

Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation

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Abstract

The world is moving toward efforts to reduce greenhouse gas emissions. Net emission reduction efforts may involve the agricultural sector through options such as planting of trees, crop and livestock management changes, and production of biofuels. However, such options can be competitive with domestic food production. In a free trade arena, reduced domestic food production could stimulate increased production and exports in other countries, which are not pursuing similar mitigative courses of action. As a consequence, net emission reductions in implementing countries may be offset by activities stimulated in other countries. In addition producers in countries where agriculture may be influenced through higher fuel or other emission related prices and opportunities have expressed concern relative to their competitive position vis a vis countries which are not trying to reduce net emissions.

We examine the competitive effects of differential mitigation efforts on agricultural food production and on international trade. In doing this we employ the assumption that the average U.S. compliance caused cost increase would also occur in other complying countries. We consider implementation: 1) unilaterally by the U.S., 2) by all Kyoto Protocol Annex I countries and 3) globally. The results, which are only suggestive of the types of effects that would be observed due to the simplifying cost assumptions, indicate compliance causes supply cutbacks in regulated countries and increases in non-regulated countries. In addition, the study results show that U.S. agricultural producers are more likely to benefit from a Kyoto Protocol like environment but that consumers are likely to be hurt in terms of their agricultural welfare.

Key words: leakage, international trade, agricultural and forest sector, greenhouse gas, mitigation implementation.

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Society has increasingly become concerned with the potential climate implications of greenhouse gas (GHG) emissions, and GHG atmospheric concentration. The Intergovernmental Panel on Climate Change, projects that GHG concentrations will cause global average temperature to increase by 1.4 to 5.8°C between 1990 and 2100 (IPCC, 2001). In turn such warming is predicted to alter agricultural production, raise sea level, change habitat boundaries for many plants and animals, and induce a number of other changes (IPCC, 2001b, USGCRP, National Assessment Team, 2000). Numerous strategies have been proposed to mitigate GHG emissions, a number of which involve agriculture and forestry (McCarl and Schneider, 2000, 2001). In particular, agriculture and forestry may be important players due to their emissions levels where as summarized in the IPCC, 2001a report agriculture is one of the primary emitters on nitrous oxide and methane with over 50% of the nitrous oxide, about 40% of the methane , a smaller set of carbon emissions due to farming activities, and the two sectors, particularly forestry are involved with larger emissions due to land use change and the sectors contain potential large sequestration and biofuel offset potential.

GHG concentrations and their climate effects are global, thus all countries will share the benefits from GHG emission (GHGE) mitigation, but in the absence of widespread trading and emission caps only countries adopting mitigation measures will directly bear the costs. This implies two things.

- ❖ Producers in emitting industries, and users of emission intensive products within countries mitigating GHG emissions are likely to experience increased production costs since mitigation actions are likely to make fuel, fertilizer and other petrochemicals prices rise along with raising the possibility of emissions related payments for land use change, fertilizer related nitrous oxide emissions, livestock related methane/nitrous oxide emissions and rice related methane emissions.
- ❖ Competing producers in non-adopting countries may gain advantage and trade market share stimulating both
 - shifts in comparative advantage and
 - expanded GHG emissions reflecting emission leakage into other countries..

This paper reports on a first order examination of the producer welfare, comparative advantage and leakage impacts of differential GHG emission (GHGE) mitigation efforts. Specifically, we examine international production and U.S. agricultural sector implications under: 1) unilateral U.S. GHGE mitigation implementation, 2) developed country implementation (in those countries falling within the Annex I^a list under the Kyoto Protocol and 3) global implementation.

^a The Annex I countries are those listed in Annex I of the United Nations Framework Convention on Climate Change.

1. Background

The welfare and leakage effects of agricultural GHG mitigation have been the subject of a number of studies. Let us review these categorized by the major issues in the bullets above.

1.1 Production cost and producer welfare

The implications of pursuing agriculturally based GHG mitigation for domestic production cost and farm income has been a concern of producer groups. For example, in 1998 the U.S. Farm Bureau advanced a position that it will not support ratification of the Kyoto Protocol (KP) unless principal international market competitor countries were also covered by the KP terms (Francl, 1997, Francl, Nadler and Bast, 1998). Francl and associates asserted that substantial farm income (up to 84%) would be lost due to increases in fuel prices. However, later analyses that considered factor substitution, product price adjustments and consumer demand reactions (McCarl et al 1997, USDA, 1999, Antle et al ,1999, Konyar and Howitt ,2000 , Peters et al, 2001) found producer welfare reductions but of much smaller magnitudes (generally below 10%). However, none of these studies considered the effects of possible payments to farmers for carbon sequestration or taxes for methane and nitrous oxide emissions from livestock, fertilization, and other sources.

More recent work by McCarl and Schneider, 1999, 2001 examined both the effects of higher input prices and the effects of possible payments for agricultural GHG offsets finding that producers can benefit in aggregate largely due to the combination of direct carbon payments and the market price increasing features associated with a substitution of carbon production for some

existing agricultural production. Similarly, Antle et al 2002 argue that producer incomes will be enhanced by carbon payments but did not consider possible market price changes.

