1) American Carbon Registry (ACR), (2) Climate Action Reserve (CAR), or (3) Verified Carbon Standard (VCS). All three of these programs have a larger portfolio of activities as potential offset credit sources than do the regulatory programs. In addition to the agriculture categories referenced in California and RGGI, the voluntary market creates offset demand for: soil carbon sequestration from agricultural practices, N^2O reductions from fertilizer management, grassland management, livestock management (including enteric fermentation), avoided conversion of grasslands, and wetlands restoration. Thus, the voluntary market covers a wide swath of the full agricultural emission reduction potential. Yet these agricultural activities have not had a high rate of adoption, either in terms of the number of projects undertaken or the percentage of credits generated (Peters-Stanley and Yon, 2013). Part of this is due to overall lack of demand for voluntary offsets and part is due to the economic particulars of agricultural mitigation activities, as discussed below.

Economic Studies May Have Underestimated Adoption Hurdles and Transaction Costs of GHG Offsets

Estimates of offset market potential in agriculture are often based on studies using economic models that capture the quantity and resource cost of GHG reduction from actions such as conservation tillage, fertilizer management, or methane capture from livestock operations. These measures are based on changes in emissions costs from standard practices. The presumption is that a landowner who expects to receive offset payments which at least cover the additional costs of changing practices will undertake the action and supply the corresponding quantity of offsets to the market. Successively higher carbon prices should induce more offset quantities, all else equal.

While this is the proper conceptual frame for examining the problem, simplifying assumptions can lead to an overestimation of offset supply response in agriculture and other sectors. These assumptions often exclude the following type of real world problems from the analysis:

- Transaction costs
- Effect of uncertainty on investment and supply decisions
- Influence of non-market factors (for example, farming as a "way of life")

The issue of ignored transaction costs is fairly well known and includes costs for: planning; measuring, reporting, and verifying; market brokering and assembling; and insuring risks. These costs can be considerable when faced on the ground and thereby require further compensation for undertaking the project. Economists such as Antle et al., (2005) have showed how different assumed levels of transaction costs can reduce expected GHG supplies ex ante, but there has been little ex post work showing how actual transaction costs have affected actual adoption. Such work could be useful in refining programs to increase participation rates. For instance, the protocols referenced here include several provisions to protect the integrity of the program by the imposed costs, such as requirements for: sampling intensity, estimating a baseline of practices, and emissions, setting aside credits in a buffer to protect against carbon reversals and leakage. Protecting program integrity is essential and should be pursued, however, the cost of pursuing perfection should be part of the ongoing discussion and refinement process.

Looking Ahead

Carbon markets seem unlikely be the driver of agricultural GHG mitigation in the United States as they were once envisioned to be. Not because the markets themselves are gone or will not materialize. GHG emission markets are actually growing at this time abroad and in the United States and could expand substantially under a number of plausible circumstances. The RGGI program is now in its second phase, with a tightened cap and higher prices (Pizer, Murray, and Newell, 2014) and the possibility that EPA's regulation of GHGs from existing power plants could spread regionalization of emissions trading in the power sector (Monast et al., 2015). Western states and other Canadian provinces could plan to link their compliance regimes with the California market, as Quebec has recently done under the auspices of the Western Climate Initiative that was developed among states and provinces toward the end of the last decade. Thus trading could expand overall, but this may not have a dramatic impact on agriculture without a change in policy. As discussed above, the policy decisions have limited agriculture's role in carbon markets. First, there has been no real effort to directly cap agricultural GHGs and create direct demand for mitigation. All demand to date has been for offsets. To date, caution has reigned in muting demand for agricultural offsets to a small number of categories covering a minority of the emissions. Cost factors have reduced the attractiveness on the supply side, especially at the prices we have seen and expect in the near future. Thus market uptake of agricultural mitigation projects has been very low and will likely remain so without policies that will enhance demand enough to raise prices sufficiently to induce a mitigation supply response.

