

# Effects of Agricultural Greenhouse Gas Emission Mitigation Policies: The Role of International Trade

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## **Abstract**

The Kyoto Protocol represents the first international agreement to reduce greenhouse gas emissions. Proposed mitigation efforts may involve the agricultural sector through such options as planting trees, crop and livestock management changes, and biofuels production. The combined use of these strategies could substantially reduce net emissions of carbon dioxide, methane, and nitrous oxide. However, countries where the Protocol imposes emissions caps have expressed concern about their competitiveness with countries that are not part of the Kyoto Protocol. In a free-trade arena, food production and exports in unregulated countries could increase and reduce market share for the producers in complying countries.

We examine the effects of differential Protocol treatments on agricultural food production and on international trade of agricultural commodities modeling under the assumption that the average U.S. compliance-caused cost increase would also occur in other complying countries. The three cases considered are (1) unilateral U.S. implementation, (2) unilateral Annex I country implementation, and (3) global implementation. 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 supply increases in nonregulated countries. In addition, the study results show that U.S. agricultural producers are likely to benefit from a Kyoto Protocol-like environment, but consumers are likely to be hurt in terms of their agricultural welfare

**Key words:** Agricultural Sector Model, crop exports, food production, greenhouse gas emission mitigation, international trade, Kyoto Protocol, leakage.

# **EFFECTS OF AGRICULTURAL GREENHOUSE GAS EMISSION MITIGATION POLICIES: THE ROLE OF INTERNATIONAL TRADE**

## **Introduction**

Society has increasingly become concerned with the emissions of greenhouse gases (GHG), the resultant atmospheric GHG concentrations, and their potential effects on climate. The Intergovernmental Panel on Climate Change (IPCC) projects that GHG concentrations will cause global mean temperatures to rise by about 0.3 degree Celsius per decade (Houghton, Jenkins, and Ephramus). Such warming in turn is predicted to raise the sea level, to change the habitat boundaries for many plants and animals, and to induce other changes (Cole et al.). The Kyoto Protocol represents the first international agreement to reduce greenhouse gas emissions. Proposed mitigation efforts may involve the agricultural sector through such options as planting trees, crop and livestock management changes, and biofuels production (McCarl and Schneider). The combined use of these strategies could substantially reduce net emissions of carbon dioxide, methane, and nitrous oxide.

Because effects of GHG emission (GHGE) reductions are global, all countries will share the benefits from GHGE mitigation efforts, but only the countries adopting the mitigation policies will bear the brunt of the costs. Producers within countries adopting agricultural GHGE mitigation strategies are likely to experience increased production costs. Non-implementing countries, therefore, may gain advantage and the market share of production from implementing and non-implementing countries may change. This has been a concern of many in the potentially affected countries. For example, the U.S. Farm Bureau Federation advances a position that it will oppose ratification of the Kyoto Protocol (KP) because principal competitor countries in international agricultural markets are not constrained by the terms of the Protocol (Francl, Nadler, and Bast).

This document reports on a study which conducted a first-order examination of the international trade impacts of differential KP-like implementation across countries.

Specifically, we examine trade and U.S. agricultural sector implications under (1) unilateral U.S. implementation, (2) unilateral U.S. and all other Annex I<sup>1</sup> country implementation, and (3) global implementation. The global implementation scenario would arise under a perfect implementation of the Joint Implementation mechanism in the KP Article 6, the Clean Development Mechanism (CDM) of Article 12, and the international trading mechanisms in Article 17.

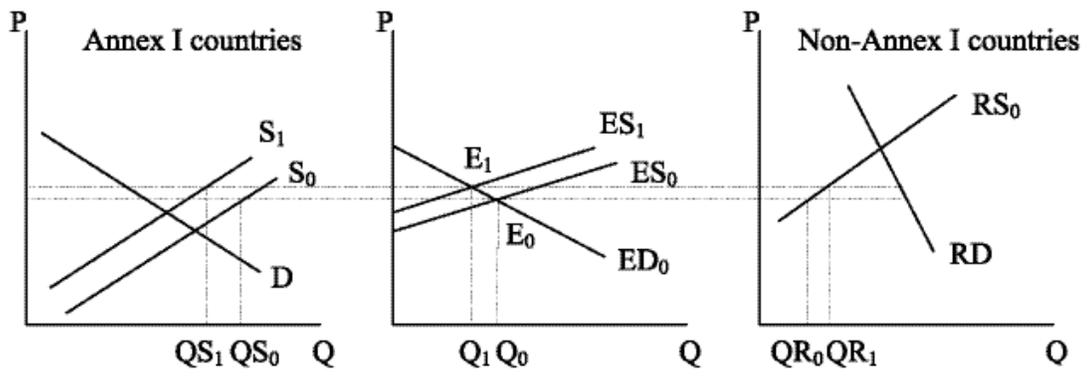
## **A Graphic Economic Analysis of GHGE Reduction Implementation**

In this section we investigate two different international implementation and trading situations involved with GHGE mitigation policy implementation. The first case considers the impacts of unilateral GHGE mitigation implementation in just one group of, say, Annex I, countries. Second, we will assume a global implementation of GHGE mitigation policies in the agricultural sector for all countries.

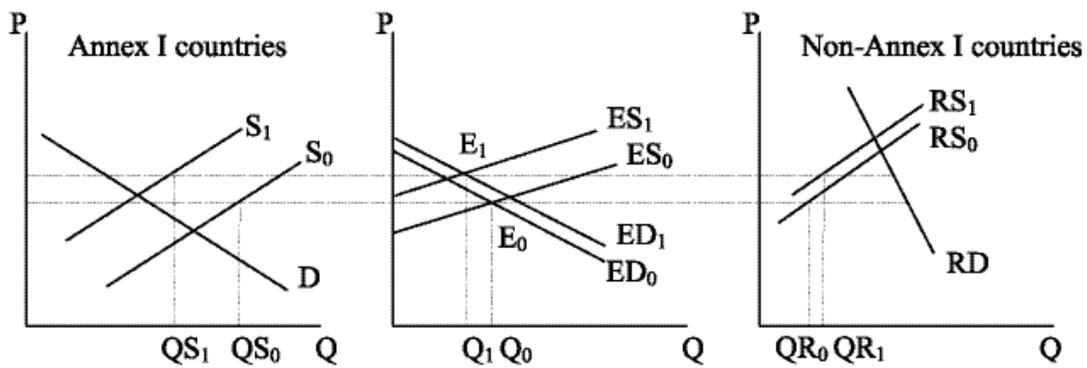
### **Unilateral GHGE Mitigation Implementation**

Suppose Annex I countries are net exporters. Let  $S$ ,  $D$ ,  $ES$ ,  $ED$  represent the aggregate domestic supply, domestic demand, excess supply, and excess demand curves of Annex I countries, respectively (Figure 1, Panel A). Similarly, let  $RS$  and  $RD$  represent the non-Annex I countries' aggregated excess supply and demand curves. The trade equilibrium between Annex I and non-Annex I countries occurs at  $E_0$ , where the Annex I countries' excess supply curve intersects the non-Annex I countries' excess demand curve. At this point, Annex I countries' exports equal the sum of imports into non-annex I countries  $Q_0$ .

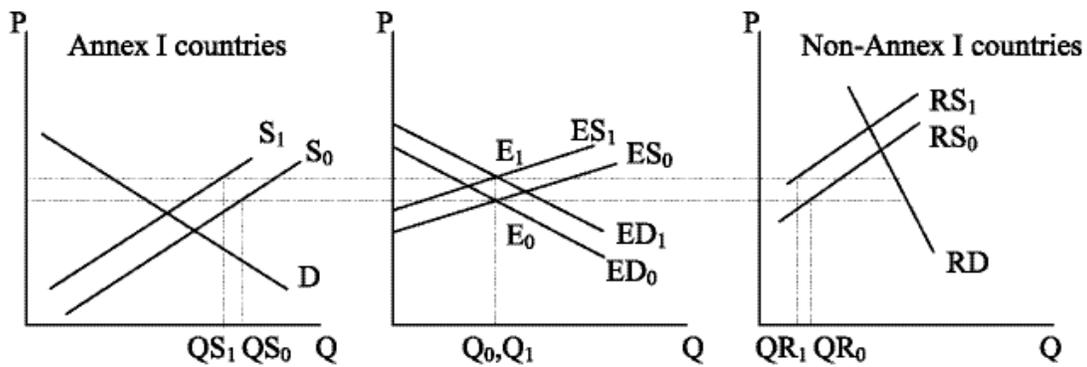
If Annex I countries alone ratify the KP, their domestic and excess supply curve would move upwards (from  $S_0$  to  $S_1$  and from  $ES_0$  to  $ES_1$ ), reflecting higher cost of domestic production. The new equilibrium would be at  $E_1$ , yielding lower levels of Annex I countries' domestic production and exports and a higher price. Non-Annex I countries would increase their aggregate food production (from  $QR_0$  to  $QR_1$ ). Assuming that emissions are proportional to food production intensity, emissions will decrease in Annex I countries but will increase in non-Annex I countries. The effect on global GHGE, however, is ambiguous depending on elasticities of involved supply and demand curves.