Across all of the studies mentioned above the assumption of constant agricultural conditions on behalf of international trading partners was made^b. However, GHGE mitigation will be wider in scope than a unilateral U.S. effort and there may be actions on behalf of other participants in the world agricultural commodity markets. Thus, when there are mitigative actions either unilaterally or globally this may have important implications for the implementing and non-implementing countries and for net GHGE reductions after leakage. This will be investigated in this paper.

1.2 Shifts in Comparative Advantage

A rich literature has emerged on shifts in comparative advantage as caused by environmental regulation. The fundamental argument is that regulations in one country may shift production to other countries (Pethig, 1976). The overall literature on this topic was reviewed by Jaffe et al who concluded "...regulation clearly imposes large direct and indirect costs on society ..." (pg 159) but they also conclude that "there is relatively little evidence ... that environmental regulations have had a large adverse effect on competitiveness" (page 157). This suggests that adjustments in production patterns may help mitigate the effects of regulations as found in the carbon tax related studies reviewed just above.

^b This is mentioned on page 41-42 of the USDA(1999) report but is not quantitatively explored.

1.3 Leakage

Leakage occurs in a GHGE context when actions to offset emissions in one country stimulate additional production and consequent emissions in other countries. Several papers have examined the potential empirical magnitude of leakage when GHG abatement actions (e.g., emissions limits, carbon taxes, or tradable permits) are applicable to only a subset of the world's countries mainly in an energy context (e.g., Oliveira-Martins et al., 1992; Smith, 1998; Bernstein et al., 1999; Barker, 1999; Babiker, 2001). These leakage estimates range from negligible (Barker, 1999) to substantial (Felder and Rutherford, 1993), but typically are in the range of 10-20 percent of targeted country emission reductions.

Agricultural and forestry related leakage studies have also been done. Wu (2000) examined leakage relative to the US Conservation Reserve Program (CRP), which pays farmers to retire land from crop production. Using data from the Natural Resources Inventory, Wu found, average leakage of about 20% within the U.S. with farmers adding additional lands but international leakage was not considered. Leakage was also found to occur with participation in U.S. crop commodity programs (Brooks et al., 1992; Hoag et al., 1993). Alig et al. (1997) examined leakage in a forestry context and find cases where the leakage rate for carbon sequestration projects exceeds 100%. Sedjo and Sohngen (2000) examine international leakage resulting from the establishment of large-scale forest carbon plantations using a model of the global timber market and find leakage rates up to 40%.

None of these investigations examined the international agricultural effects which we will attempt herein.

2. Scope of GHGE Reduction Implementation

In this paper we will examine the leakage and comparative advantage implications of three different international implementation and trading cases.

1. Case I – Unilateral implementation where a country or a group of countries decides to unilaterally implement GHG mitigation. This might happen today the Kyoto Protocol is implemented internationally without U.S. participation or if the U.S. implements the President's Clean Air Initiative and the rest of the world fails to implement the KP. In these cases, one would expect the implementing countries would be expected to experience higher costs of domestic production yielding lower levels of their domestic production and exports, and higher prices. Simultaneously, non-implementing countries would be expected to increase domestic production and world market share thereby offsetting some of the GHG emission gains in implementing countries.
2. Case II – Partial global implementation where a relatively large group implement GHG mitigation policies. This might have happened if the KP was implemented as envisioned by all Annex I countries but the Clean Development Mechanism(CDM) turned out to be an ineffective way of drawing other countries into GHG emission mitigating activities. In such a case, the Annex I countries would be expected to lose comparative advantage on average relative to Non-Annex I countries. The net impacts on individual Annex I countries and magnitude of emission leakage, however, might be different from Case I.

3. Case III – Global implementation where all countries implement a mitigation policy. This might have happened if the world would have implemented the KP and involve also all Non-Annex I countries through mechanisms such as the CDM. In this setting, all countries would experience higher costs of production.

3. Modeling

The cases mentioned above will be evaluated herein. To do that we need a model that portrays global agricultural trade and simultaneously allows examination of detailed GHGE mitigation possibilities within implementing countries. A model with such global scope and regional detail was not available or practical to construct for this investigation. Thus, we used a model that satisfies some of the needed characteristics and combined it with an assumption laden analytical approach.

Specifically we used the greenhouse gas version of the U.S. Agricultural Sector Model (ASMGHG) developed by Schneider (2000) and McCarl and Schneider (2001). This model arose from the base ASM as described in McCarl et al. (2001) and Chang et al. (1992) with the addition of details on soil type dependent production (developed in conjunction with USDA NRCS) and a global trade representation via spatial equilibrium models for eight commodities as developed by Chen and McCarl (2000) and Chen (1999). The combined ASMGHG model considers agricultural production, consumption, and trade in developed and developing countries simultaneously. Overall characteristics of the model are discussed below.

