Implications of a Carbon Based Energy Tax for U.S. Agriculture

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Abstract

Policies to mitigate greenhouse gas emissions are likely to increase the prices for fossil fuel based energy. Higher energy prices would raise farmers' expenditures on machinery fuels, irrigation water, farm chemicals, and grain drying. To compute the economic net impacts of increased farm input costs on agricultural production after market adjustment, we employ a price endogenous sector model for United States agriculture. Results show little impact on net farm income in the intermediate run.

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Greenhouse gas (GHG) atmospheric concentrations have increased significantly in recent history and are projected to continue to do so. The Intergovernmental Panel on Climate Change (IPCC) asserts that increasing GHG concentrations will cause global temperatures to rise by about 0.3 degree Celsius per decade (Houghton, Jenkins, and Ephramus). Such forecasts have led to widespread suggestions that society turn attention to GHG emission reduction. In 1992, the United Nations Framework Convention on Climate Change (UNCCC) was established with the "ultimate objective" of stabilizing GHG concentrations in the atmosphere. In 1997 in Kyoto, a first international agreement under the UNCCC was reached (Bolin, UNCCC). Thirty eight countries, mainly developed nations in North America, Europe, Asia, and Australia, agreed to reduce emissions of carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons, and sulphur hexafluoride by various percentage points below 1990 levels.

The Kyoto Protocol will be effective for a five-year period between 2008 and 2012. As of August 2002, 84 Parties have signed and 79 Parties have ratified or acceded to the Kyoto Protocol (United Nations). While the U.S. government is unlikely to accede to the Protocol, it has announced an independent domestic climate change policy (U.S. President). The target of this new policy is to reduce greenhouse gas intensity - the ratio of greenhouse gas emissions to economic output - by 18 percent over the next decade. Carbon sequestration and renewable fuel incentives are specifically mentioned as two key domestic initiatives.

International or domestic greenhouse gas emission reduction efforts could directly or indirectly impact many sectors of the economy including agriculture. McCarl and Schneider (2000) argue that there are several ways agriculture may participate in or be influenced by greenhouse gas emission reduction efforts.

- Agriculture may need to reduce emissions since it releases substantial amounts of methane, nitrous oxide, and carbon dioxide.
- Agriculture may enhance its absorption of GHGE by creating or expanding sinks.
- Agriculture may provide products, which substitute for GHG emission intensive products displacing emissions
- Emission mitigation policies in non-agricultural sectors may alter production input prices.

This study examines an effect within the last category of impacts. In particular, agricultural input expenditures rise if the energy sector is subjected to carbon abatement policies either through an emission tax or a cap on total emissions.

Agricultural enterprises use energy in numerous ways. Machinery operations, irrigation water pumping, application of fertilizers and pesticides, and grain drying consume the bulk of crop management related energy (Hrubovcak and Mohinder). Farmers could respond to higher energy prices by reducing tillage intensity, lowering fertilizer consumption, realigning crop mixes, reducing irrigation, or otherwise changing the usage of other factors of production (e.g., land, labor, and capital) relative to energy.

Graphical Economics of a Carbon Permit Price

Figure 1 shows a simple graphical representation of an energy tax induced supply shift and allows us to qualitatively examine the likely impacts. Through the carbon tax producers incur additional costs, hence the aggregate supply curve shifts to the left. Accordingly, the new market equilibrium yields higher prices and lower quantities. Table 1 summarizes the welfare effects on economic segments.

In this case, consumers lose areas G, H, and I due to higher prices of agricultural goods. Simultaneously, producers experience a tradeoff between increased costs and increased revenues. Under the assumption of a parallel supply shift, producers loose the equivalent of areas D, E, and F. Third, the government collects revenue equivalent to the tax level (t) times the new equilibrium quantity or areas D + E + G + H. Society as a whole then incurs a dead weight loss (areas I plus F in Figure 1).

For a policy to be attractive, environmental gains have to at least offset the dead weight loss plus any policy transaction cost. . Environmental gains may not only relate to lower levels of targeted greenhouse gas emissions but also to reduced levels of other environmental externalities, i.e. soil erosion.

Numerical Analysis Approach and Assumptions

To simulate the aggregated farm sector response to increased energy prices, we use ASMGHG - a mathematical programming based model of the U.S. agricultural sector. The model is an extension of earlier versions as documented in Baumes (1978), Chang et al. (1992), McCarl et al. (2001), and Schneider (2000). ASMGHG solves for prices, production, consumption, and international trade in 63 U.S. regions for 22 traditional and 3 biofuel crops, 29 animal products, and more than 60 processed agricultural products. Trade relationships are integrated between and within the U.S. and 28 major foreign trading partners (Chen, 1999). Environmental impacts are integrated by linking ASMGHG activities to results from biophysical simulation models. For example, soil carbon sequestration estimates for a complete and consistent set of crop management options across all ASMGHG model regions are simulated using the Environmental Policy Integrated Climate (EPIC[1], Williams et al., 1989) model. Afforestation is incorporated in ASMGHG through a forestry response curve (Schneider and McCarl, 2002a) generated using the Forest and Agricultural Sector Optimization Model [FASOM-Adams et al. (1996), Alig et al. (1998)]. The spectrum of environmental impacts includes not only greenhouse gas emission and absorption but also water pollution from agricultural chemicals and soil erosion.

The general mathematical structure of ASMGHG is documented in Schneider and McCarl (2002b). Details on the implementation of major greenhouse gas mitigation strategies are given in Schneider (2000) and Schneider and McCarl (2002b). For this study, we augmented the accounting of fossil fuel based emissions from agricultural activities. In particular, we incorporated detailed estimates on fossil fuel quantities, which are either combusted directly on-farm or embodied in manufactured inputs. To analyze the agricultural impacts of carbon emissions based energy taxes, we imposed hypothetical taxes on all fossil fuel quantities as additional cost. Subsequently, we solved ASMGHG for each tax level and assessed changes relative to the no-carbon-price baseline. The next section details data sources and mathematical implementation in ASMGHG.

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[1] For this study, we used EPIC version 8120. Details about this version are available from the EPIC team or the related web page at: http://www.brc.tamus.edu/blackland/.