Panel A: Partial implementation of agricultural GHGE mitigation policies



Panel B: Global agricultural GHGE mitigation policies with different supply shifts



Panel C: Global agricultural GHGE mitigation policies with similar supply shifts

FIGURE 1. Effects of agricultural mitigation policies on trade

## **Worldwide GHGE Mitigation Implementation**

In this scenario, supply curves for traditional agricultural products shift left both in Annex I and non-Annex I countries (Figure 1, Panels B, C). As a result, the equilibrium price in the world market would increase. We can expect total production as well as global GHGE would decrease. The impact of a global mitigation policy on individual countries depends on the country-specific link between food production and GHGE. If mitigation policies induce substantial supply shifts in some countries but only small shifts in others, production may increase in the latter countries. Overall, global implementation of GHGE mitigation policies is likely to smooth the cost of emission reduction.

## **Model Description**

We will use a model to evaluate the empirical magnitude of alternative levels of GHG emission trading. In particular, the detailed greenhouse gas version of the U.S. Agricultural Sector Model (ASM) developed by Schneider is used. This model arose from the base ASM as described in Chang et al. and McCarl et al. with the addition of details on soil types (developed in conjunction with USDA-NRCS) and a trade representation via spatial equilibrium models for eight commodities as developed by Chen and Chen and McCarl. The combined model, hereafter called ASMGHG, considers agricultural production, consumption, and trade in developed and developing countries simultaneously. Overall characteristics of the model are discussed next.

### **U.S. Agricultural Sector Model**

Like many agricultural sector models, ASMGHG is set up as price-endogenous mathematical program, following the market equilibrium and welfare optimization concept developed in Samuelson and in Takayama and Judge. ASMGHG simulates the competitive equilibrium in the agricultural commodity markets as well as in key input markets. Demand for commodities and supply for farming inputs are aggregated for each of 63 regions in the United States and for 28 foreign countries. Exports and imports are modeled in ASMGHG via excess supply and demand curves or a spatial equilibrium model, depending on commodity. Specifically, spatial equilibrium trade components are explicitly included for corn, sorghum, soybeans, rice, and four types of wheat (hard red spring and winter wheat, soft wheat, and hard wheat). 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 (USDA-NASS, USDA 1994a,b,c), and the USDA SWOPSIM model (Roningen, Sullivan, and Dixit).

### **Modeling Greenhouse Gas Emissions and Mitigation Strategies**

The original ASM model did not contain greenhouse gas emission components; Schneider added such a component. The component introduces choice variables and/or GHG net emission accounting to consider changes in crop mix, tillage, irrigation, fertilization, afforestation, biofuel production, and livestock management. Livestock management options involve (1) herd size, (2) methane reduction strategies including liquid manure system alterations on dairy and hog farms, and (3) enteric fermentation management involving use of growth hormones for dairy cows. A detailed description of all considered mitigation strategies and data sources is contained in Schneider. ASMGHG contains emission accounting equations, which add up

- direct carbon emissions from fossil fuel use (diesel, gasoline, natural gas, heating oil, LP gas) in tillage, harvesting, or irrigation water pumping as well as altered soil organic matter (cultivation of forested lands or grasslands);
- indirect carbon emissions from manufacture of fossil fuel intensive inputs (fertilizers, pesticides);
- carbon savings from increases in soil organic matter (reduced tillage intensity, conversion of arable land to grassland and from tree planting);
- carbon offsets from biofuel production (ethanol, power plant feedstock via production of switchgrass, poplar, and willow);
- nitrous oxide emissions from fertilizer usage and livestock manure;
- methane emissions from enteric fermentation, livestock manure, and rice cultivation;
- methane savings from manure management changes, and methane and nitrous oxide emission changes from biomass power plants.

Individual emissions and emission reductions were converted to carbon equivalent measures using global warming potential from the IPCC (21 for methane and 310 for nitrous oxide).

## **Experimental Results and Implications**

Three alternative policy implementation scenarios were run to examine the impacts of the scope of international GHGE mitigation efforts. The first scenario assumes mitigation efforts in U.S. agriculture only. The second corresponds to a KP-like situation with agricultural provisions applying to all Annex I countries. The third involves worldwide implementation. All three scenarios were analyzed for alternative CE-prices ranging from \$0 to \$500 per ton. Major results are illustrated for CE-prices up to \$100 per ton. In addition, we tabulated scenario results corresponding to price levels of \$20, \$100, and \$400 per ton of carbon equivalent.

### **Unilateral Implementation in the United States Alone**

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 shown in Figures 2–6. The effects on U.S. agricultural GHGE by gas category are summarized in Figure 2. Total CE-equivalent emissions decline steadily as the CE-price rises. At \$100 per ton, net emissions of CE from U.S. agriculture are about zero. Net emissions of carbon dioxide are negative for CE-prices beyond \$55 per ton. At \$100, the realized levels of carbon sequestration from carbon sinks offset agricultural emissions of methane and nitrous oxide. As Table 2 shows, net emission values from agriculture can be substantially negative if CE-prices are extremely high; i.e., a CE-price of \$400 per ton yields annual net emission of -168 million metric tons (mmt).

Figure 3 shows the effects in the United States of increasing CE-prices on domestic agricultural production, prices, and exports for major trading crops under the unilateral implementation. All indices show the percentage changes from a zero-carbon-price base situation corresponding to no action on the greenhouse gas emission reduction front. Comparison of Figure 2 and Figure 3 confirms our assumption 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. In addition, because the United States is a major world agricultural trading country, it influences production in other countries. As shown in Table 1 and Figure 4, U.S. unilateral CE-prices lead to expanded world production and exports in both Annex I (U.S. not included) and non-Annex I countries.

**TABLE 1. Results on Fisher Ideal Price and Quantity Indices of production, price, and trade at different carbon equivalent prices for greenhouse gas emissions**

	Mitigation Policy in								
	USA Only			Annex I Countries			All Countries		
	\$20	\$100	\$400	\$20	\$100	\$400	\$20	\$100	\$400
	U.S.								
Trading crops production	99.09	93.47	66.20	99.64	97.09	88.84	100.59	105.11	114.91
All production	99.04	97.53	96.34	99.16	97.43	97.00	99.32	98.59	95.70
Trading crops prices	101.18	112.06	226.40	102.08	120.72	357.31	103.65	140.35	635.79
Overall agricultural product prices	101.42	110.60	196.32	101.82	113.44	225.04	102.28	121.68	307.17
Exports	97.44	81.77	18.84	99.50	97.65	104.13	103.28	126.92	203.97
	All Countries Except U.S.								
Exports	100.83	107.95	145.25	100.66	106.64	143.73	96.58	78.34	68.83
Imports	99.24	95.88	85.94	100.23	105.65	142.17	100.56	105.59	145.06
Prices	101.06	107.94	148.68	102.44	123.02	408.12	104.83	154.08	889.01
	Annex I Countries (excluding U.S.)								
Exports	100.69	102.66	113.00	98.81	92.31	80.19	99.94	99.25	89.37
Imports	99.32	95.86	85.55	102.84	128.95	269.59	101.73	111.48	155.95
Prices	101.20	109.21	156.57	103.00	128.20	487.18	105.44	161.80	1008.84
	Non-Annex I Countries								
Exports	100.93	112.22	174.45	102.15	120.13	261.04	93.85	57.60	38.13
Imports	99.19	95.89	86.22	98.43	89.71	58.90	99.76	101.68	138.88
Prices	100.95	107.04	143.28	102.03	118.96	332.63	104.39	148.11	796.69