3.1 General Structure of the U.S. Agricultural Sector Model

Like many agricultural sector models, ASMGHG is a price-endogenous mathematical program following the market equilibrium and welfare optimization concept developed in Samuelson (1952), and Takayama and Judge (1971). ASMGHG assumes individual producers and consumers cannot influence commodity or input market prices. Production and use of farming inputs are portrayed in 63 regions in the U.S. and for 28 foreign regions. Data on currently observed trade quantities, prices, transportation costs, and supply and demand elasticities were obtained from Fellin and Fuller (1997, 1998), USDA statistical sources (1994a, b, c; annual), and the USDA, SWOPSIM model (Roningen, 1991).

3.2 Modeling Greenhouse Gas Emissions and Mitigation Strategies

Schneider (2000) added a GHGE mitigation component to the United States part of ASM. This component introduces production alternatives and GHG net emission accounting to reflect the GHG consequences of changes in crop mix, tillage, irrigation, fertilization, afforestation, biofuel production and livestock management. Livestock management options involve: 1) herd size, 2) liquid manure system alterations on dairy and hog farms, 3) enteric fermentation management involving use of growth hormones for dairy cows and 4) stocker/feedlot production system adoption. A detailed technical description of all considered mitigation strategies is contained in Schneider (2000). In terms of GHGE accounting ASMGHG considers:

- Direct carbon emissions from fossil fuels (diesel, gasoline, natural gas, heating oil, and LP gas) used in tillage, harvesting, or irrigation water pumping.

- Carbon emissions or sequestration arising from altered soil organic matter stimulated by adopted tillage system or land use change to and from croplands, forestlands and grasslands.
- Indirect carbon emissions from manufacture of fossil fuel intensive inputs (fertilizers, pesticides).
- Carbon offsets from biofuel production (ethanol, power plant feedstock via production of switchgrass, poplar, and willow) as well as associated methane and nitrous oxide emission changes from biomass combustion.
- Nitrous oxide emissions from fertilizer usage.
- Methane emissions from enteric fermentation, and rice cultivation.
- Methane savings from manure management changes as well as both methane and nitrous oxide emission alterations from herd size alterations.

Individual emissions were converted to carbon equivalent measures using global warming potential from the IPCC(2001 a) report (23 for methane and 296 for nitrous oxide).

Obviously this GHG component only examines detailed emission management possibilities in the U.S. but not in the rest of the world. This limitation implies that global adjustment to GHGE mitigation incentives cannot simulated accurately outside the U.S. but instead is approximated using simplifying assumptions in the remainder of the analysis.

4. Experimental Results and Implications

Three alternative mitigation implementation scenarios are simulated. The first scenario assumes unilateral mitigation efforts in U.S. agriculture only. The second corresponds to a KP like situation with simultaneous implementation in all Annex I countries. The third involves worldwide implementation. Since we do not model the whole economy we simulate agricultural actions in terms of an exogenous carbon equivalent (CE) price that would obviously be set in a general equilibrium setting generating the supply curve of agricultural offsets. All scenarios are analyzed over a range of exogenously set carbon equivalent (CE) prices ranging from 0 to 500 dollars per ton.

4.1 Unilateral Implementation in Just the United States

The U.S. agricultural sector effects of a unilateral U.S. emission policy implementation over a range of CE prices are listed in Table 1 and 2, which show percentage changes from a zero CE price. Total CE emissions decline steadily as the price rises. At \$100 per ton, net emissions of CE from U.S. agriculture are about zero with the realized levels of carbon sequestration from carbon sinks offsetting all agricultural emissions.

The results in Tables 1 and 2 confirm that emission reductions are obtained at the expense of conventional crop production. Increasing CE prices cause decreases in U.S. production and exports along with increases in prices for conventional agricultural commodities. In addition, since the U.S. is a major trading country, production in other countries is influenced and comparative advantage shifts partially to those countries. Across the range of prices substantial leakage can be observed. For example, at a \$100 price total U.S. production falls by

2.5% with traded production falling by 6.5% but global production only falls by 0.40% and production in non U.S. Annex I and non Annex I countries expands by 2.66% and 12.22% respectively.

Welfare impacts for unilateral implementation of GHGE mitigation efforts in the U.S. are listed in Table 2. U.S. consumers' surplus decreases monotonically with CE-price increases. Producers' surplus on the other hand is only reduced for CE-prices below \$55 per ton but increases above that level. The change in producers' surplus arises from both the traditional commodities markets and the CE-price induced GHG payments/charges. These payments/charges include: 1) charges at the CE-price for emissions from land use change, fuel use, livestock, rice, fertilization and other emissions; 2) higher costs for fertilizer and other inputs due to the embodied emissions in their manufacture; 3) sequestration payments for increased soil, grassland and forest carbon storage; and 4) payments for the production of biofuels. In the U.S. only implementation case, producer gains from higher commodity prices more than offset losses from lower levels of domestic production. GHG accounting results in a net cost if emissions charges outweigh sequestration and biofuel payments. For prices below \$100 per ton, net emissions are positive resulting in additional sectoral cost. Above this price, the amount of carbon sequestration and biofuel related carbon offsets exceed emissions and thus provide additional sectoral revenue. The results also differ from the pure carbon tax studies showing larger total welfare impacts than the most comparable USDA(1999) and McCarl et al(1977) studies as the emissions effects on non CO₂ gasses cause larger cutbacks and bigger welfare effects. They also show consideration of international adjustment is also relevant.