Farm Level Cost Changes Under Carbon Based Energy Taxes

The change in production expenditure is generally calculated as

$$(1)\quad \Delta x_{r,c,s,j} = \sum_{g}\left[p_g^{CE}\cdot\sum_{f} a_{f,r,c,s,j}^{Inp}\cdot\sum_{ff}\left(s_{ff,f,r,c,g}\cdot CE_{ff,r,g}\right)\right],$$

where $\Delta x_{r,c,s,j}$ represents the per acre cost change by region (index r), crop (index c), land type (index s), and management alternative (index j); p_g^{CE} the hypothetical carbon equivalent price imposed on greenhouse gas emission account (index g); $a_{f,r,c,s,j}^{Inp}$ the per acre use of agricultural production factor (index f) by region, crop, land type, and management alternative; $s_{ff,f,r,c,g}$ the net requirement of fossil fuel type (index ff) per unit of agricultural production factor by region and crop; and $CE_{ff,r,g}$ the net emissions by greenhouse gas account and region from one unit of each relevant fossil fuel type. Details on data sources and computations of individual terms in equation (1) are given below.

The first right hand side term in equation (1) is p_g^{CE} - the carbon price. The current price level is zero and future prices, which could result from an energy tax policy are unknown. To overcome this uncertainty, we simulate a wide range of hypothetical carbon prices from $0 to $500 per ton carbon equivalent. While prices, as high as $500 per ton of carbon equivalent, appear unlikely, they are useful to show trends and to gain model insight. In addition, the variable cost of computing additional price scenarios beyond the expected price range is low.

Input use coefficients $a_{f,r,c,s,j}^{Inp}$ and fuel requirements $s_{ff,f,r,c,g}$ are established for all agricultural production factors inputs (index f). These include directly used fossil fuels (index ff) and other inputs ($f \notin ff$), whose manufacturing processes require large amounts of fossil fuel based energy. Direct uses in this analysis include fuel for tractors and self propelled machinery and on-farm energy for irrigation and grain drying. Indirect uses of fossil fuels refer to off-farm requirements during the manufacturing or delivering process of agricultural inputs. In this study, we integrate data for off-farm fuel consumption for manufacturing of fertilizer and pesticides, and for irrigation water pumping. Because of data deficiencies, fossil energy used to produce other inputs into agriculture, such as farm machinery and equipment, is not included. Technical details on computation of both the $a^{Inp}_{f,r,c,s,j}$ and $s_{ff,f,r,c,g}$ coefficients are described below for each relevant input category.

The final term in equation (1) $CE_{ff,g}$ refers to net carbon emissions from all directly or indirectly used primary fossil fuel based energy sources. Numerical values for these coefficients were developed based on recent reports of the U.S. Department of Energy. In particular, net emissions in ASMGHG amount to 2.77 kg CE per gallon of diesel, 2.26 kg CE per gallon of gasoline, 14.86 kg CE per thousand cubic feet of natural gas, and 10.97 kg CE per thousand cubic feet of liquefied petroleum gas. Electricity is, for modeling purposes, also regarded as primary energy source. However, the net carbon emission coefficients differ across states depending on the average fuel input composition in electrical power plants in each region. For example, one kilo watt hour of electricity causes net emissions of 278 g per CE in North Dakota, 233 g CE in Iowa, 103 g CE in South Carolina, 181 g CE in Texas, and 35 g in Oregon with a U.S. average of 166 g CE.

<u>On-farm fossil fuel use</u>

Fossil fuels are combusted on-farm to operate tractors and agricultural machinery and devices. ASMGHG uses information from USDA crop production surveys to determine the direct fossil fuel use requirements (dff) for modeled regions, crops, and management practices. Explicitly excluded, however, are fuel requirements for irrigation and drying. These are accounted for through other greenhouse gas accounts as described below. Implementation of fossil fuel requirements into ASMGHG is straight forward because the crop production survey data list these requirements by fuel type in units per acre. Thus, the $a^{Inp}_{f\in ff,r,c,s,j}$ coefficients are directly taken from survey data. Furthermore, implied fossil fuel shares $s_{ff,f,r,c,"dff"} = 1\big|_{ff=f}$ and $s_{ff,f,r,c,g} = 0\big|_{ff\neq f,g\neq "dff"}$.

Irrigation

Greenhouse gas emissions from irrigation (ire) are caused through on- and off-farm water pumping and the associated fossil fuel use. These emissions vary depending on location and irrigation system. In ASMGHG, the irrigation intensity $a^{Inp}_{f="irrH_2O",r,c,s,j}$ is specified in feet per acre and comes directly from USDA crop production surveys. On-farm fossil fuel requirements for irrigation water ($s_{ff,f="irrH_2O",r,c,"ire"}$) are available from crop production surveys and from special irrigation surveys (USDC, 1994). In addition, to on-farm requirements, fossil energy may also be required off-farm to supply irrigation water. However, we did not have data to accurately include off-farm requirements.

Grain Drying

To compute the fossil energy consumption for post harvest drying of grains two types of information were established: first the amount of water to be removed by the drying operation and second the amount of fossil energy needed to remove one unit of water. The drying requirement in moisture points per acre was then calculated using

(2) $a^{Inp}_{f=drying,r,c,s,j} = \Delta m^{\%H_2O}_{r,c,j} \cdot a^{Comm}_{r,c,s,j}$,

where represents, $\Delta m^{\%H2O}_{r,c,j}$ the average number of excess moisture percentage points per unit of grain yield (**ERS/USDA) and $a^{Comm}_{r,c,s,j}$ the grain yield. All coefficients are indexed and dimensioned as indicated in equation (2). The energy requirements $s_{ff,f=drying,r,c,g}$ to dry one unit of corn or rice by one moisture percentage point were taken from the literature (Bern (1998), Breez (2001), Thompson (1999)). Requirements for other grains such as wheat, soybeans, and sorghum were assumed to equal those for corn with adjustments being made for different bushel weights.

Fertilizers

Applications of fertilizer cause both direct and indirect emissions of greenhouse gases. Fertilizers can directly impact soil carbon sequestration and nitrous oxide emission through changes in C/N ratio, ph-value, nitrification, de-nitrification, and air volatilization. These impacts are computed through EPIC simulations and integrated into ASMGHG's soil carbon and nitrous oxide emission accounts. Direct emissions of carbon dioxide arising from fuel combusted during the application of fertilizer are part of the on-farm fuel emission account.