However, as discussed in Lewandrowski and Zook's article in this *Choices* theme, there are a host of other vehicles by which farmers could engage more in agricultural mitigation. These include government-sponsored farm programs to private sector supply chain initiatives, and joint public-private partnerships focused on voluntary GHG mitigation. These all have potential to expand agricultural mitigation activity, but their scale will depend on sustained public and private sector budget commitments. As part of a policy portfolio, one has to ask whether agricultural mitigation is better suited to a carbon market approach, as discussed here, or as part of complementary policies, as discussed in Lewandrowski and Zook. The market approach can favor cost-effective levels of participation within agriculture and across all regulated sectors, but may continue to be limited by current market rules and demand. Complementary policies seem more certain to induce higher levels of participation than we see from markets, but possibly at a higher cost per unit of emissions reduced. Thus, the rationale for complementary policies to induce agricultural mitigation may rest as much or more on non-carbon benefits from these actions such as water quality improvement or biodiversity protection.

For More Information

Antle, J.M., S.M. Capalbo, K.H. Paustian, and K. Ali. 2005. "Estimating the Economic Potential for Agricultural Soil Carbon Sequestration in the Central United States Using an Aggregate Econometric-Process Simulation Model." Working Paper, Program on Greenhouse Gas Mitigation and Climate Change, Montana State University.

Lewandrowski, J. and K. Zook. 2015. "GHG Mitigation in the Absence of a National Carbon Market." *Choices* Vol 30, (2).

Metcalf, G. and J.M. Reilly. 2008. "Policy Options for Controlling Greenhouse Gas Emissions: Implications for Agriculture." *Choices* Vol 23 (1): 34-37.

Monast, J, T. Profeta, J. Tarr, and B. Murray. 2015. "Enhancing Compliance Flexibility Under the Clean Power Plan: A Common Elements Approach to Capturing Low-Cost Emissions Reductions." Policy Brief NI PB 15-01. Nicholas Institute for Environmental Policy Solutions, Duke University. Available online: http://nicholasinstitute.duke.edu/sites/default/files/publications/ni_pb_15-01.pdf.

Murray, B.C., P.T. Maniloff and E.M. Murray. 2014. "Why Have Greenhouse Emissions in RGGI States Declined? An Econometric Attribution to Economic, Energy Market, and Policy Factors." Duke Environmental Economics Working Paper Series Working Paper EE 14-0. Available online: http://sites.nicholasinstitute.duke.edu/environmentaleconomics/working-paper-series/

Murray, B.C., B.L. Sohngen, and M.T. Ross. 2007. "Economic Consequences of Consideration of Permanence, Leakage and Additionality for Soil Carbon Sequestration Projects." *Climatic Change* 80:127-143.

Murray, B.C., B.L. Sohngen, A.J. Sommer, B.M. Depro, K.M. Jones, B.A. McCarl, D. Gillig, B. DeAngelo, and K. Andrasko. 2005. EPA-R-05-006. "*Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*." Washington, D.C: U.S. Environmental Protection Agency, Office of Atmospheric Programs.

Peters-Stanley, M and D. Yon. 2013. “Maneuvering the Mosaic: State of the Voluntary Carbon Markets 2013.” A report by Forest Trends’ Ecosystem Marketplace and Bloomberg New Energy Finance. Available online: http://www.forest-trends.org/documents/files/doc_3898.pdf.

Pizer, W, B. Murray, and R. Newell. 2014. “How to Manage Carbon Prices – Lessons from the Northeast.” The Hill blog. Available online: http://thehill.com/blogs/pundits-blog/energy-environment/223130-how-to-manage-carbon-prices-lessons-from-the-northeast.

Reed, D. 2012. Quoted in “New agriculture offset protocol expands opportunities for farmers to participate in the carbon market.” Climate Action Reserve. Available online:http://www.climateactionreserve.org/blog/2012/06/28/new-agriculture-offset-protocol-expands-opportunities-for-farmers-to-participate-in-the-carbon-market/.

Wara, M and D. Victor. 2008. “A Realistic Policy on International Carbon Offsets”. PESD Working Paper #74. Stanford University. Available online: http://iisdb.stanford.edu/pubs/22157/WP74_final_final.pdf.

United States Environmental Protection Agency. 2009. *EPA Analysis of the American Clean Energy and Security Act of 2009 H.R. 2454 in the 111th Congress*. U.S. Environmental Protection Agency Office of Atmospheric Programs. Available online: http://www.epa.gov/climatechange/Downloads/EPAactivities/HR2454_Analysis.pdf.