Trade surplus measures the welfare of consumers and producers in non-U.S. countries attributable to trade of agricultural commodities. If the U.S. alone implements agricultural provisions for mitigation, the impact on welfare in other countries is negative with the magnitude getting bigger as the CE-price increases.

The results are also suggestive of what would happen under a rest of the world implementation of Kyoto without U.S. participation. Namely one would expect the mirror image of the findings here with market share flowing to the U.S. and a leakage effect. On the other hand recent analyses by integrated assessment groups (i.e. Babicker et al ,2002) show that under such circumstances it is likely that carbon prices will be very low in the \$3 to \$10 range and perhaps Kyoto combined with the U.S. 18% greenhouse gas intensity reduction climate change strategy.

4.2 Representing Mitigation Induced Shifts in ROW Countries

Mitigation efforts in regions outside of the U.S. could not be modeled explicitly because we did not have detailed data of production technologies in foreign regions, rather having excess supply curves. Thus, a simplifying assumption was made to depict the supply shifts in foreign countries. Namely, the average price increase and production decrease observed for each traded commodity in U.S. agriculture was assumed to proportionally apply to agricultural production in other countries. Thus, if for a given CE price average U.S. prices for rice went up by x percent and production down by y percent, the same shift was applied to rice supply in foreign regions in all implementing countries. We used this crude approximation because alternative reasonable

assumptions were not available^c. Empirical results derived from supply shifts in non-U.S. countries should therefore be considered illustrative but not definitive. In presenting our empirical results we will focus on a comparison between the various implementation scenarios examined.

4.3 Full Annex I Implementation

The results for full Annex I country implementation are shown in Table 1. U.S. agricultural production and exports decline but not as much as in the unilateral case. This diminished response reflects the fact that only the non-Annex I countries now have comparative advantage over U.S. agriculture. Leakage occurs in non-Annex I countries whose production expands by 20 percent at a \$100 CE price. Prices of traded agricultural commodities increase slightly more under full Annex I implementation. The welfare results show overall U.S. welfare is reduced less but consumers lose even more than under unilateral implementation. On the other hand, U.S. producers always gain.

Annex I countries' net exports are highest under U.S. unilateral implementation but lowest if all Annex I countries are subjected to agricultural mitigation policies. Equivalently, non-Annex I countries' net exports are highest under full Annex I country implementation. All of these observed changes become more substantial the more the CE-price increases. Note that the Annex I accounts displayed in all figures do not involve the U.S. to avoid double counting.

^c It is also not clear if the cost increases elsewhere would be bigger or smaller as expansions elsewhere may involve new land development which could be subject to substantial carbon taxes.

Total emission reductions from U.S. agriculture are almost identical for all scenarios up to CE-prices of \$55 per ton (Figure 1). Above \$85 per ton of CE, additional emission reductions become smaller under full Annex I country implementation. For example, at a CE-price of \$100 per ton, emission reductions are about 11 percent lower than for U.S. alone implementation. U.S. emissions rise because higher commodity prices lead to more intensive production and less adoption of sequestration and emission control activities. This would be offset by emission reductions in the Annex I agriculture but we cannot quantitatively represent that in our model as we do not have model components depicting emissions in those countries and extrapolation of U.S. rates would involve even more heroic assumptions than we are now making.

4.4 Global GHGE Mitigation Implementation

Provisions in the KP permit emissions credits where GHGE emission reductions from projects in non-Annex I countries may be counted as part of the emission reduction obligation for project sponsors in Annex I countries. If such provisions were implemented, low cost activities in agriculture could be exploited globally. This situation is represented by the last scenario, where production globally is shifted using the U.S. average price and cost shift assumptions as explained above. Tables 1 and 2 list the main impacts. We find increased U.S. market shares at the expense of foreign countries, particularly the non-Annex I ones. Leakage is contained with all regions decreasing aggregate production. Prices rise more than in the U.S. unilateral or KP cases. Note this is a property of the assumptions as we have successively shifted more and more of the total model supply curve.

U.S. producers welfare gains are highest in such a situation and consumers losses. Global mitigation efforts affect the level of emissions. The more countries implement GHGE mitigation policies, the smaller are net emission reductions from U.S. agriculture. For example, at a CE-price of \$100 per ton, emissions offsets are about 21 percent lower than for U.S. unilateral implementation.

5. Conclusions

The prospect of greenhouse gas emission mitigation policies has stimulated a wide search for cost-efficient emission reduction methods. Agriculture including forestry has been proposed as a relatively cheap source of net emission reductions. However, concerns have been expressed about agricultural abatement policies being hosted in only a subset of all countries. The comparative advantage gained in the agricultural sectors of non-host countries could distort trade patterns, harm domestic agricultural producers in host countries, and lead to increased emissions in non-host countries. Our investigation in the context of the U.S. agricultural sector, confirm tradeoffs between agricultural emission reductions and traditional food and fiber production. In particular, the two most carbon abating strategies, afforestation and production of biofuels, cause the greatest decline in traditional agricultural production. If the positive relationship between agricultural production and agricultural emissions also holds in foreign countries, then our results imply increased greenhouse gas emissions in non-host countries. However, the consequences of such emission leakage would not necessarily be incurred by non-host countries but by those countries, which are most vulnerable to climate change.