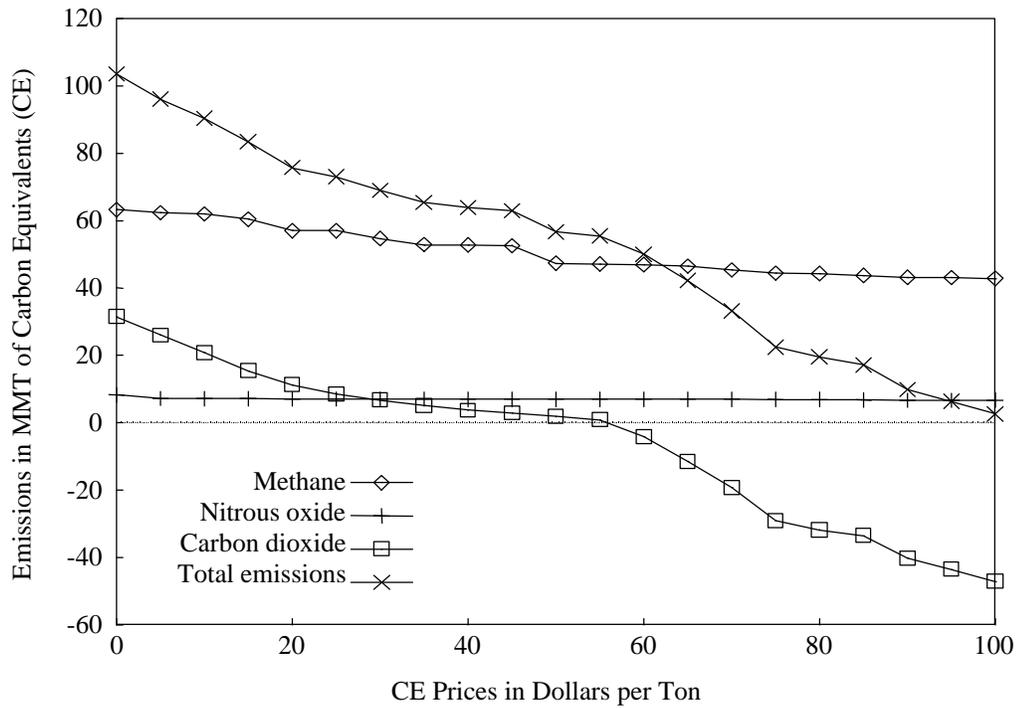
Note: Trading crops production includes the production for corn, soybeans, sorghum, rice, and four kinds of wheat defined previously; all production includes production for all primary products (crops and livestock) defined in the model.

The impacts of GHGE mitigation efforts on agriculture sector welfare are listed in Table 2 and illustrated in Figures 5-6. While U.S. consumers' surplus decreases monotonically with CE-price increases, producers' net surplus decreases only for low CE-price levels but increases for CE-prices above \$55 per ton. Producers' net surplus arises from two sources: traditional production activities and CE-price-induced GHG payments/charges. In a U.S.-only implementation, producers always gain in the production account due to commodity price increases, which more than offset production declines. The effects on the total CE GHGE account depend on the magnitude of carbon prices. For prices below \$100 per ton, emission charges exceed sequestration payments. However, if carbon prices exceed \$100, net GHGE payments to farmers become positive (Table 2).

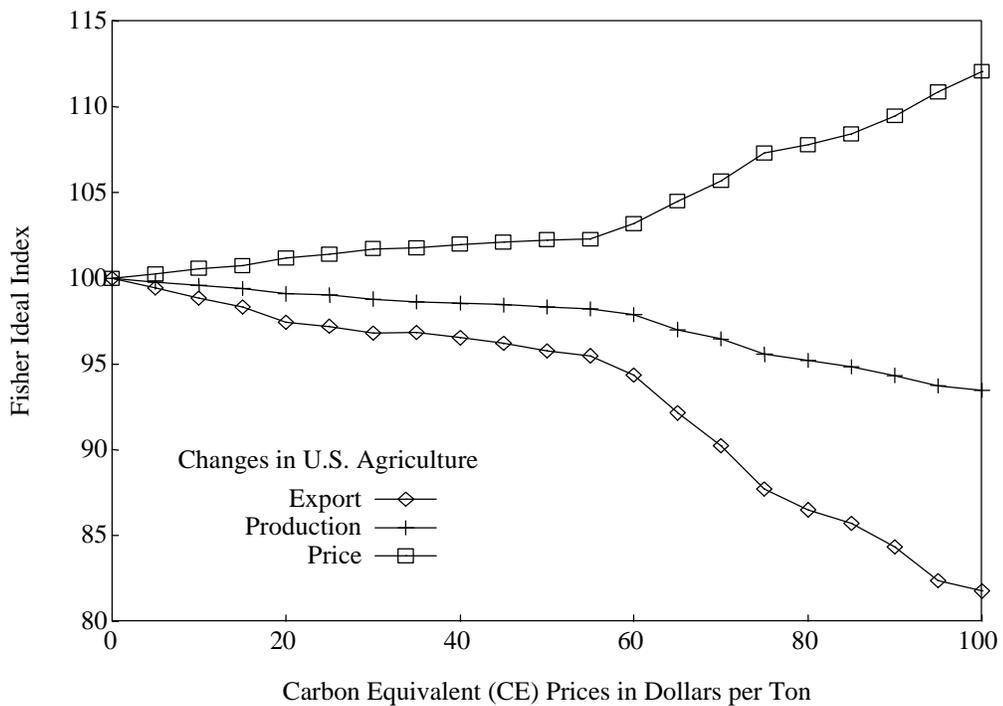
**TABLE 2. Impacts of mitigation policies on agricultural sector welfare (million dollars) and U.S. emissions (mmt) at different carbon equivalent prices**

	Mitigation Policy in								
	USA Only			Annex I Countries			All Countries		
	\$20	\$100	\$400	\$20	\$100	\$400	\$20	\$100	\$400
U.S. consumers' surplus	-1,240 (-0.10)	-9,159 (-0.77)	-66,818 (-5.65)	-1,536 (-0.13)	-11,355 (-0.96)	-79,193 (-6.69)	-1,976 (-0.17)	-17,607 (-1.49)	-117,011 (-9.89)
U.S. producers' surplus	-161.70 (-0.36)	7,430 (16.35)	121,252 (266.82)	449 (0.99)	13,037 (28.69)	197,108 (433.74)	1,479 (3.26)	27,336 (60.15)	391,136 (860.71)
Producers' surplus related to agricultural production	1,353 (2.98)	7,689 (16.92)	54,085 (119.02)	1,976 (4.35)	14,380 (31.64)	155,475 (342.13)	3,024 (6.65)	30,037 (66.10)	396,125 (871.69)
Gross total welfare in U.S. agricultural sector	113 (0.01)	-1,471 (-0.12)	-12,732 (-1.04)	440 (0.04)	3,025 (0.25)	76,282 (6.21)	1,048 (0.09)	12,430 (1.01)	279,120 (22.71)
GHG charges/payments	-1,514	-259	67,167	-1,526	-1,342	41,633	-1,545	-2,701	-4,989
Net total welfare in U.S. agricultural sector	-1,402 (-0.11)	-1,730 (-0.14)	54,435 (4.43)	-1,087 (-0.09)	1,683 (0.14)	117,915 (9.59)	-497 (-0.04)	9,728 (0.79)	274,125 (22.31)
Foreign countries' agricultural trade surplus	-395 (-0.16)	-3,516 (-1.45)	-27,546 (-11.39)	2,140 (0.89)	17,902 (7.40)	392,761 (62.45)	5,360 (2.22)	42,156 (17.44)	213,136 (88.16)
Gross total agricultural welfare	-282 (-0.02)	-4,986 (-0.34)	-40,278 (-2.74)	2,579 (0.18)	20,928 (1.42)	227,276 (15.45)	6,408 (0.44)	54,586 (3.71)	492,249 (33.47)
Net total agricultural welfare	-1,796 (-0.12)	-5,245 (-0.36)	26,889 (1.83)	1,053 (0.07)	19,585 (1.33)	268,909 (18.28)	4,863 (0.33)	51,884 (3.53)	487,260 (33.13)
U.S. agricultural GHG emissions	76.74	2.58	-167.92	76.32	13.40	-104.08	77.23	27.01	12.47
U.S. agricultural GHG emission reductions	-27.89 (-26.92)	-101.05 (-97.50)	-271.55 (-262.03)	-27.32 (-26.36)	-90.21 (-87.05)	-207.72 (-200.43)	-26.40 (-25.48)	-79.62 (-73.93)	-91.16 (-87.97)