Indirect emissions per unit of fertilizer (ief) are accounted for explicitly in ASMGHG. The indirect fuel use per acre is according to equation (1) the product of fertilization rate $a^{Inp}_{nt,r,c,s,j}$ times $s_{ff,nt,g="ief"}$, the indirect energy requirement per unit of fertilizer. The basic fertilizer rates $a^{Inp}_{nt,r,c,s,j}$ (nt = nutrient index) were taken from crop surveys. For alternative nitrogen fertilization scenarios, these rates were adjusted according to the assumption used. The fossil energy requirements to manufacture one unit of fertilizer ($s_{ff,nt,g="ief"}$) depend on the type of manufacturing process chosen. In ASMGHG, one weighted average coefficient per nutrient is used based on computations by Bhat et al. (1994). Note that $s_{ff,nt,g="ief"}$ are not indexed over region and crops.

<u>Pesticides</u>

ASMGHG also uses one explicit emission account for indirect emissions from pesticide (iep) applications. Particularly, the manufacturing of pesticides involves energy from a series of chemical reactions such as heating, stirring, distilling, filtering, drying, and similar processes. Pesticides are formulated as active ingredients before finally being packed for commercial release. We use four data sources to approximate fuel requirements per acre associated with the application of pesticides. First, each crop production budget contained an estimate of the expenditure on herbicides (index hc), fungicides (index fc), and insecticides (index ic). Second, the National Agricultural Statistics Service (NASS) compiled and supplied to us a database with the average amount of active ingredient ($\hat{a}^{Inp}_{ai,pc,r,c,t}$) used in each state for each crop during the years 1990 to 2000 (Bennett, 2002). Third, Bhat et al. (1994) estimated the net energy requirement ($s_{"energy",ai}$) for 32 active pesticide ingredients (index ai). Fourth, the shares of individual energy sources of fossil fuel type f ($s_{ff,ai,g="iep"}$) used for or embodied in each active ingredient ai were taken from Green (1987).

To calculate the fossil fuel intensity of pesticide applications, we need to compute the average per-acre use of active ingredient by crop, region, and management alternative ($a^{Inp}_{f=ai,r,c,s,j}$) and the amount of each fossil fuel type per unit of active ingredient

($s_{ff,ai,g="iep"}$). We assume relative shares of active ingredients for each crop and each region to be constant across all management alternatives but allow total amounts to vary between. Then, we use management specific data of total expenditure on herbicides, fungicides, and insecticides to estimate the per-acre use of active ingredients for alternative management practices. In particular, we use

$$(3)\quad a^{Inp}_{ai,r,c,s,j} = \sum_{pc}\left(\frac{x_{pc,r,c,j}}{\overline{x}_{pc,r,c}} \cdot \overline{\hat{a}}^{Inp}_{ai,pc,r,c}\right),$$

where $x_{pc,r,c,j}$ is the expenditure on pesticide (index pc, {pc} ={hc,ic,fc}), $\overline{x}_{pc,r,c}$ the weighted average expenditure over all management practices (see equation (4)), and $\overline{\hat{a}}^{Inp}_{ai,pc,r,c}$ the active ingredient rate compiled by NASS averaged over a ten year history (see equation (5)).

$$(4)\quad \overline{x}_{pc,r,c} = \frac{\sum_{j}\left(x_{pc,r,c,j} \cdot LAND_{r,c,s,j}\right)}{\sum_{j} LAND_{r,c,s,j}}$$

$$(5)\quad \overline{\hat{a}}^{Inp}_{ai,pc,r,c} = \frac{\sum_{t} \hat{a}^{Inp}_{ai,pc,r,c,t}}{\sum_{t} 1}.$$

The share of each fossil fuel type on each active ingredient $s_{ff,f=ai,r,c}$ is calculated as product of energy requirement $s_{"energy",ai}$ as provided by Bhat et al. (1994) times individual shares $s_{ff,ai}$ as provided by Green (1987).

Sectoral Sensitivity Results

Increased energy prices affect agriculture in multiple ways. These impacts include management changes at the farm level, agricultural market adjustments with feedbacks to agricultural producers and consumers, and environmental consequences. In representing our results, we focus on the national impacts regarding changes in welfare, input usage, tillage system adoption, greenhouse gas emission levels, and erosion.

A few characteristics of ASMGHG and their ramifications on the results are useful for accurate interpretation of the output from the analysis:

1 ASMGHG solutions represent the intermediate-run equilibrium in the agricultural sector after complete adjustment to demand and supply shifts, which are induced by policies or new technologies. Thus, the impacts of higher prices for fossil fuel based energy are simulated as if they were fully in place.

2 ASMGHG allows choice of crop mix, tillage method, irrigation method, and rotation as well as levels of consumption, processing, and international trade. Higher energy costs incurred by U.S. producers encourage not only adoption of energy sparing crop and livestock management in the U.S. but will also reduce affected commodity demand and U.S. net exports.

3 ASMGHG is a price endogenous model, which reflects demand curves for exported and domestically consumed products. Changes in production costs are matched by changes in crop sale prices. Consequently, higher energy prices are likely to transfer into higher consumer prices.

4 Throughout this analysis we assume that input providers can pass on all energy tax related cost increases to farmers and that they will not alter the input manufacturing process substituting either within energy sources or between energy and non-energy inputs.

Welfare Impacts

Total welfare changes due to increased energy cost are reflected by changes in the value of ASMGHG's welfare based objective function. Consistent with economic theory, total welfare declines as the price of energy increases. A $25 per ton of carbon tax applied to fossil energy, for example, will cost the agricultural sector about 1.32 billion dollars annually an amount equivalent to 2.83 percent of 46.4 billion dollars, the observed net farm income in 2000 (USDA Agricultural Statistics 2002). Governmental revenue from the imposition of fossil fuel taxes account for 96 percent or about 1,26 billion dollars of this net social loss in agricultural markets while the remaining 4 percent or about 60 million dollars represent dead weight losses due to a new market equilibrium. Note however, that social welfare computation in ASMGHG does not account for environmental benefits or losses from changes in GHGE and other externalities, financial losses in non-agricultural sectors of the economy, and transaction costs to implement an energy tax.

Increased energy cost does not only reduce total agriculture welfare it also affects welfare distribution in the agricultural sector. Among agricultural market segments, consumers incur the biggest absolute losses for carbon prices above $25 per ton of carbon. On the producer side, higher revenues partially compensate farmers for increased costs of production (Figure 4). In relative terms, however, producers' impacts are still larger than the consumers' surplus impacts. This implies that it may be desirable to redistribute the agriculture-based revenues from the energy tax to the agricultural producers to spread out the costs of the program.