The findings of this paper have several implications for policy makers. First, if national agricultural greenhouse gas mitigation policies are not synchronized with foreign greenhouse gas emission policies, substantial leakage may occur. For example, if an international treaty like the Kyoto Protocol were implemented, emission reductions in Annex I countries would most likely be accompanied by emission increases in Non-Annex I (developing) countries. Several alternatives exist to prevent emission increases through agriculture in non-host countries. For example, the Kyoto Protocol proposes Joint Implementation (JI) and Clean Development Mechanisms (CDM). Through such mechanisms, host countries could establish incentives for agricultural producers in non-host countries to avoid emission intensive technologies.

Second, U.S. farmers' would benefit from a larger number of countries hosting greenhouse gas emission mitigation policies. The more countries abate greenhouse gases through the agricultural sector, the higher agricultural commodity prices would be. Income support has been a longtime objective of American farm bills and carbon payments/taxes contribute to farm income support but at the expense of consumers. The unanswered general equilibrium question is whether the consumer is better off if GHGE mitigation is carried out in agriculture as opposed to elsewhere in the economy but this is beyond the scope of this study. If the U.S. and other potential host countries would financially support Clean Development Mechanism initiatives in non-host countries, i.e. Non-Annex I countries, a portion of that expenditure could pay back because higher agricultural prices eliminate the need for expensive farm bills.

Third, if implementation of an equivalent mitigation policy or CDM in all countries is politically infeasible, trade policies might need to be negotiated to discourage increases in non-participating countries and to discourage leakages.

Fourth, credits for agricultural emission abatement could be discounted to reflect likely emission leakage through agricultural sectors in non-host countries. This adjustment would imply higher discount factors for agricultural mitigation strategies, which divert farmland. Such strategies are afforestation and biofuel production. However, strategies, which are complementary to traditional food and fiber production, such as reduced tillage, would remain eligible for full credit. A differential treatment of agricultural mitigation strategies would then increase the relative adoption of complementary strategies and thus reduce leakage.

Fifth, consumers of agricultural products incur higher expenses due to price increases. The more countries participate in mitigation efforts, the higher are losses to both domestic and foreign consumers. Consequently, more people may become dependant on governmental aid to ensure sufficient food consumption.

There are also implications for modelers. Our results show deviation from the results of previous studies, which only looked at fossil fuel based carbon emission taxes. Consideration of emissions from other sources such as methane, nitrous oxide and land related carbon releases are also important and should be considered in future studies. The results also show international adjustments and potential leakage are important modeling concerns.

The quantitative effects presented in this study reflect several simplifying assumptions and uncertain data, and should therefore be considered preliminary. While efforts will continue

to improve the underlying data, the basic nature of our findings is unlikely to change.

Possible extensions to our work could also involve a general equilibrium analysis.

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References

- Alig, R.J., D.M. Adams, J.M. Callaway, S.M. Winnett and B.A. McCarl, "Assessing Effects of Mitigation Strategies for Global Climate Change with an Intertemporal Model of the U.S. Forest and Agriculture Sectors", *Environmental and Resource Economics*, 9, 259-274, 1997.
- Antle, J.M., S.M. Capalbo, J.B. Johnson, and D. Miljkovic. (1999). "The Kyoto Protocol: Economic Effects of Energy Prices on Northern Plains Dryland Grain Production." *Agricultural and Resource Economics Review* 28(1):96-105.
- Antle, J.M., S.M. Capalbo, S. Mooney, E.T. Elliott, and K.H. Paustian. 2002. "A Comparative Examination of the Efficiency of Sequestering Carbon in U.S. Agricultural Soils." *American Journal of Alternative Agriculture* 17(3):109-115.
- Babiker, M. H. 2001. "Subglobal Climate-Change Actions and Carbon Leakage: The Implications of International Capital Flows." *Energy Economics* 23:121-139.
- Babiker, M.H., H.D. Jacoby, J.M. Reilly and D.M. Reiner , "The Evolution of a Climate Regime: Kyoto to Marrakech" *Environmental Science and Policy* 5(3): 192-206.

- Barker, T. 1999. "Achieving a 10 percent Cut in Europe's Carbon Dioxide Emissions using Additional Excise Duties: Coordinated, Uncoordinated and Unilateral Action using the Econometric Model E3ME." *Economic Systems Research* 11(4):401-421.
- Bernstein, P., W. D. Montgomery, and T. F. Rutherford. 1999. "Global Impacts of The Kyoto Agreement: Results from The MS-MRT Model." *Resource and Energy Economics* 21:375-413.
- Brooks, H.G., Satheesh V. Aradhyula, and S.R. Johnson. 1992. "Land Quality and Producer Participation in U.S. Commodity Programs." *Review of Agricultural Economics* 14(1):105-115.
- Chang, C.C., B.A. McCarl, J.W. Mjelde, and J.W. Richardson. "Sectoral Implications of Farm Program Modifications." *Amer. J. of Agr. Econ.* 74(1992):38-49.
- Chen, C. C. "Development and Application of a Linked Global Trade-Detailed U.S. Agricultural Sector Analysis System." PhD Dissertation, Texas A&M University, May 1999.
- Chen, C. C., and B. A. McCarl, "The Value of ENSO Information to Agriculture: Consideration of Event Strength and Trade", *Journal of Agr. and Resource Econ.*, 25,2(2000):368-385.
- Chomitz, Kenneth M. 2002. "Baseline, Leakage and Measurement Issues: How Do Forestry and Energy Projects Compare?" *Climate Policy*.
- Felder, S., and T. Rutherford. 1993. "Unilateral CO2 Reductions and Carbon Leakage: The Consequences of International Trade in Oil and Basic Materials." *Journal of Environmental Economics and Management* 25:162-176.