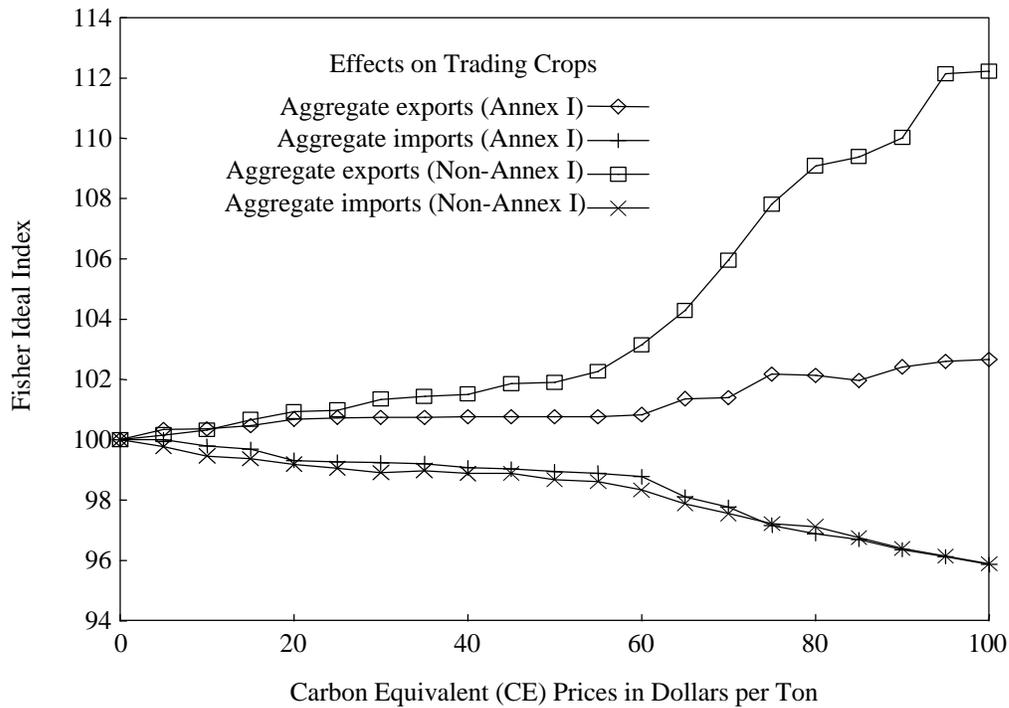
Total welfare effects from a unilateral implementation in the United States are summarized in Figure 6. U.S. agricultural surplus represents the sum of U.S. consumers' and producers' surplus. Up to a CE-price of about \$60 per ton, total U.S. agricultural welfare decreases. Beyond \$60, this trend is reversed and total welfare in the United States increases at the expense of welfare in foreign countries. Trade surplus measures the welfare of consumers and producers in non-U.S. countries attributable to trade of



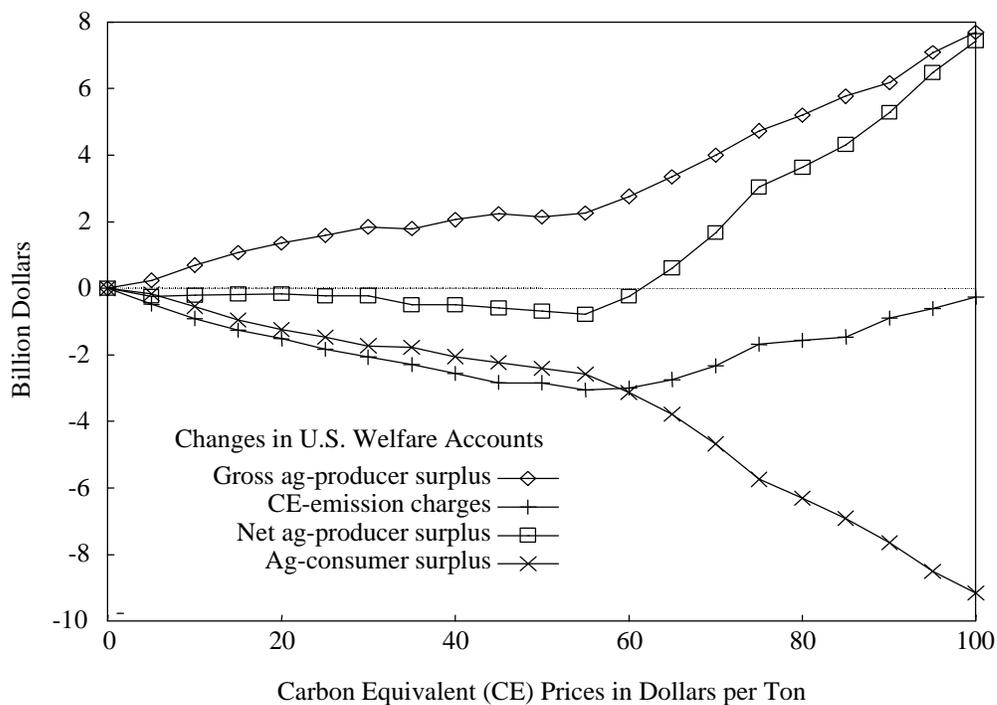
**FIGURE 2. Carbon equivalent prices and emissions of greenhouse gas components**



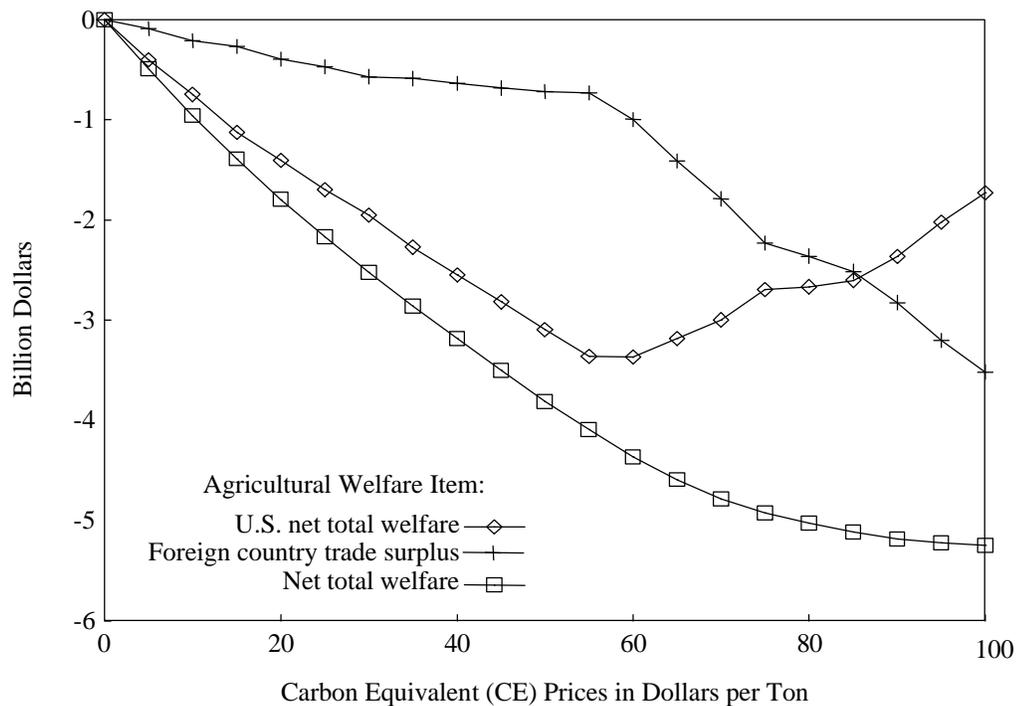
**FIGURE 3. Carbon equivalent prices and production, prices, and exports of trading crops as measured by the Fisher Index (unilateral implementation in the U.S. only)**



**FIGURE 4. Carbon equivalent prices and foreign countries' trade activities as measured by the Fisher Index (unilateral implementation in the U.S. only)**



**FIGURE 5. Carbon equivalent prices and welfare changes in the U.S. agricultural sector (unilateral implementation in the U.S. only)**



**FIGURE 6. Carbon equivalent prices and total welfare changes in the agricultural sector (unilateral implementation in the U.S. only)**

agricultural commodities. If the United States 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. Consumer losses in non-U.S. countries exceed producer gains.

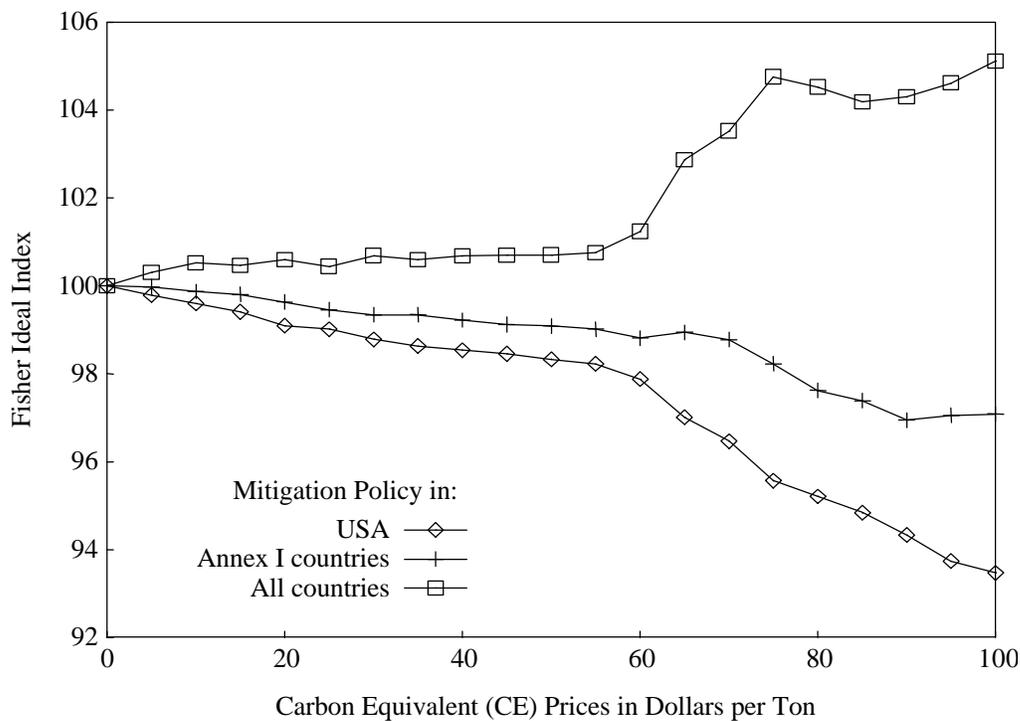
### Modeling Mitigation-Induced Shifts in ROW Countries