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GHG Mitigation in the Absence of a National Carbon Market

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A greenhouse gas (GHG) market is an appealing solution to mitigate GHG emissions because policy makers could "cap" emissions at some predetermined level and market forces would then allocate the required emissions reductions to those entities that could supply them most cost-effectively. If the carbon market resembled those outlined in the Climate Security Act of 2008, the American Clean Energy and Security Act of 2009, and the American Power Act of 2010 which were introduced into Congress in past years, agricultural producers would not be legally required to reduce their emissions but would be allowed to generate "offset credits" by taking voluntary actions that reduce GHG emissions or increase carbon sequestration in soils and biomass. These credits could then be sold to entities in covered sectors, which could use them to satisfy their emissions reduction obligation.

While conceptually appealing, the United States does not have a national carbon market. The last attempt to establish one ended in July of 2010 when the U.S. Senate announced it would not consider companion legislation to the American Clean Energy and Security Act that was passed by the House of Representatives on June 26, 2009. In the period since, there has been no serious attempt to establish a national carbon market. In this absence, a number of public and private sector entities have moved to consider alternative approaches for tapping some of the GHG mitigation potential of the agricultural sector. Three of the most prominent approaches are: placing greater emphasis on GHG mitigation in the United States Department of Agriculture's (USDA) conservation and renewable energy programs, facilitating private sector-led supply chain initiatives to reduce the carbon footprint of specific products, and supporting joint public-private efforts centered on voluntary GHG mitigation.

USDA Programs

USDA's conservation, renewable energy, and energy efficiency programs incentivize farms to adopt many practices that result in GHG mitigation. The Conservation Reserve Program (CRP) provides farmers with annual payments and other incentives to shift environmentally sensitive cropland to grasses, trees, and other conservation covers for periods of 10 to15 years. These shifts typically increase the carbon stored in soils and vegetation, and decrease carbon dioxide (CO2) and *nitrous oxide* (N2O) associated with field operations. The Environmental Quality Incentives Program (EQIP) provides technical and financial assistance to farmers to adopt a variety of conservation practices on lands that remain in production. USDA's Natural Resources Conservation Service (NRCS) has identified 35 EQIP supported practices that increase carbon sequestration and reduce emissions of CO2, methane (CH4), and N2O (USDA, NRCS, 2014). USDA Rural Development's (RD) Rural Energy for America Program (REAP) provides financial assistance to farms to install renewable energy systems (such as solar panels, wind mills, and anaerobic digesters) and to invest in improved energy efficiency (for example, more energy-efficient irrigation pumps). Expanding the supply of renewable energy and improving farm energy efficiency can mitigate CO2 emissions by reducing the demand for energy generated from fossil fuels. Between 2009 and 2011, REAP funded projects produced over 6.5

million *megawatt hour* (Mwh) of renewable energy and improved energy efficiency (USDA, RD, 2012).

USDA has increasingly emphasized improving the scientific understanding of climate change and the technical and economic challenges it poses to U.S. agriculture and forestry. In 2014, for example, USDA published comprehensive entity-scale methods for quantifying GHG fluxes from agriculture and forestry operations (Eve et al., 2014). It also established a network of regional Climate Hubs to provide region specific information and guidance on climate related technologies and risk management practices. In the conservation and energy programs, this emphasis has focused on quantifying and tracking mitigation benefits. For 2011, USDA estimated the GHG mitigation benefits of CRP, REAP, and the NRCS conservation programs at, respectively, 51.6, 11.9, and 1.9 teragrams (Tg) equivalent carbon dioxide (CO2e) (U.S. Department of State, 2014).

While significant in magnitude, the GHG mitigation benefits of USDA's conservation and energy programs have largely been achieved while targeting other conservation, energy, and rural economy objectives. This raises the policy option of using these programs to explicitly incentivize GHG mitigation. The approach would be to pay producers to adopt practices, technologies, and land uses that reduce the emissions associated with their operations or increase the carbon stored in soils and vegetation.

The potential costs and GHG benefits of a USDA program to incentivize farmers to mitigate GHG emissions would depend on how the program was structured. For example, an approach based on existing programs, authorities, and funding levels would likely be more limited in scope, resources, and mitigation potential than an approach based on new authorities and additional funding. Recent work, however, provides some insights regarding the overall mitigation potential of incentivizing a specific set of farm-level GHG mitigation options.