ASMGHG welfare results can be compared to those from other analyses. Francl, Nadler, and Bast (1998) estimated the effect of energy taxes on individual farmer's cost and net profit at 25 cents per gallon fuel tax, which translates into a $111 per ton carbon price. Based on their analysis, farmer's net income would fall by 24 percent. This is substantially higher than our $100 carbon tax estimate, which indicates farm net income would fall only by about 0.9 to 3.7 percent. There are two explanations. First, Francl, Nadler, and Bast (1998) used simple budgeting precluding price adjustments and consumer effects. Second, their calculations of fertilizer and pesticide price increases suggested that the cost of these inputs would increase by about 20 percent which is substantially higher than our implied estimates.

Antle et al. simulated economic effects of energy prices on Northern Plain grain producers. For a $110 carbon tax they estimated variable costs to rise between 3 and 13 percent. Note that Antle et al. only allow for acreage substitution, holding prices constant. Omission of price adjustments, however, leads to overstatement of negative producer impacts as illustrated in Figure 1. Third, our results are slightly higher than USDA estimates which at $23 per ton predict welfare losses of about half of a percent. Applying ASMGHG results from the $25 per ton of carbon tax scenario to USDA's net farm cash baseline of 74.2 billion dollars, producers income would decrease by 0.95 percent.

Finally, an Ag-sector analysis by Konyar and Howitt estimates a 2.3 percent increase in farmers' net revenue at a carbon equivalent price of $348 per ton. Interpolating ASMGHG's $200 and $500 scenario results to a fuel tax level of $348 per ton of carbon, we calculate a 6.1 percent income decrease relative to a 44 billion dollar net farm income baseline or a 3.8 percent income decrease relative to USDA's 74.2 billion dollar baseline. Note that a $348 per ton of carbon tax represents an extreme case.

Perspective on potential welfare costs can also be gained by considering costs relative to budget expenditures. Important agricultural operations such as Iowa corn farms use about $50 worth of fertilizer per acre, $15 worth of drying and about $11 worth of diesel fuel in order to produce the state average of 150 bushels of corn per acre, which brings the farmer a gross revenue of $375 per acre at an average sales prices of $2.50 per bushel. If one uses the $100 carbon tax energy price increases this adds about $3.30 to diesel costs, $7.50 to natural gas based drying, and about $3.50 to fertilizer cost, which in relative terms is only about a four percent increase in cost relative to the per acre revenue value. Thus a relatively low impact is not surprising. Clearly, farm program revisions and other policies have had larger implications.

Impacts on Crop Management and Environmental Indicators

The imposition of energy taxes causes relatively small reductions in cropped land, irrigation water use, fertilizer and pesticide use. The larger adjustments are found in terms of tillage use with a shift toward less intensive tillage. At higher permit prices a movement to no till largely dominates this shift. This leads to a potential reduction in erosion at the carbon prices above $100 per TCE. If one accepts an estimate that soil erosion costs the U.S. about $2.06 per ton (updated from Ribaudo by Faeth), then the value of the erosion reduction is about $30 million substantially offsetting the social loss of $45 million at a $25 permit price. This also indicates that a carbon permit price program may lower the cost of other agricultural soil erosion control and resource conservation programs.

Concluding Comments

Agriculture may find itself operating under higher energy prices due to domestic or international greenhouse gas emission reduction efforts and the potential impact of those efforts on the price of energy and energy related inputs. Our analysis suggests that the U.S. agricultural sector is not very sensitive to increased energy costs. The reduction in agricultural welfare is small compared to total welfare and is largely offset by the implied tax revenues. Non-agricultural sectors may be more significantly affected. Reduction in the greenhouse gas externality would also offset the losses. Agricultural management adjustments include a slow reduction in irrigation intensity and a potential decrease in intensive tillage, especially at higher carbon prices. Similarly, soil erosion may be lower at higher carbon prices.

Bibliography

Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Richie, B.A. McCarl, J.D. Glyer, R.B. Curry, J.W. Jones, K.J. Boote and L.H. Allen. "Global Climate Change and U.S. Agriculture." *Nature* 345(1990):219-224.

Antle, J.M, S.M. Capalbo, J.B. Johnson, and D. Miljkovic. "The Kyoto Protocol: Economic Effects of Energy Prices on Northern Plains Dryland Grain Production." *Agricultural and Resource Economics Review* 28(April 1999):1,96-105.

Bhat, M.G., B.C. English, A.F. Turhollow, and H. Nyangito. *Energyin Synthetic Fertilizers and Pesticides: Revisited*. Research Report # ORNL/Sub/90-99732/2, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January 1994.

Bennett, N. Environmental and Demographics Section, National Agricultural Statistics Service, Personal Communication, May 2002.

Benson, V. National Resource Conservation Service, U.S. Department of Agriculture Crop Enterprise Budgets, Personal Communication, February 1999.

Bern, C. "Preserving the Iowa Corn Crop: Energy Use and CO2 Release" *Applied Engineering in Agriculture* 14(3, 1998):293-299

Brees, M. "Corn and Irrigated Corn Budgets for Southeast Missouri", University of Missouri, December 2001.

Bolin, B. "The Kyoto Negotiations on Climate Change: A Science Perspective." *Science* 279(January 16, 1998):330-331

Chang, C.C., J.D. Atwood, K. Alt, and B.A. McCarl. "Economic Impacts of Erosion Management Measures in Coastal Drainage Basins." *Journal of Soil and Water Conservation* 49(1994):606-611.

Chang, C., B.A. McCarl, J. Mjelde, and J. Richardson. "Sectoral Implications of Farm Program Modifications." *American Journal of Agricultural Economics* 74(1992):38-49.

Faeth, P. "Methods for Economic Analysis of Agricultural Sustainability." United Nations Environment Programme Environmental Economics Unit, http://www.unep.ch/eteu/econ/ecoser22.htm, July 1996 .

Francl, T., R. Nadler, and J. Bast. "The Kyoto Protocol and U.S. Agriculture." Heartland Policy Study No. 87, [Online]. Available HTTP: www.heartland.org/studies/gwag-study.htm, October 30, 1998.

Green, M. 1987. "Energy in Pesticide Manufacture, Distribution, and Use." *Energy in Plant Nutrition and Pest Control* ed. Z.R. Helsel. New York: Elsevier, pp. 165-96.

Helsel, Z.R. "Energy in plant nutrition and pest control." Elsevier Science Publishing Company, Inc., New York, NY, 1987.