Mitigation efforts in agricultural sectors outside the United States could not be modeled explicitly because we did not have detailed modeling of production activities in foreign regions, but we had information on supply curves for major trading crops. Thus, a simplifying assumption was made to depict the supply shifts in foreign countries. Namely, the average price increase and production decrease observed in U.S. production was assumed to apply proportionally to the production in the foreign countries. Thus, under a particular CE-price, if average U.S. prices went up by  $a$  percent and production went down by  $b$  percent, the same shift was applied to foreign supply curves for all commodities in the implementing countries. This is clearly a crude approximation of what would happen, but we felt that alternative reasonable assumptions were not

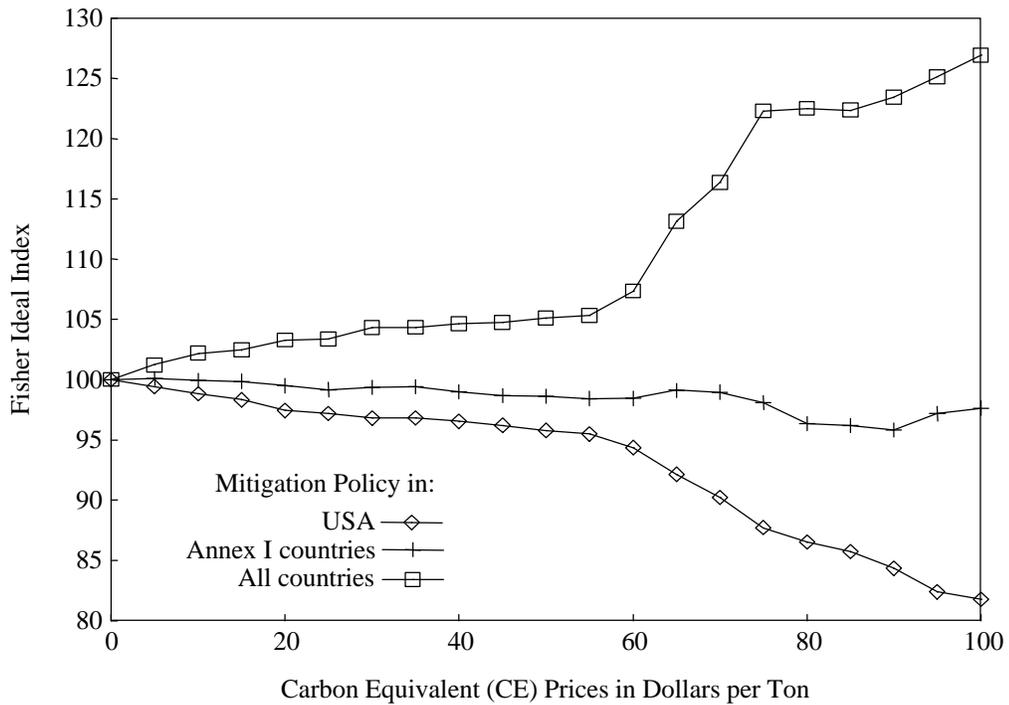
available. Empirical results derived from supply shifts in developing countries should therefore be considered illustrative but not definitive. In presenting our empirical results we will focus on a comparison between the various implementation scenarios examined.

### Full Annex I Implementation

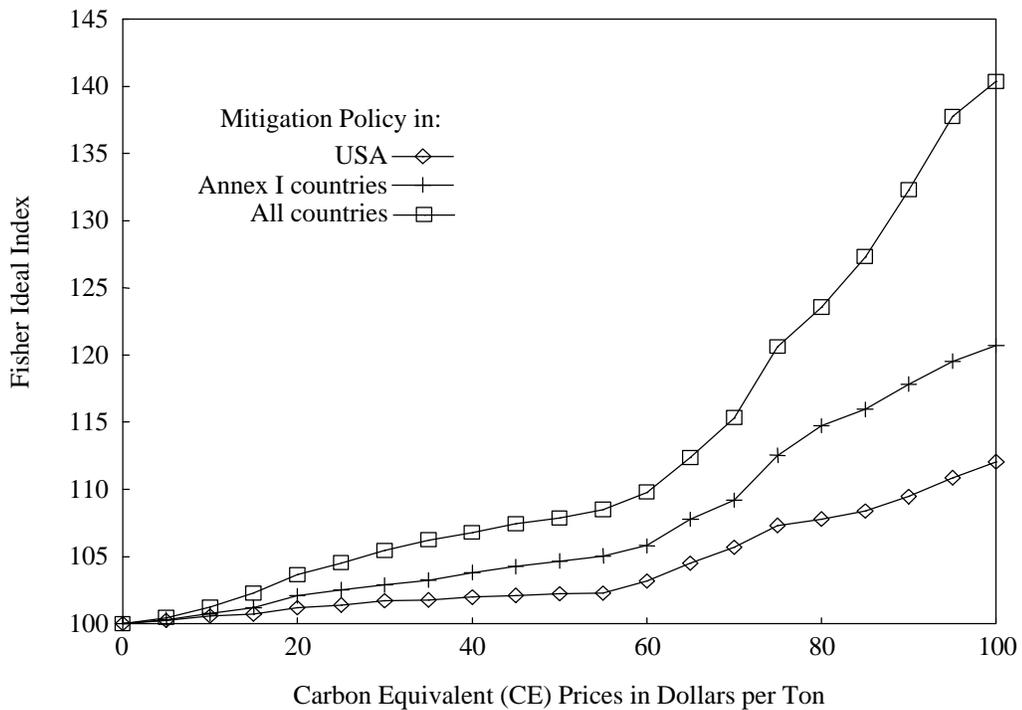
The results for the full Annex I countries implementation are shown in Table 1 and Figures 7-16. In terms of U.S. agriculture, these results are somewhat similar to those under the unilateral U.S. implementation. U.S. production (Figure 7) and exports (Figure 8) decline; however, the rate of change is noticeably lower, particularly for CE-prices above \$60 per ton. This diminished response reflects the fact that only the non-Annex I countries now have comparative advantage over U.S. agriculture as their costs have not been influenced. Prices of traded agricultural commodities increase slightly more under full Annex I implementation (Figure 9). The welfare results shift, with U.S. producers always gaining and consumers losing even more than under unilateral implementation (Figure 10). Overall, U.S. welfare falls less under this more global implementation (Figure 11).



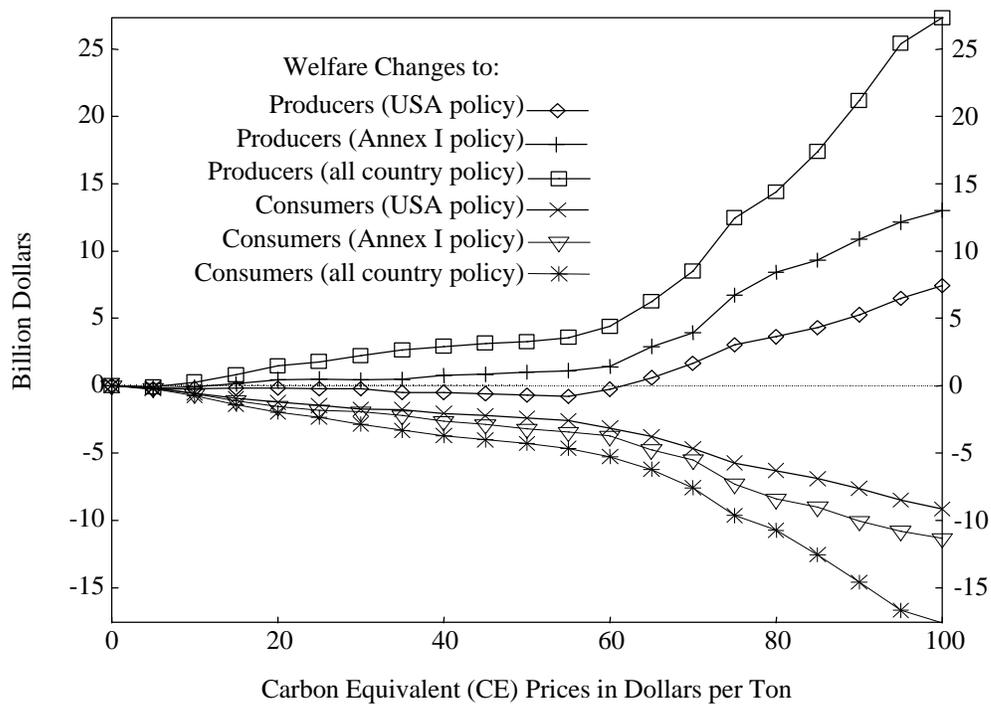
**FIGURE 7. Carbon equivalent prices and U.S. domestic production of trading crops as measured by the Fisher Index**