ICF International (ICF) (2013) identifies 20 farm-level practices and technologies that various representative farms could adopt to reduce their GHG footprint—including changes in tillage intensity, nutrient management, manure management, and land uses. ICF differentiates farms by region, size, and commodity produced. For each farm and mitigation option combination, ICF calculates the incentive, in dollars per metric ton (MT) of CO2 mitigation that just covers the farm's adoption cost; this is labeled the "CO2 break-even price". Lewandrowski et al., (2014) incorporate these 20 mitigation options into a marginal abatement cost curve (MACC) framework and develop a farm-sector supply curve for GHG mitigation. At $20 per MT CO2, the MACC indicates that U.S. farms supply mitigation equal to 55 Tg CO2e. One interpretation is that USDA could facilitate about 55 Tg CO2e of new mitigation by offering farmers $20 per MT CO2 to adopt one of the 20 technologies and practices reflected in the MACC. The total cost would be about $1.1 billion, and would generate soil health, water quality, air quality, and habitat benefits in addition to GHG mitigation.

Supporting Private Sector GHG Mitigation Actions

Many private companies and other non-federal entities have made voluntarily commitments to reduce their GHG footprint. Examples include the National Hockey League (NHL, 2014), Chevrolet (2014), and more than 1,300 partners that have joined the U.S. Environmental Protection Agency's (EPA) Green Power Partnership (EPA, 2014). These commitments typically include a stated GHG mitigation goal, a timeframe to achieve it, a detailed action plan, periodic reporting on progress, and independent third party verification that the mitigation being reported is real.

While USDA cannot mandate how private voluntary GHG mitigation commitments are structured, operationalized, or enforced, it can use a variety of non-payment-to-farmer incentives and policies to help make these commitments occur more frequently. Three private-sector led GHG mitigation initiatives are described below along with the USDA policies that have been used to support them.

Reducing GHG Emissions in the Supply-Chain for Fluid Milk

In 2009, the dairy industry, working through the Dairy Innovation Center (DIC), committed to reduce the GHG emissions associated with the supply chain for fluid milk by 25% by 2020 (DIC, 2013a). The commitment included four on-farm projects aimed at improving farm profitability and mitigating GHG emissions. The programs, described below, focus on expanding farm production of clean energy, improving farm energy efficiency, and decreasing farm energy consumption. The dairy industry has set a mitigation goal for the four programs of 2.68 Tg CO2e annually by 2020 (DIC, 2014). Progress is reported annually in DIC's Greenhouse Gas Reduction Projects Progress Report (DIC, 2014).

Farm Smart is an online decision support tool that allows farms to assess the environmental impacts of their operations, including their energy use and GHG footprint, using a standard set of methodologies and metrics. Farm Smart was pilot tested in 2012 using a set of dairy farms encompassing 60,000 cows with annual milk production of 150 million gallons. In 2013, testing was expanded to farms and dairy retailers nationwide. GHG mitigation goals for 2020 include reducing dairy sector use of nitrogen fertilizer by 10% and reducing annual GHG emissions associated with fluid milk production by 230,000 MT CO2e.

The Farm Energy Efficiency Program promotes energy conservation, energy efficiency, and GHG reductions on dairy farms by connecting producers with opportunities for energy audits and equipment upgrades, largely through EQIP. Between 2011 and 2013, DIC's partnership with NRCS resulted in 667 on-farm energy audits. These audits identified potential energy savings of over 55,500 million British thermal units (MmBTU), potential GHG reductions of 11,500 MT CO2e, and potential cost savings of over $2 million. Program goals for 2020 include conducting 7,200 energy audits, improving farm energy efficiency 10 to 35%, and reducing GHG emissions for fluid milk by 50,000 MT CO2e.

The Dairy Power/Biogas Capture and Transport project promotes the capture and utilization of biogas through the adoption of anaerobic digester systems on dairy farms. In 2013, DIC supported an assessment of the potential market for digester related products on confined dairy operations over 500 cows (Informa Economics, 2013; DIC, 2013a). Assuming all such dairies installed digesters, potential products included 11.7 Mwh of electricity, 440 thousand tons of nitrogen and phosphorous fertilizers, and 30 million cubic yards of fiber. The market value of these products was estimated at over $1.9 billion. The potential GHG mitigation benefits were estimated at 34.3 Tg CO2e. Program goals for 2020 include the adoption of 1,300 additional digesters on U.S. dairy farms.

Finally, the Cow of the Future program advances scientifically sound and economically viable methods of reducing enteric fermentation CH4 emissions from dairy cows through improved nutrition, genetics, and health. Under this program, DIC released a report entitled *Considerations and Resources on Feed and Animal Management* (DIC, 2013b). The report discusses economic and environmental considerations of known feed and animal best management practices. Program goals for 2020 include reducing GHG emissions for fluid milk by 600,000 MT.