- Fellin, L., and S. Fuller. "Effects of Privatizing Mexico's Railroad System on U.S.- Mexico Overland Grain/Oilseed Trade." *Transportation Research Forum*, 37(March 1998):46-64.
- Fellin, L., and S. Fuller. "Effects of Proposed Waterway User Change on U.S. Grain Patterns and Producers." *Transportation Research Forum*, 36(June 1997):11-25.
- Francel, T. 1997. Potential Economic Impact of the Global Climate Treaty on the Agricultural Sector .American Farm Bureau Federation, Park Ridge, IL.
- Francel, T., R. Nadler, and J. Bast. "The Kyoto Protocol and U.S. Agriculture." *The Heartland Institute*. No. 87 (October 1998) <http://www.heartland.org/studies/gwag-sum.htm>.
- Hoag, D.L., B.A. Babcock, and W.E. Foster. 1993. "Field-Level Measurement of Land Productivity and Program Slippage." *American Journal of Agricultural Economics* February:181-189.
- IPCC, 2001a, Climate Change 2001: The Scientific Basis, Cambridge University Press, New York.
- IPCC, 2001b, Climate Change 2001: Impacts, Adaptation and Vulnerability, Cambridge University Press, New York.
- Jaffe, A.B., S.R. Peterson, P.R. Portney, and R.N. Stavins. "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature*, Vol. XXXIII (March 1995), pp.132-163.

- Konyar, K. and R.E. Howitt. (2000). "The Cost of the Kyoto Protocol to US Crop Production: Measuring Crop Price, a Regional Acreage and Input Substitution Effects". *Journal of Agricultural and Resource Economics* **25**, 347-3367
- McCarl, B.A., C.C. Chang, J.D. Atwood, and W.I. Nayda. "Documentation of ASM: The U.S. Agricultural Sector Model." Texas A&M University, <http://ageco.tamu.edu/faculty/mccarl/asm.html>, 2001.
- McCarl, B.A., M. Gowen, U.A. Schneider and T. Yeats, "The Impact of Carbon Permit Prices on the U.S. Agricultural Sector", Prepared for: Climate Policies and Programs Division, U.S. EPA, 1997, <http://ageco.tamu.edu/faculty/mccarl/papers/759.pdf>.
- McCarl, B.A. and U. Schneider, "Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective", *Review of Agricultural Economics*, 22(1), 134-159, 2000.
- McCarl B.A. and U.A. Schneider, "The Cost of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry", *Science*, Volume 294 (21 Dec), 2481-2482, 2001.
- Murray, B.C., B.A. McCarl and H.C. Lee, "Estimating Leakage From Forest Carbon Sequestration Programs", Presented at 2002 World Congress of Environmental and Resource Economists, Monterey, California, June, 2002.
- Oliveira-Martins, J., J.M. Burniaux, and J.P. Martin. 1992. "Trade and the Effectiveness of Unilateral CO₂-Abatement Policies: Evidence from GREEN." OECD Economic Studies No.19.

- Peters, M., R. House, J. Lewandrowski, and H. McDowell. "Economic Impacts of Carbon Charges on U.S. Agriculture." *Climatic Change*. 50(4): 445-473; Sep 2001.
- Pethig, R. "Pollution, welfare and environmental policy in the theory of comparative advantage", *Journal of Environmental Economics and Management* 2 (1976), 160-169.
- Roningen, V. O., J. Sullivan, and P. Dixit. "Documentation of the Static World Policy Simulation (SWOPSIM) Modeling Framework." Washington, DC, Economic Research Service, USDA. Staff Report AGES 9151, 1991.
- Samuelson, P. "Spatial Price Equilibrium and Linear Programming" *American Economic Review*, 42(1952): 283-303.
- Schneider, U. "Agricultural Sector Analysis on Greenhouse Gas Emission Mitigation in the United States." PhD Dissertation, Texas A&M University, December 2000.
- Schneider, U.A. and B.A. McCarl. "Economic Potential of Biomass for Greenhouse Gas Emission Reductions: Comparative role in Agriculture", *Proceedings of conference on Sustainable Energy: New Challenges for Agriculture and Implications for Land Use* Wageningen University, The Netherlands, 2000.
- Smith, C.. 1998. "Carbon Leakage: An Empirical Assessment Using a Global Econometric Model." In *International Competitiveness and Environmental Policies*, Terry Barker and Jonathan Kohler, eds., pp.143-169. Massachusetts: Edward Elgar Publishing, Inc.
- Sparks Companies, Inc. 1999. United Nations Kyoto Protocol: Potential Impacts on U.S. Agriculture. McLean. VA.