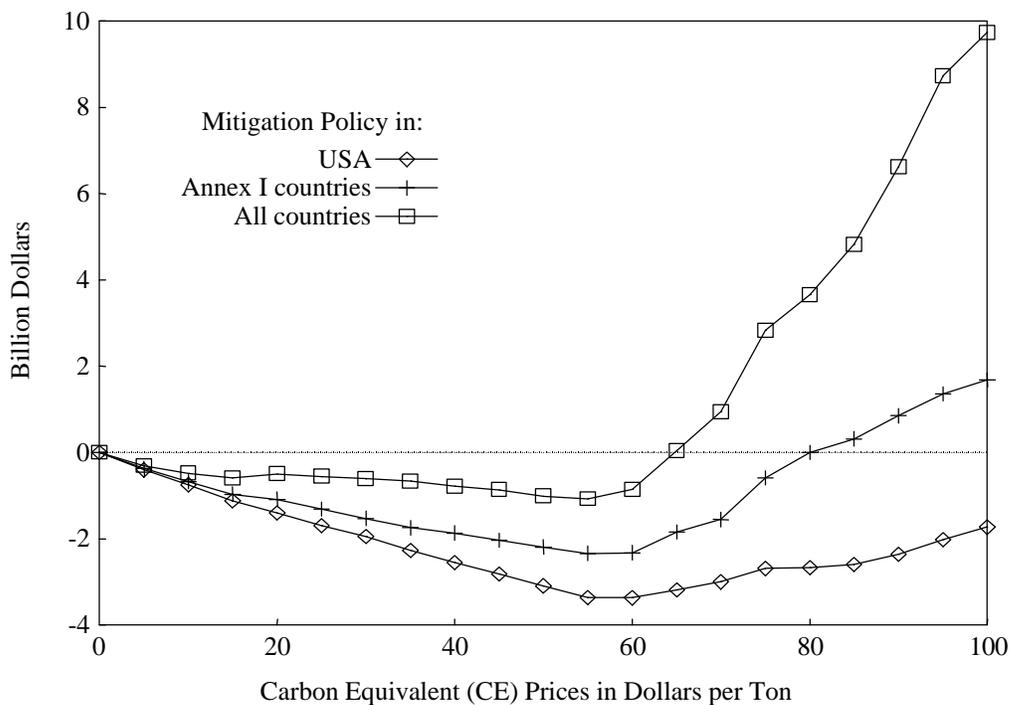
**FIGURE 8. Carbon equivalent prices and U.S. exports of trading crops as measured by the Fisher Index**



**FIGURE 9. Carbon equivalent prices and U.S. prices for trading crops as measured by the Fisher Index**



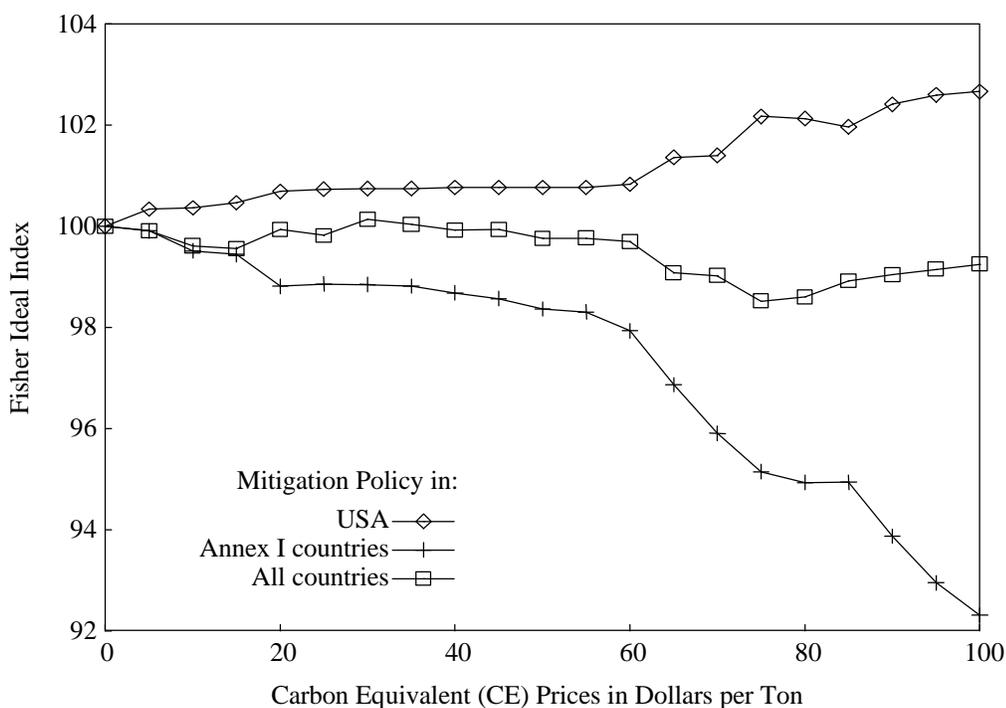
**FIGURE 10. Carbon equivalent prices and welfare changes to U.S. consumers and U.S. producers**



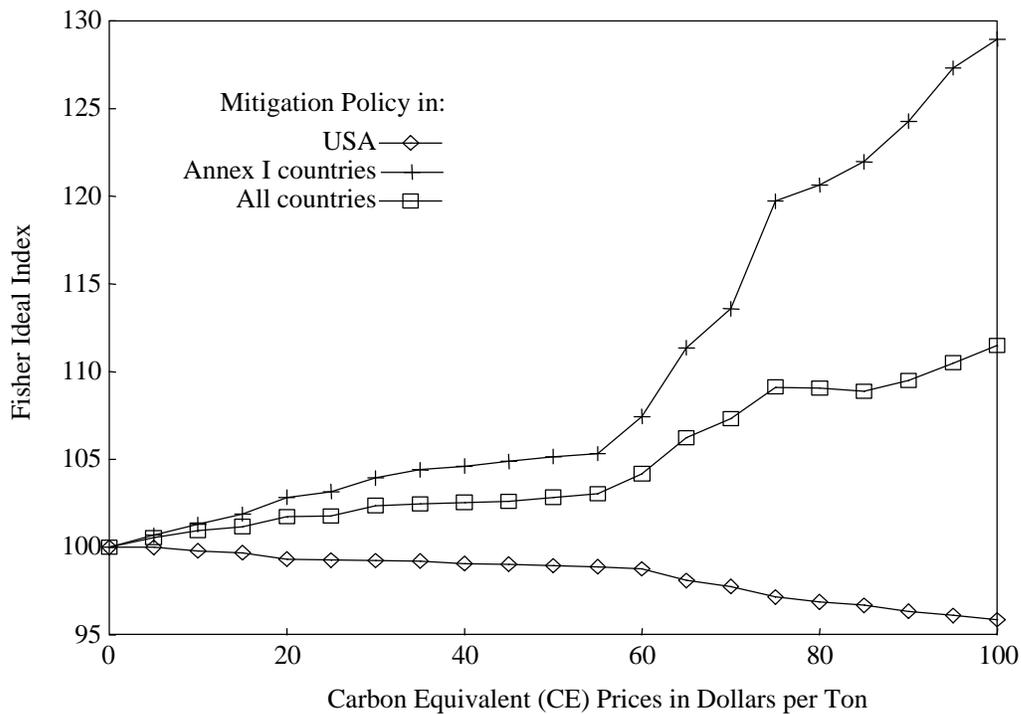
**FIGURE 11. Carbon equivalent prices and net welfare changes in the U.S. agricultural sector**

In Figures 12-15, non-U.S. countries' trade activities are displayed. 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 (Figures 12-13). Equivalently, non-Annex I countries' net exports are highest under full Annex I country implementation (Figure 14-15). All of these observed changes become more substantial the more the CE-price increases. Note that to avoid double counting, the Annex I accounts displayed in all figures do not include the United States.