Prairie Pothole Region Grasslands Project (PPRGP):

The Prairie Pothole Region (PPR) contains thousands of shallow wetlands known as "potholes." These potholes provide critical nesting habitat for many duck species and sequester large amounts of carbon in the soil. In the United States, the PPR includes parts of North Dakota, Montana, South Dakota, Minnesota, and Iowa. Currently, the U.S. PPR loses about 50,000 acres of native grasslands per year due to conversions to cropland (Climate Trust, 2014). These conversions significantly reduce the carbon stored in the affected soils (Euliss et al., 2006). Emission rates are estimated to the range between 0.5-2 MT of CO2 per acre per year.

In November 2014, Chevrolet Motor Company, Ducks Unlimited (DU), The Climate Trust, and USDA announced a partnership to generate carbon offsets through voluntary actions that avoid conversions of private grasslands to row crops. Enrolled lands can be used for hay production and grazing but not crop-based agriculture. In exchange for a perpetual grassland easement, participating farmers and ranchers receive revenue derived from the transaction of carbon credits. Carbon credits are generated and saleable for 20 years.

The PPRGP began in 2011, when NRCS awarded DU a Conservation Innovation Grant (CIG) to fund the development of a methodology to quantify the carbon emissions that would be avoided if prairie grasslands, under threat of conversion to row crops, were preserved as grasslands. In 2013, the methodology was approved by The American Carbon Registry (ACR), a major U.S. carbon offset registry (ACR, 2014). ACR's approval was critical because it provided credibility that the project's offsets were real and verifiable.

Through an existing agreement with U.S. Fish and Wildlife Service (USFWS), DU has the ability to transfer easements it secures on private property to USFWS (DU, 2009). Through this agreement, the easements secured by DU in the PPRGP are held, monitored, and enforced by the USFWS.

In addition to the CIG grant, USDA supported the PPRGP by allowing private landowners to simultaneously enroll their grasslands in a special grazing lands EQIP project (USDA NRCS, 2012). The EQIP project targets grasslands covered by expiring CRP contracts and provides landowners with financial and technical assistance to establish or enhance grazing systems (such as installing fencing, planting forage, prescribed grazing, forage harvest management, and water infrastructure development). To complete the partnership, the Climate Trust and the Bonneville Environmental Foundation negotiated a purchase agreement with Chevrolet for nearly 40,000 MT of carbon credits generated by PPRGP. The project is part of Chevrolet's publicly announced goal of reducing eight million metric tons of GHG emissions between 2010 and 2015 (Climate Trust, 2014; Chevrolet, 2014).

Lower Mississippi Valley Grouped Afforestation Project (LMVGAP)

The Mississippi River alluvial plain once supported around 51.9 million acres of riparian forests, of which less than 12.4 million acres remain (TNC, 1992). Much of the Lower Mississippi Valley's forested wetland systems have been significantly altered by human use, which makes the area a priority for forest restoration efforts. In 2009, as part of a broader strategy to restore bottomland hardwood forests in the Lower

Mississippi River Basin, Disney and The Nature Conservancy (TNC) formed a collaboration called the Lower Mississippi Valley Grouped Afforestation Project (LMVGAP). LMVGAP initially targets 2,000 acres for restoration.

LMVGAP prioritizes lands that would likely stay in agricultural production in the absence of carbon financing. Private property owners who enroll land in LMVGAP receive a payment from TNC in exchange for granting TNC a permanent conservation easement and the right to transact carbon credits derived from the restored forest. TNC has committed to deliver a portion of these carbon credits to Disney in exchange for the financing that made the easement acquisitions possible. USDA supports the collaboration by allowing landowners to participate in both LMVGAP and the CRP or *Wetlands Reserve Program* (WRP). TNC works with USDA to condition easements on lands being enrolled in either a 15 year CRP contract or a 30-year WRP contract—for completeness, the Agricultural Act of 2014 terminated the WRP and rolled its existing contracts into the Agricultural Conservation Easement Program. Additionally, land currently covered by a CRP grassland practice contract may be converted to a forest practice contract. LMVGAP covers the cost of site preparation and tree planting, while USDA and landowners share the cost of hydrologic restoration (TNC, 2011).