Helsel, Z.R. "Energy and alternatives for fertilizer and pesticide use." In: Fluck, R.C. (ed.) Energy in Farm Production, vol.6 in Energy in World Agriculture, Elsevier, New York, pp.177-201,1992.

Houghton, J.T., G.J. Jenkins, and J.J. Ephramus (eds.). 1990: Climate Change: The IPCC Scientific Assessment. Cambridge University Press, Cambridge.

Hrubovcak, J. and M. Gill. "Energy." Section 3.3 In: *Agricultural Resources and Environmental Indicators, 1994*, Edited by Margot Anderson, Agricultural Handbook No. 705. 216 pp, Economic Research service (ERS), Washington DC, September 1997.

Konyar K. and R.E. Howitt. "The Cost of the Kyoto Protocol to U.S. Crop Production: Measuring Crop Price, Regional Acreage, Welfare, and Input Substitution Effects." *Journal of Agricultural and Resource Economics* 25(2, December 2000):347-367.

McCarl, B.A. and U.A. Schneider. "U.S. Agriculture's Role in a Greenhouse Gas Mitigation World: An Economic Perspective." *Review of Agricultural Economics* 22, No.1(2000):134-159.

McCarl, B.A. and U.A. Schneider (2001). "Greenhouse Gas Mitigation in U.S. Agriculture and Forestry." *Science* (21 December 2001):2481-2482.

McCarl, B.A. and T.H. Spreen. "Price Endogenous Mathematical Programming As a Tool For Sector Analysis." *American Journal of Agricultural Economics* 62(1980):87-102.

McCarl, B.A., C.C. Chang, J.D. Atwood, and W.I. Nayda, "Documentation of ASM: The U.S. Agricultural Sector Model." Unpublished Report, Texas A&M University, 2001, [Online]. Available HTTP: ageco.tamu.edu/faculty/mccarl/asm.htm.

McCarl, B.A. M. Gowen, U.A. Schneider and T. Yeats, "The Impact of Carbon Permit Prices on the U.S. Agricultural Sector", Report for USEPA, ICF Inc. Washington D.C. 1999.

Ribaudo, M.O. "Water Quality Benefits from the Conservation Reserve Program." Agricultural Economic Report No. 606. Resources and Technology Division, Economic Research Service. U.S. Department of Agriculture. February 1989.

Schneider, U.A. *Agricultural Sector Analysis on Greenhouse Gas Emission Mitigation in the U.S.*, PhD Dissertation, Department of Agricultural Economics, Texas A&M University, December 2000.

Schneider, U.A. and B.A. McCarl 2002a. "Economic Potential of Biomass Based Fuels for Greenhouse Gas Emission Mitigation." Forthcoming in Special Edition of *Environmental and Resource Economics*.

Schneider, U.A. and B.A. McCarl 2002b. "The Potential of US Agriculture and Forestry to Mitigate Greenhouse Gas Emissions - An Agricultural Sector Analysis." Working Paper 02-WP 300, Center for Agricultural and Rural Development, Iowa State University, May 2002.

Thompson, J.F. 1999. "High Temperature Rice Drying" Working paper, Cooperative Extension University of California, Davis, August 3

United Nations, Framework Convention on Climate Change, Kyoto Protocol. Climate Change Secretariat (UNFCCC). [Online]. Available HTTP: http://unfccc.int/resource/convkp.html (August 2002).

U.S. Department of Agriculture (USDA), Office of the Chief Economist, "Economic Analysis of U.S.Agriculture and the Kyoto Protocol." USDA Global Change web site, http://www.usda.gov/oce/gcpo/Kyoto.pdf , May 1999.

U.S. Department of Commerce (USDC), Census of Agriculture, Report AC92-RS-1. Farm and Ranch Irrigation Survey, Washington DC, 1994

U.S. Department of Energy, Energy Information Administration. *Annual Energy Review*. [Online]. Available at http://www.eia.doe.gov/emeu/aer/, April 2002.

U.S. President, White House, Global Climate Change Policy Book. Washington, DC, 2002.