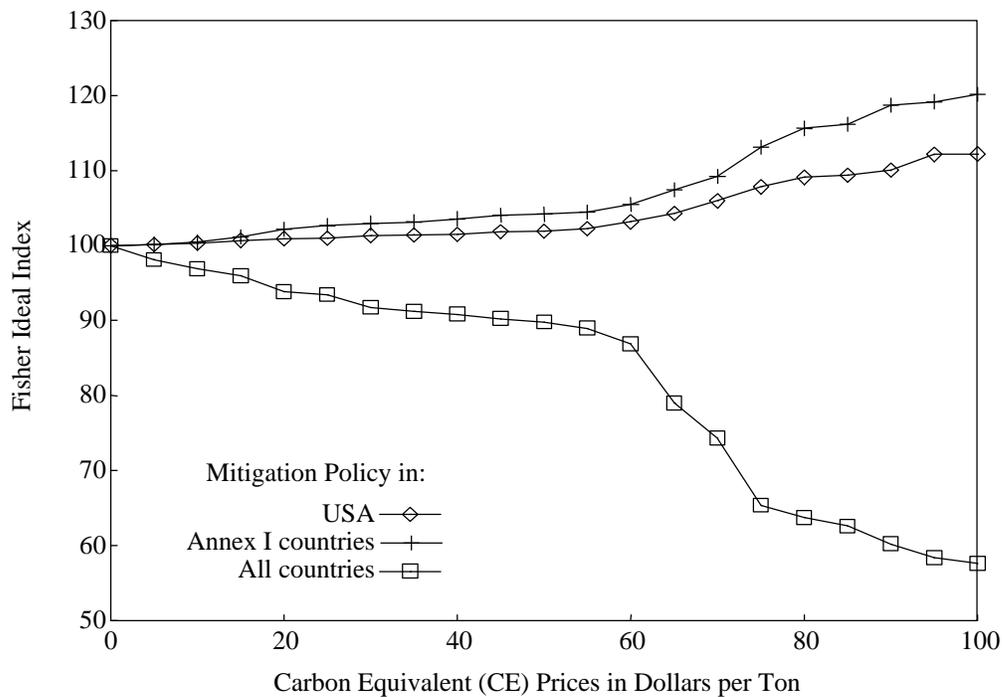
Total emissions reductions from U.S. agriculture are almost identical up to the CE-prices of \$55 per ton (Figure 16). Above \$85 per ton of CE, additional emissions reductions become visibly smaller under full Annex I country implementation. For example, at a CE-price of \$100 per ton, emissions reductions are about 11 percent lower than for implementation of United States alone. 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 emissions reductions in the Annex I agriculture. However, we cannot account for that fact as we do not have



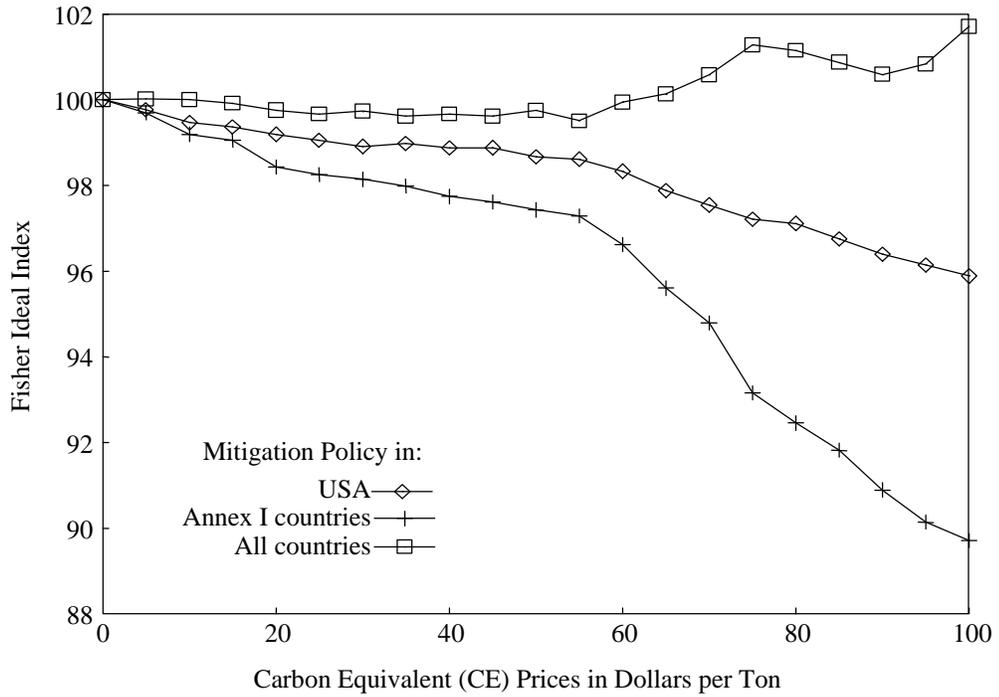
**FIGURE 12. Carbon equivalent prices and crop exports by Annex I countries as measured by the Fisher Index**



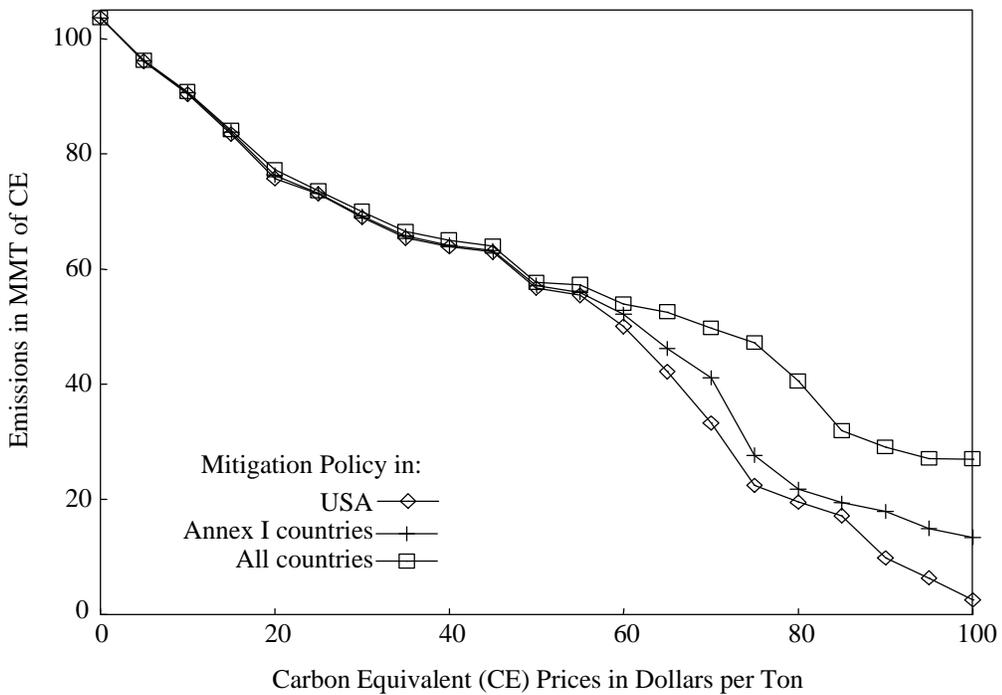
**FIGURE 13. Carbon equivalent prices and crop imports by Annex I countries as measured by the Fisher Index**



**FIGURE 14. Carbon equivalent prices and crop exports by non-Annex I countries as measured by the Fisher Index**



**FIGURE 15. Carbon equivalent prices and crop imports by non-Annex I countries as measured by the Fisher Index**



**FIGURE 16. Carbon equivalent prices and net carbon emissions from U.S. agriculture**

emissions modeled in those countries and extrapolation of U.S. rates would involve even more heroic assumptions than we are now making.

### **Global GHGE Mitigation Implementation**

Provisions in the Kyoto Protocol permit emissions offset 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. In such circumstances, low-cost activities in agriculture can be exploited globally. Thus, in the last scenario we examine a case where production is shifted globally using the U.S. average price and cost shift assumptions as explained above. Tables 1-2 list the main impacts. We find an increasing world market share for the United States at the expense of foreign countries, particularly the non-Annex I ones. Prices rise more than in the unilateral case (Figure 9). Note that this is a property of the assumptions, as we have shifted successively more and more of the supply curves.

On the welfare side, U.S. producers benefit even more from such a situation but consumers lose even more (Figure 10). In terms of emissions, the more countries that implement GHGE mitigation policies, the smaller are the net emission reductions from U.S. agriculture (Figure 16). For example, at a CE-price of \$100 per ton, emissions offsets are about 21 percent lower than for U.S. unilateral implementation.

## **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. In the U.S. agricultural sector, our results confirm trade-offs 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 most likely would be accompanied by emission increases in non-Annex I (developing) countries. Several alternatives exist to prevent emissions increases through agriculture in non-host countries. For example, the Kyoto Protocol proposes Joint Implementation and Clean Development Mechanisms. Through such mechanisms, host countries could establish incentives for agricultural producers in non-host countries to adopt technologies that do not increase emissions.