LMVGAP establishes credibility that its carbon-offsets are real and verifiable in several ways. First, LMVGAP follows the requirements of the Verified Carbon Standard (VCS), which provides independent validation for the project design and the methods and processes by which offsets will be quantified and verified (VCS, 2011). VCS has validated the LMVGAP project design for privately owned lands in Louisiana, Arkansas, and Mississippi. Verification will occur periodically in the future as the forests mature and sequester additional carbon in soils and biomass (VCS, 2011). VCS requires that 10% of the project's certified carbon credits remain unsold to insure against the risk that less carbon gets sequestered than the methodology predicted. VCS also requires an additional credit withholding to account for potential "leakage"--carbon emissions from off-site forest conversions motivated by producers replacing some of the land removed from crop production by the project (VCS, 2011). Finally, TNC requires that participating landowners sign an affidavit certifying that without the easement payments they would not have placed their property in permanent conservation (TNC, 2014).

The financing made possible through the TNC/Disney collaboration, combined with the payments provided through CRP or WRP, provide an incentive that is sufficient for participating landowners to overcome the opportunity costs of converting land from agricultural use to forests. As a result, more forested wetlands are restored, more carbon is sequestered, and there is more certainty that the wetlands will remain wetlands after their enrollment in CRP or WRP expires than if TNC or USDA had acted alone.

Looking to the Future

Achieving any significant portion of agriculture's GHG mitigation potential will require large numbers of farms to adopt technologies and practices that reduce the GHG emissions associated with their crop and livestock production systems or increase the quantity of carbon stored in soils and vegetation. Farms that adopt such technologies and practices, however, will typically incur costs and may face additional risks. While the costs can range from relatively modest decreases in expected net revenues for some cropping practices to several million dollars for advanced anaerobic digester systems (ICF, 2013), it is unlikely that large-scale adoption of any GHG mitigating practice or technology will occur unless farms can recover the adoption costs and address the associated risks.

From a policy standpoint, establishing a national carbon market with agricultural offsets would be a straight forward framework to enable farms to recover costs and address risks associated with adopting GHG mitigating practices and technologies. Such a market would make GHG mitigation a commodity complete with production technologies, production costs, and expectations about total output and net revenue. Absent a national carbon market, other policy approaches can be used to promote additional GHG mitigation in the farm sector.

Through its conservation and energy programs, USDA has extensive experience incentivizing farms to adopt specific conservation practices. To date these programs have generally not had a primary focus on GHG mitigation. Even so, farm participation in three programs—CRP, EQIP, and REAP—currently produces GHG mitigation on the order of 65 Tg CO2e annually. One policy option to foster additional GHG mitigation in the farm sector is to incentivize the adoption of select practices and technologies based on their GHG mitigation potential. For example, offering farmers a fixed payment per MT CO2e mitigation achieved, would encourage farms to identify the most cost-effective GHG mitigation technologies and practices for their circumstances and provide the funds necessary to cover some or all of the costs of adoption. The overall mitigation potential of such payments would largely be determined by the share of the adoption costs covered and program budget.

USDA can also facilitate and encourage private-sector led GHG mitigation initiatives through a variety of non-payment-to-farmer incentives. In the context of the DIC's commitment to reduce GHG emissions, the PPRGP, and LMVGAP, these incentives have included funding the development of methods and tools to measure and track the GHG benefits associated with specific actions, providing funding for on-farm energy audits, and allowing farmers to simultaneously enroll land in a USDA conservation program and a private-sector led initiative.

These incentives reduce the costs associated with developing credible metrics and processes for measuring, monitoring, and tracking GHG mitigation. They also help farms identify specific areas in their operations where mitigation is most cost-effective. Finally, by allowing public and nongovernmental organizations to pool their resources, producers can be offered higher mitigation payments. This allows more mitigation to be achieved than if entities act individually.