Takayama, T. and G.G. Judge. "Spatial and Temporal Price and Allocation Models."

North-Holland Publishing Company, 1971.

United Nations, Framework Convention on Climate Change. *Kyoto Protocol*. Climate Change Secretariat (UNFCCC). [Online]. Available at

<http://www.unfccc.de/resource/convkp.html>, March 1998.

United States Department of Agriculture. Agricultural Statistics various issues, 1950-1996, Washington DC. (<http://www.usda.gov/nass/pubs/agstats.htm>), annual.

United States Department of Agriculture, Office of the Chief Economist, 1999. Economic Analysis of U.S. Agriculture and the Kyoto Protocol,

<http://www.usda.gov/oce/gcpo/Kyoto.pdf>.

United States Department of Agriculture. Foreign Agricultural Trade of the United States, Washington DC. <http://usda.mannlib.cornell.edu/reports/erssor/trade/fau-bb/>, 1994a.

United States Department of Agriculture. Grain: World Market and Trade, Washington DC, 1994b.

United States Department of Agriculture. Oilseed: World Market and Trade, Washington DC, 1994c.

United States Global Change Research Program, National Assessment Synthesis Team , [Climate Change Impacts on the United States - Overview Report: The Potential Consequences of Climate Variability and Change](#); Cambridge University Press, New York, 2000.

- Wu, J. 2000. "Slippage Effects of the Conservation Reserve Programs." *American Journal of Agricultural Economics* 82:979-992.
- Wu, J., D. Zilberman, B.A. Babcock. 2001. "Environmental and Distributional Effects of Conservation Targeting Strategies." *Journal of Environmental Economics and Management* 41, 333-350.

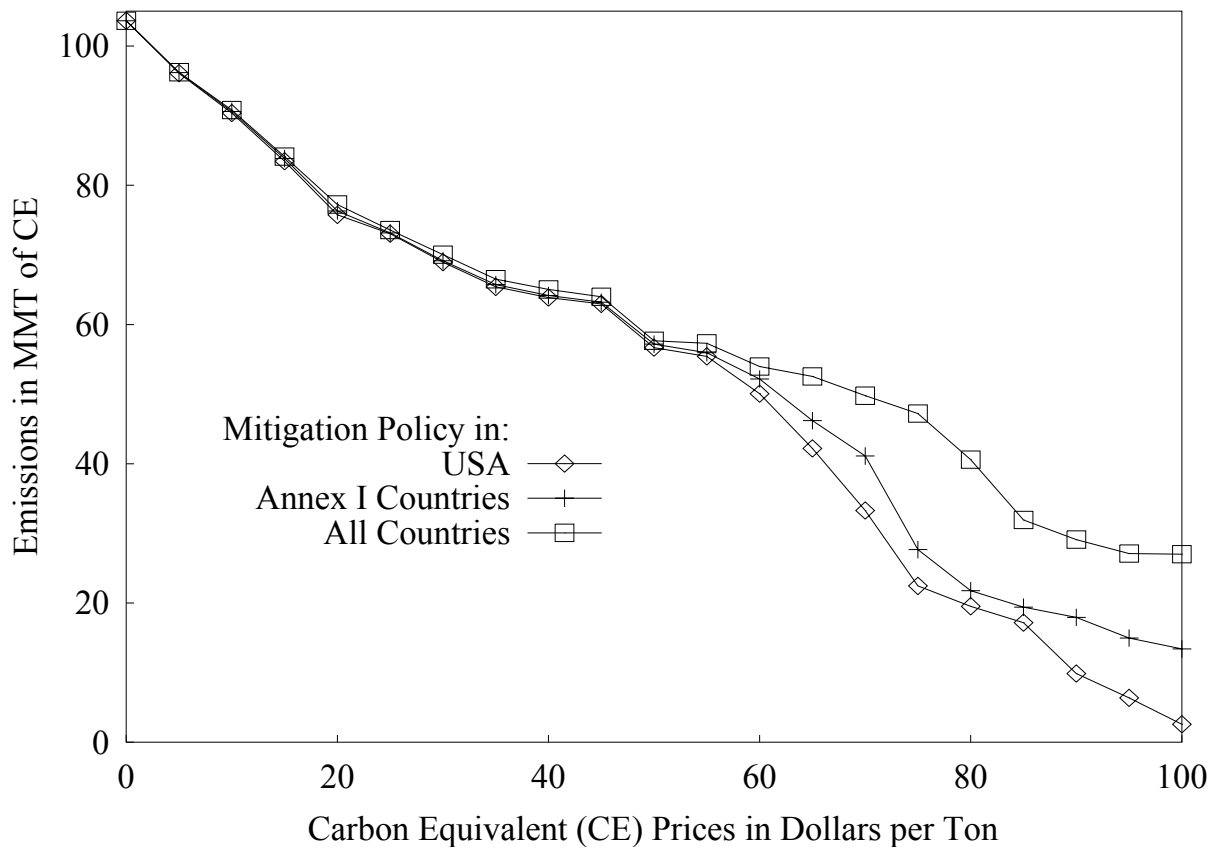


Figure 1 Carbon Equivalent Prices and Net Carbon Emissions from U.S. Agriculture

Table 1 Impacts of Carbon Equivalent Prices on Fisher Ideal Price and Quantity Indices of Production, and Trade^d