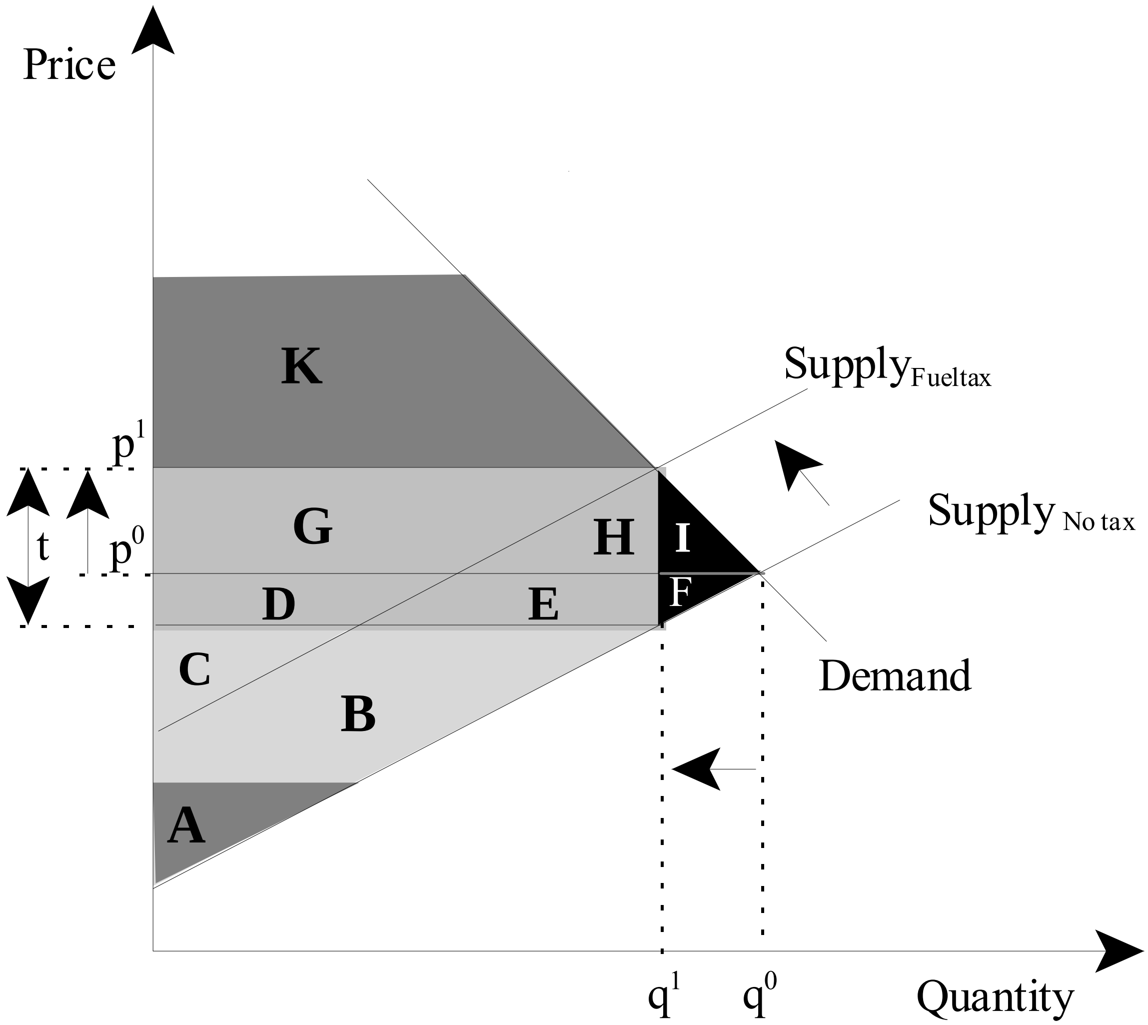

Figure 1 **Fuel Tax Induced Supply Shift**

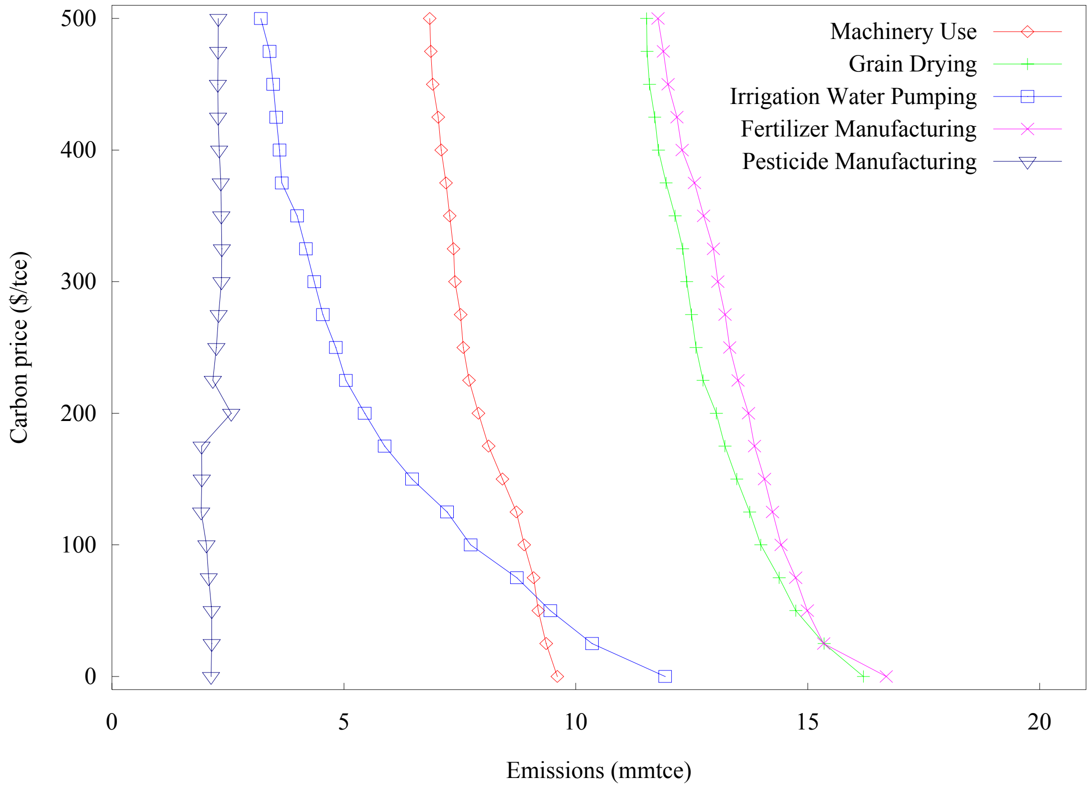

Figure 1 **Impact of energy taxes on fossil fuel based emission from U.S. agriculture**

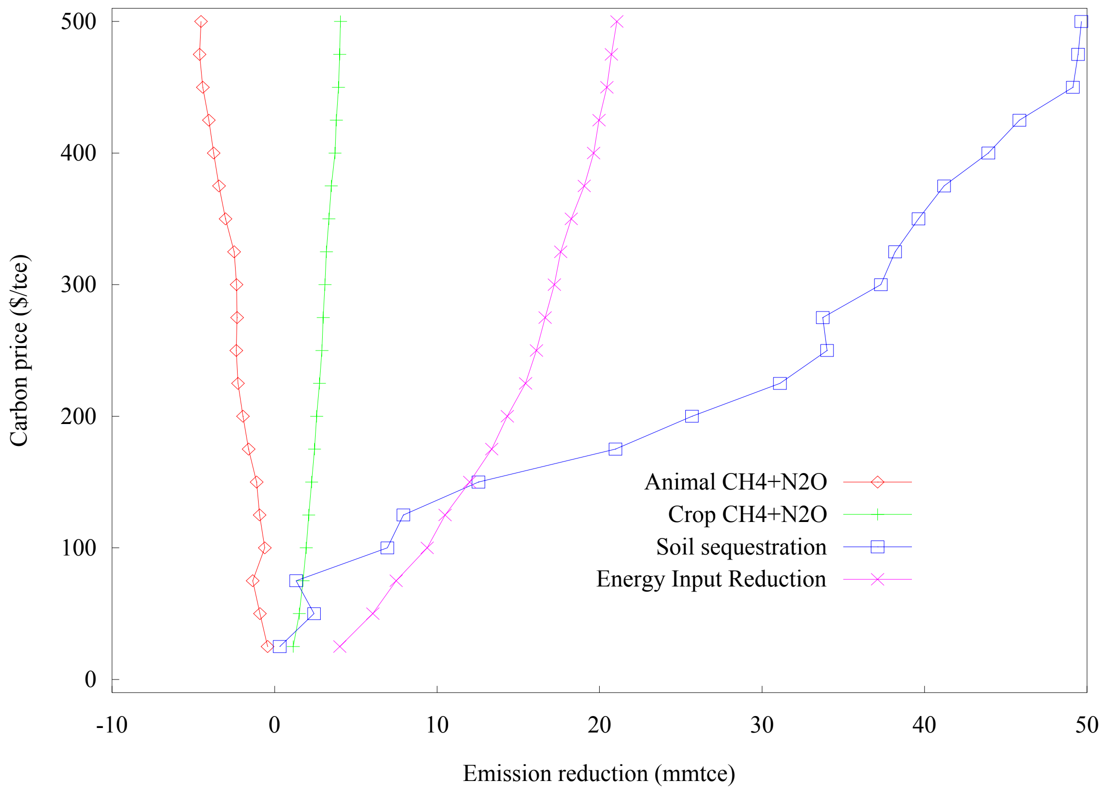

Figure 2 **Impact of energy taxes on mitigation of greenhouse gases in U.S: agriculture**