Second, U.S. farmers would benefit from a larger number of countries hosting greenhouse gas emission mitigation policies. Increasing the number of countries that abate greenhouse gases through the agricultural sector would lead to higher agricultural commodity prices. Income support has been a longtime objective of American farm bills. If the United States and other potential host countries would support financially a Clean Development Mechanism in non-host countries, i.e., Annex I countries, a portion of that expenditure could return, because higher agricultural prices eliminate the need for expensive farm bills.

Third, if implementation of an equivalent mitigation policy or Clean Development Mechanism in all countries is politically infeasible, trade policies could be established to protect producers in host countries from unfair international competition. For example, import tariffs, quotas, or export subsidies could be used to limit or offset the comparative advantage of agricultural producers in non-host countries. Note that value-based trade restrictions, which do not discriminate among agricultural products with different emission levels, would encourage non-host countries to produce emission-intensive commodities.

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 that divert farmland, such as afforestation and biofuel production. However, strategies that 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 the losses to both domestic and foreign consumers. Consequently, more people may become dependant on governmental aid to ensure sufficient food consumption.

Quantitative effects presented in this study reflect several simplifying assumptions and uncertain data, and therefore should be considered preliminary. While efforts will continue to improve the underlying data, the basic nature of our findings is unlikely to change.

## Endnote

1. According to the definition in the Kyoto Protocol, the “Party included in Annex I” refers to a party included in Annex I to the United Nations Framework Convention on Climate Change, as may be amended, or to a party which has made a notification under Article 4, paragraph 2(g), of this convention.

## Appendix

### Review of the Spatial Equilibrium Version of the U.S. Agricultural Sector Model (ASMSE)

#### Details on the Mathematical Structure of ASMSE

The objective function is a blending of the spatial equilibrium and price endogenous sector models. In particular, the first two lines include typical terms in conventional sector models with farm programs, containing terms giving the area under the demand equations ( $\int \phi(Q_i) dQ_i$  for commodity  $i$  less the area under the regional ( $k$ ), U.S. factor supply curves for perfectly elastic production costs associated with production process  $j$  ( $C_{ijk}X_{ijk}$ ), and quantity-dependent ( $\int \beta(L_k)dL_k$  and  $\int \alpha(R_{rk})dR_{rk}$ ) prices for land  $L$  and factor  $r$ . The next four lines pertain to the spatial equilibrium model, with line three counting the area under the rest-of-world (ROW) excess demand curves minus the area under the excess supply curve for the commodity in the ROW. Line four sums the transportation costs between the U.S. regions and the foreign regions for U.S. imports and exports (USFTRD). Line five calculates the transportation costs among the foreign regions (FTRD). Line six represents the transportation costs between regions in the United States (USTRAN). Line seven introduces goods movements from the U.S. regions to the national demand at historic price differences.

*Objective Function in ASMSE.*

$$\begin{aligned}
 \text{Max} : & - \sum_i \sum_j \sum_k C_{ijk} X_{ijk} - \sum_k \int b(L_k) dL_k - \sum_k \sum_r \int a(R_{rk}) dR_{rk} \\
 & + [ \sum_i \int y(Q_i) dQ_i \\
 & + \sum_i \sum_c \int (ED(FQD_{ic}) - ES(FQS_{ic})) dRQ_{ic} \\
 & - \sum_k \sum_i \sum_c \text{USFTRD}_{ick} \times \text{USFCST}_{ick} \\
 & - \sum_i \sum_c \sum_d \text{FTRD}_{icd} \times \text{FFCST}_{icd} \\
 & - \sum_i \sum_k \sum_l \text{USTRAN}_{ikl} \times \text{USCST}_{ikl} \\
 & - \sum_i \sum_k \text{PDIF}_{ik} \times \text{TN}_{ik} ]
 \end{aligned} \tag{1}$$

where

i	indexes commodities,	$X_{ijk}$	denotes commodity I acreage in $j^{\text{th}}$ production process in U.S. region k,
j	indexes production processes,		
k, l	indexes U.S. regions,		
c, d	indexes ROW regions,	$USFTRD_{ick}$	denotes trade between ROW region c and U.S. region k of commodity i,
r	indexes resources,		
$L_k$	denotes land usage in region k,		
$Q_i$	denotes consumption of $i^{\text{th}}$ product,	$USFCST_{ikc}$	denotes transportation cost from U.S. region k to ROW region c for commodity i,
$FQD_{ic}$	denotes excess demand quantity in ROW region c for commodity i,		
$FQS_{ic}$	denotes excess supply quantity in ROW region c for commodity i,	$FTRD_{icd}$	denotes trade between ROW regions c and c1 of commodity i,
$RQ_{ic}$	denotes commodity I consumption in ROW region c,	$FFCST_{icd}$	denotes transportation cost from ROW regions c and c1 for commodity i,
$R_{rk}$	denotes resource supply for U.S. region k of resource r,	$USTRAN_{ikl}$	denotes shipment between U.S. regions k1 and k of commodity i,
$\varphi(Q_i)$	denotes inverse U.S. demand function for commodity i consumed,	$USCST_{ikl}$	denotes transportation cost between U.S. regions k1 and k for commodity i,
$\alpha(R_{rk})$	denotes inverse U.S. factor supply function for resource r in region k,	$PDIF_{ik}$	denotes price difference between U.S. region k and U.S. national market for commodity i, and
$\beta(L_k)$	denotes inverse U.S. land supply function in region k,		
$ED(FQD_{ic})$	denotes inverse excess demand function in importing ROW region c,	$TN_{ik}$	denotes U.S. national consumption of commodity i from U.S. region k.
$ES(FQS_{ic})$	denotes inverse excess supply function in exporting ROW region c,		
$C_{ijk}$	denotes commodity i cost in $j^{\text{th}}$ production process per acre in U.S. region k,		

Equation (2) below illustrates the supply and demand balance for the traded farm program goods with detailed world trade modeling for U.S. regions. The first item in this equation represents regional nonparticipating farm program production and production in the United States that is participating but not eligible for payment (that which is above farm program yield). The other items in equation (2) are variables for the shipments among U.S. regions (USTRAN), between U.S. regions and foreign countries (USFTRD), and between regions and the national U.S. market (TN).

*Regional Balance for Traded Goods in the United States.*

$$\begin{aligned}
 & - \sum_j Y_{fjk} \times X_{fjk} - \sum_c USFTRD_{fck} - \sum_l USTRAN_{flk} \\
 & + \sum_c USFTRD_{fkc} + \sum_l USTRAN_{fkl} \leq 0, \text{ for all } f, k
 \end{aligned} \tag{2}$$

where

f index trade commodities which is a subset of i,

$Y_{fjk}$  denotes commodity f per acre yield in  $j^{\text{th}}$  production process in U.S. region k.

*National Balance for Traded Goods.*

$$Q_f - \sum_k TN_{fk} \leq 0, \text{ for all } f \tag{3}$$

where aggregate demand (Q) is balanced with the quantities (TN) from the regions (k) by commodity (f).

*National Balance for Non-traded Goods in the United States.*

$$Q_h - \sum_k \sum_j Y_{hjk} \times X_{hjk} \leq 0, \text{ for all } h \tag{4}$$

where h is the index for non-trade commodities, which is a subset of i.

*Regional Land Constraint in the United States.*

$$\sum_i \sum_j X_{ijk} \leq L_k, \text{ for all } k. \tag{5}$$

*Other Regional Resources Constraints in the United States.*

$$\sum_i \sum_j f_{rijk} \times X_{ijk} \leq R_{rk}, \text{ for all } r, k \tag{6}$$

where  $f_{rijk}$  denotes per acre resource r usage for commodity i in the  $j^{\text{th}}$  production process in U.S. region k.

Overall, equations (2) and (3) balance demands and supplies in regional and national markets for traded goods. Equation (4) is the U.S. national supply and demand balance constraint for non-trade and non-farm program goods. Equations (5) to (6) depict land and other resources constraints for region k in the U.S. The land constraint is modified to satisfy the set-aside requirement for deficiency payment.

Country Balance for Traded Goods.

$$\begin{aligned} &+FQD_{i c} + \sum_k USFTRD_{i c k} + \sum_{c l} FTRD_{i c d} \\ &- FQS_{i c} - \sum_k USFTRD_{i k c} - \sum_{c l} FTRD_{i d c} \leq 0, \text{ for all } i, c \end{aligned} \quad (7)$$

where foreign region demand (FDQ), exports to the U.S. (USFTRD), and exports to the rest of the world (FTRD) are balanced against foreign region supply (FDS), imports from the U.S. (USFTRD), and imports from the rest of the world (FTRD).

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