| | Mitigation Policy in | | | | | | | | |
|--|----------------------|--------|--------|--------------------------|--------|--------|---------------|--------|--------|
| | US Only | | | US and Annex I Countries | | | All Countries | | |
| | \$10 | \$20 | \$100 | \$10 | \$20 | \$100 | \$10 | \$20 | \$100 |
| U.S. | | | | | | | | | |
| Production of Traded Crops | 99.60 | 99.09 | 93.47 | 99.87 | 99.64 | 97.09 | 100.52 | 100.59 | 105.11 |
| All Production | 99.33 | 99.04 | 97.53 | 99.93 | 99.16 | 97.43 | 99.47 | 99.32 | 98.59 |
| Overall Agricultural Product Prices | 100.57 | 101.42 | 110.60 | 100.76 | 101.82 | 113.44 | 101.22 | 102.28 | 121.68 |
| Exports | 98.84 | 97.44 | 81.77 | 99.93 | 99.50 | 97.65 | 102.19 | 103.28 | 126.92 |
| Production of traded commodities in rest of world | | | | | | | | | |
| Global production | 99.96 | 99.93 | 99.60 | 99.95 | 99.91 | 99.44 | 99.98 | 99.94 | 99.71 |
| Annex I Countries (excluding U.S.) | 100.36 | 100.69 | 102.66 | 99.51 | 98.81 | 92.31 | 99.61 | 99.94 | 99.25 |
| Non-Annex I Countries | 100.32 | 100.93 | 112.22 | 100.49 | 102.15 | 120.13 | 96.89 | 93.85 | 57.60 |

^d Note: Trading crops production includes the production for corn, soybeans, sorghum, rice, and four kind of wheat defined previous; all production includes production for all primary products (crops and livestock) defined in the model.

Table 2 Impacts of Carbon Equivalent Prices on Agricultural Sector

Welfare (Million Dollars) and U.S. Emissions (MMT)^e

| | Mitigation Policy in | | | | | | | | |
|--|----------------------|--------------------|-------------------|-------------------|-------------------|--------------------|------------------|-------------------|--------------------|
| | USA Only | | | Annex I Countries | | | All Countries | | |
| | \$10 | \$20 | \$100 | \$10 | \$20 | \$100 | \$10 | \$20 | \$100 |
| U.S. Consumers' Surplus | -540 (-0.05) | -1,240 (-0.10) | -9,159 (-0.77) | -607 (-0.05) | -1,536 (-0.13) | -11,355 (-0.96) | -749 (-0.06) | -1,976 (-0.17) | -17,607 (-1.49) |
| Net U.S. Producers' Surplus with GHG tax/pay | -207.32 (-0.46) | -161.70 (-0.36) | 7,430 (16.35) | -71.61 (-0.16) | 449 (0.99) | 13,037 (28.69) | 264.39 (0.58) | 1,479 (3.26) | 27,336 (60.15) |
| Ag Producers' Surplus without GHG Pay | 696 (1.53) | 1,353 (2.98) | 7,689 (16.92) | 835 (1.84) | 1,976 (4.35) | 14,380 (31.64) | 1172 (2.58) | 3,024 (6.65) | 30,037 (66.10) |
| Total Welfare without GHG Pay | 156 (0.01) | 113 (0.01) | -1,471 (-0.12) | 228 (0.02) | 440 (0.04) | 3,025 (0.25) | 424 (0.03) | 1,048 (0.09) | 12,430 (1.01) |
| Total GHG payments to agriculture | -903 | -1,514 | -259 | -907 | -1,526 | -1,342 | -908 | -1,545 | -2,701 |
| Net Welfare | -748 (-0.06) | -1,402 (-0.11) | -1,730 (-0.14) | -678 (-0.06) | -1,087 (-0.09) | 1,683 (0.14) | -484 (-0.04) | -497 (-0.04) | 9,728 (0.79) |
| Foreign Country Surplus | -210 (-0.09) | -395 (-0.16) | -3,516 (-1.45) | 1012 (0.42) | 2,140 (0.89) | 17,902 (7.40) | 2557 (1.06) | 5,360 (2.22) | 42,156 (17.44) |
| Global Agric. Welfare | -54 (-0.003) | -282 (-0.02) | -4,986 (-0.34) | 1240 (0.08) | 2,579 (0.18) | 20,928 (1.42) | 2981 (0.2) | 6,408 (0.44) | 54,586 (3.71) |
| U.S. Agricultural GHG Emissions | 90.37 | 76.74 | 2.58 | 90.61 | 76.32 | 13.40 | 90.81 | 77.23 | 27.01 |

^e The numbers in parentheses give the percentage change with respect to the zero CE-price scenarios.

Gross welfare items exclude GHGE charges/payments.