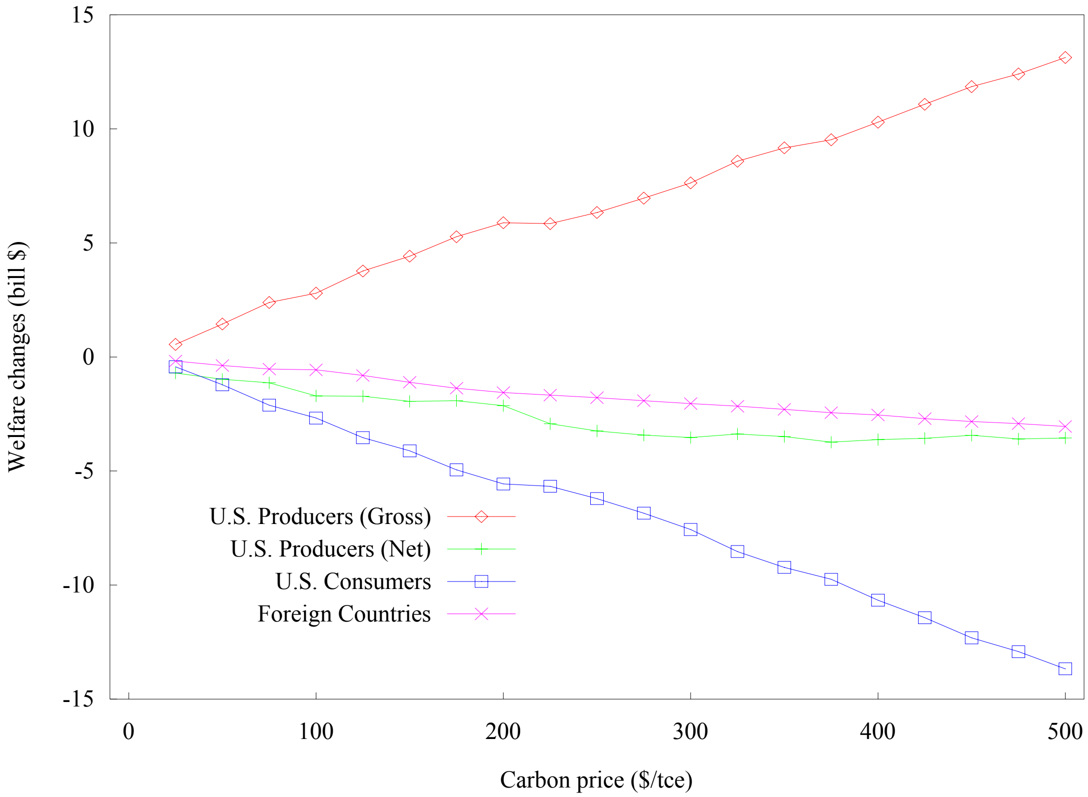

Figure 3 Welfare impacts of energy taxes on agricultural sector

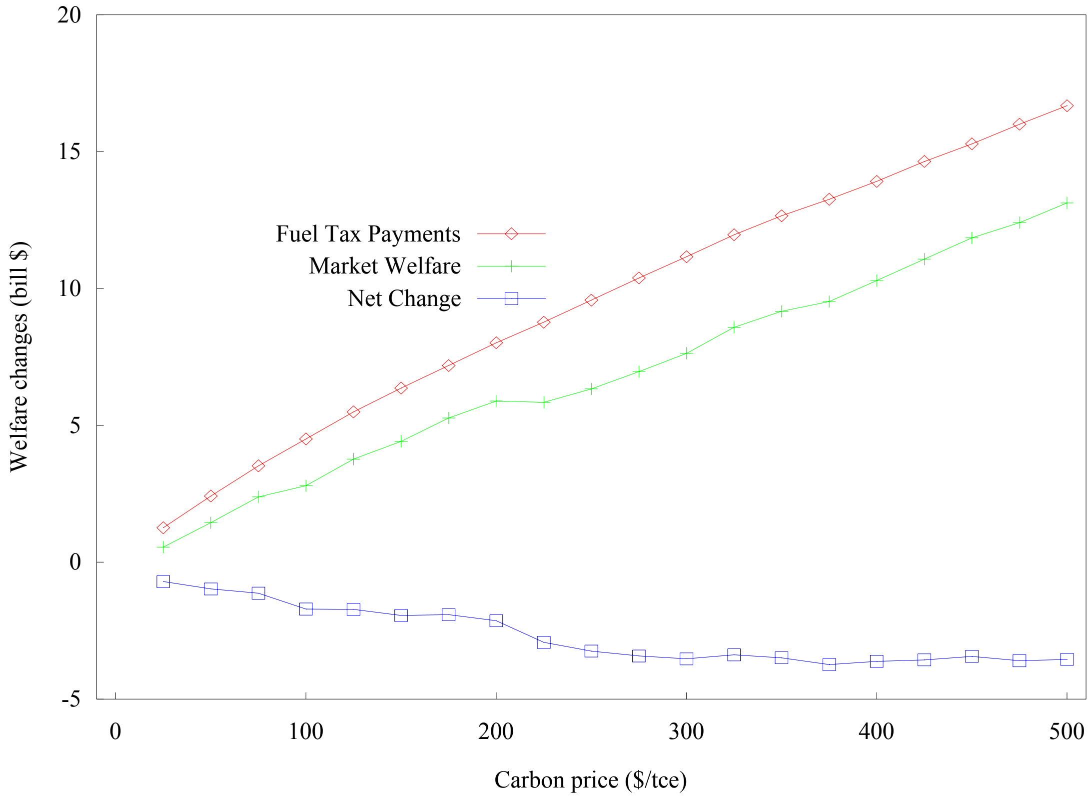

Figure 4 Welfare impact of energy taxes on agricultural producers in the U.S.