For More Information

American Carbon Registry (ACR). 2014. *Avoided Conversion of Grasslands and Shrublands to Crop Production.* Available online*:* http://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-avoided-conversion-of-grasslands-and-shrublands-to-crop-production and http://americancarbonregistry.org/about-us/mission

Chevrolet, 2014. http://www.chevrolet.com/culture/article/carbon-footprint-reduction.html

Climate Trust. 2014. http://www.climatetrust.org/chevrolet-invests-in-greenhouse-gas-reductions-through-the-protection-of-prairie-grasslands/

Dairy Innovation Center (DIC). 2014. Greenhouse Gas Reduction Projects 2013 Progress Report. Available online: http://www.usdairy.com/~/media/usd/public/sustainability%20greenhouse%20gas%20reduction%20projects%202013.pdf

Dairy Innovation Center (DIC). 2013a. *2013 U.S. Dairy Sustainability Report*. Available online: http://www.usdairy.com/~/media/usd/public/2013%20u.s.%20dairy%20sustainability%20report.pdf

Dairy Innovation Center (DIC). 2013b. *Considerations & Resources on Feed and Animal Manage*ment. Available online: http://www.usdairy.com/~/media/usd/public/considerationsresourcesonfeed-animalmgt.pdf

Ducks Unlimited. 2009. Avoided Grassland Conversion Project in the Prairie Pothole Region. Available online: https://s3.amazonaws.com/CCBA/Projects/Ducks_Unlimited_Avoided_Grassland_Conversion_Project_in_the_Prairie_Pothole_Region/20090323_du_agc_ccba_final_for_release.pdf

Euliss, H.N., R.A. Gleason, A. Olness, R.L. McDougal, H.R. Murkin, R.D. Robarts, R.A. Bourbonniere, and B.G. Warner. 2006. "North American Prairie Wetlands are Important Nonforested Land-Based Carbon Storage Sites." Science of the Total Environment. 361 (2006): pp 179-188. Available online: http://www.sciencedirect.com/science/article/pii/S0048969705004195

Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar (Eds). 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. Offices of the Chief Economist, U.S. Department of Agriculture, Washington, DC. 606 pages. July. Available online: http://www.usda.gov/oce/climate_change/estimation.htm

ICF International (ICF). 2013. Greenhouse Gas Mitigation Options and Costs For Agricultural Land and Animal Production Within the United States. Washington, DC: ICF International. Prepared for USDA, Climate Change Program Office. Available online: http://www.usda.gov/oce/climate_change/mitigation_technologies/GHGMitigationProduction_Cost.htm

Informa Economics. 2013. National Market Value of Anaerobic Digester Products. Available online: http://www.usdairy.com/~/media/usd/public/nationalmarketvalueofanaerobicdigesterproducts.pdf.pdf

Lewandrowski, J., D. Pape, D. Man, and R. Steele. 2014. "A Farm-Level Up Assessment of the GHG Mitigation Potential of U.S. Agriculture." Paper presented at ACES Conference 2013. Available online: http://www.conference.ifas.ufl.edu/aces/presentations/Dec%2009%20Tuesday/4%20Session%201A%20Grand%20Ballroom%20Salon%20A/Lewandrowski%20Jan.pdf

The National hockey League (NHL). 2014. http://www.nhl.com/green/report/index.html#header

The Nature Conservancy (TNC). 1992. The Forested Wetlands of the Mississippi River: An Ecosystem in Crisis. Baton Rouge, LA. *Cited in* Mitsch, W. J., and M.E. Hernandez. 2013. Landscape and Climate Change Threats to Wetlands of North and Central America. *Aquatic Sciences*. 75(1), 133-149. Available online: http://dx.doi.org/10.1007/s00027-012-0262-7.

The Nature Conservancy (TNC). 2011. LMVGAP Enrollment Flyer.

The Nature Conservancy (TNC). 2014. Personal communication with Hamilton Hardman.

United States Department of Agriculture, *Natural Resources Conservation Service*, (USDA, NRCS). 2012. Fact Sheet: Special EQIP Project for Grazing Lands in Central and Eastern North Dakota. Available online: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1081518.pdf

United States Department of Agriculture, *Natural Resources Conservation Service*, (USDA, NRCS). 2014. Available online: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/climatechange/?cid=stelprdb1044982

United States Department of Agriculture, Rural Development. 2012. *The Impact of the Rural Energy for America Program on Promoting Energy Efficiency and Renewable Energy*. Available online: http://www.rurdev.usda.gov/Reports/rdREAPReportMarch2012.pdf.

United States Department of State. 2014. *2014 United States Climate Action Report.* Available online: http://www.state.gov/e/oes/rls/rpts/car6/index.htm

United States Environmental Protection Agency (EPA). 2014. Available online: http://www.epa.gov/greenpower/toplists/top100.htm

Verified Carbon Standard (VCS). 2011. VCS Standard. Available online: http://www.v-c-s.org/sites/v-c-s.org/files/VCS%20Standard,%20v3.0.pdf

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