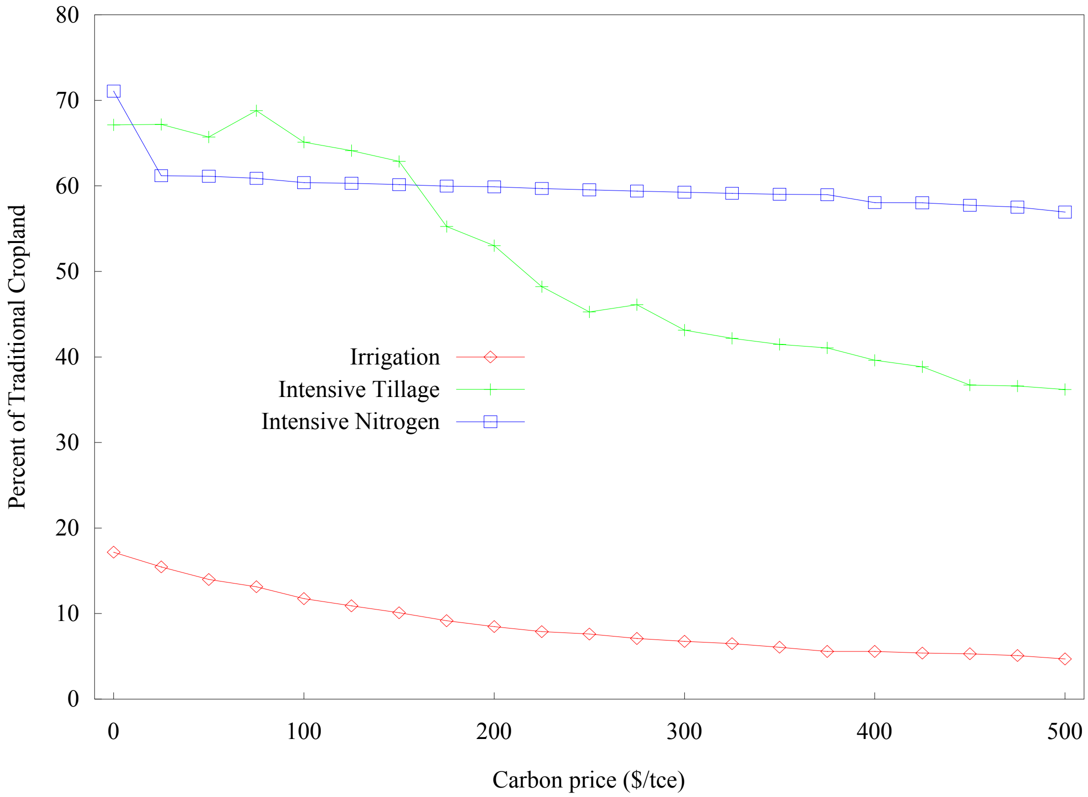

Figure 5 Impact of energy taxes on agricultural management in the U.S.

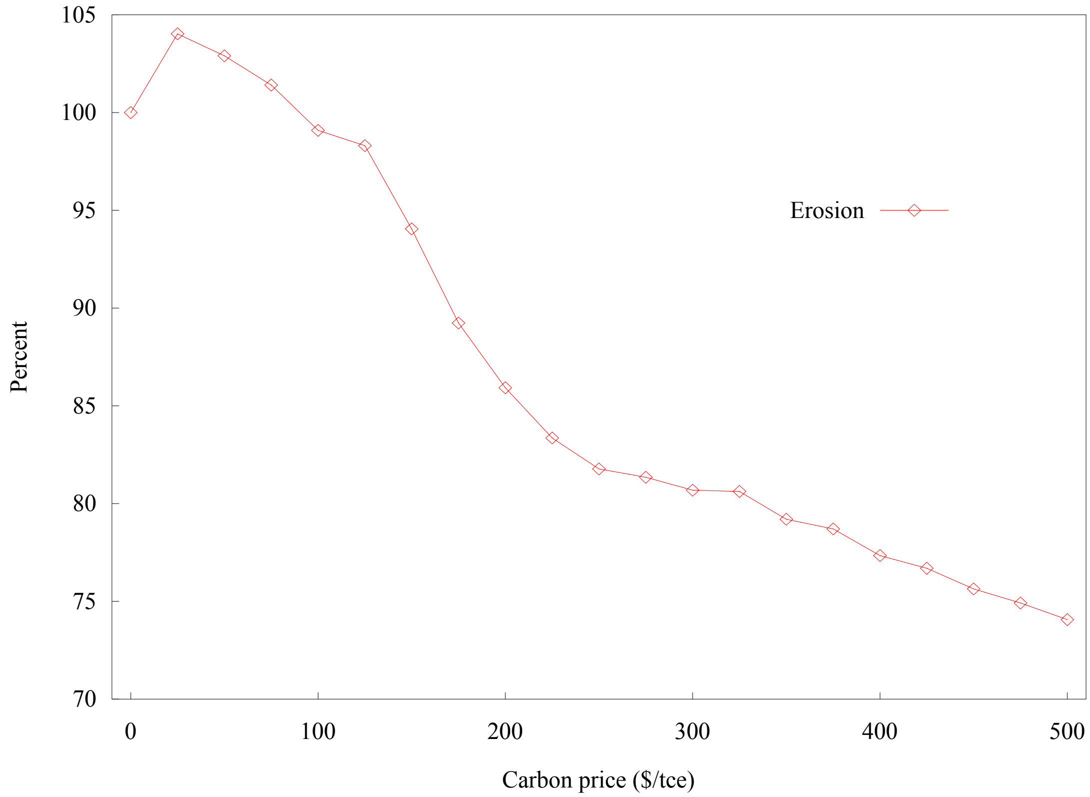

Figure 6 Impact of energy taxes on erosion on the U.S. cropland

Table 1 Welfare Accounting After Tax Induced Supply Shift

Agricultural Market Segment	Change in Welfare
Producers	- A - B - E - F + G
Consumers	- G - H - I
Government	+ D + E + G + H
Total[2]	- F - I

[2] Note that for a parallel shift of the supply curve, area A equals area C. But areas C plus area B equal area D plus area G. Hence areas A and B equal areas D and G.

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