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Economic Analysis of the Impacts of the Kyoto Protocol on U.S. Agriculture

USDA Global Change Program Office

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0. Executive Summary

Introduction

Climate is a major determinant of agricultural productivity, defining to a large extent how and where crops are grown. Climate change, which is caused in part by the release of greenhouse gases into the atmosphere, can affect growing seasons, precipitation and evaporation patterns, pest infestations, and weather variability—all of which can impact food and fiber production.

The international community is addressing climate change through the United Nations Framework Convention on Climate Change, which the United States ratified in 1992 and has over 170 member countries. The Convention seeks to stabilize atmospheric concentrations of greenhouse gases at safe levels. The Kyoto Protocol, which requires the advice and consent of the Senate, formalizes this commitment and calls for the industrialized nations to reduce their average national emissions over the period 2008-2012 to about five percent below 1990 levels.

Key elements of the Protocol include: 1) a multi-year commitment period; 2) the inclusion of all six greenhouse gases (enabling reductions of one gas to be used to substitute for increases in emissions of another); 3) allowing international emissions trading and joint implementation among countries that take on binding targets; 4) a clean development mechanism that allows industrial countries or firms to earn credits for projects in the developing world; and 5) the inclusion of limited set of activities that sequester carbon (with provisions to expand the list of carbon sequestering activities to include agricultural management practices). These elements, particularly emissions trading, can

significantly reduce the costs of meeting emissions reductions target.

The potential effects of the Kyoto Protocol on U.S. agriculture depend, in part, on the degree of energy price increases, the energy intensity of agricultural production, the ability of the sector to adjust to changes in energy prices, and the degree to which international competitiveness is affected by changes in energy costs. To assess the economic impacts of the Kyoto Protocol on U.S. agriculture, we analyze three levels of energy cost increases which reflect carbon price increases associated with levels of emissions trading: 1) a \$14 per metric ton carbon price (reflecting full emissions trading); 2) a \$100 per metric ton carbon prices (reflecting limited emissions trading); and 3) a \$200 per metric ton carbon price (reflecting no trading).

We use the U.S. Regional Agricultural Sector Model (USMP) which is designed for general purpose economic, environmental, and policy analysis. USMP is linked with USDA production practices surveys, the USDA multi-year baseline, and geographic information system databases such as USDA's National Resources Inventory. USMP predicts how changes in farm, resource, environmental, or trade policy, commodity demand or technology will affect regional supply of crops and livestock, commodity prices and demand, use of production inputs, farm income, government expenditures, participation in farm programs, and environmental indicators. USMP incorporates agricultural commodity supply, use, and policy measures, as well as natural resource and environmental impacts derived through biophysical models.

We evaluate a generic policy which raises input prices according to embodied carbon—in practice such a policy could take the form of a permit, tax, cap, or some other instrument that effectively

charges firms based on the carbon used in production. Because the Kyoto Protocol calls for compliance within the period 2008-2012 we impose the emissions reduction policy in 2010. We evaluate the medium-run equilibrium impacts of the policy on U.S. agriculture. The analysis is "comparative static" which means that it compares conditions in the initial equilibrium situation with conditions after the agricultural economy has adjusted to a new, medium-run, equilibrium. We apply the carbon price increases to the U.S. agriculture sector as it is projected to be in 2010. We also examine how agriculture could contribute to reductions of net greenhouse gas emissions using a broad range of management practices that sequester carbon in agricultural soils.

We find that under low carbon prices increases, *which are consistent with implementation of the key features of the Protocol*, the impact on agricultural output, prices, income and competitiveness are minimal. As carbon prices increase, the impact on the sector is more pronounced particularly for irrigated cropping systems. At low carbon prices, net cash returns decline by less than a half percent, relative to the baseline. At high carbon prices, which do not reflect the implementation of the key features of the Protocol, net cash returns decline about 4 percent. The sector responds to increases in energy costs by reducing input use, altering management practices to include less energy-intensive practices, and changing crop mix.

Major Results

Effects on Crop Prices, Supply and Use: A \$14/mt carbon price leads to crop price increases of less than 1 percent, averaging around 1 cent per bushel for feedgrains and wheat. With a \$100/mt

carbon price, feedgrain, wheat and rice prices rise 1 to 4 percent. A \$200/mt carbon price boosts feedgrain, wheat and rice prices 2 to 7 percent. Relative changes among feedgrains (corn, sorghum, barley, oats) on the supply side depend on their relative energy and carbon intensity in production, and on the demand side depend on their relative protein and energy content in constituting animal feed rations. Rice price rises more than other crops owing to its greater energy and carbon intensity in production. Soybean, silage and hay prices rise less than 1 percent in all scenarios owing to lesser carbon intensity in production.

The \$14/mt carbon price leads to negligible output declines of 0.6 percent or less; \$100/mt permit prices lead to feedgrain and wheat production declines of 1 to 2 percent; and \$200/mt permit prices lead to declines of 2 to 4 percent relative to the baseline. Soybean production impacts are half those of feedgrains owing to the lesser carbon intensity in production, while rice production declines are greater due to its greater carbon intensity in production.

Domestic crop use declines negligibly (less than 0.5 percent) with the \$14/mt carbon charge. Crop export impacts are similarly negligible except that rice and barley exports decline 1 percent. The \$100/mt and \$200/mt carbon scenarios see minimal declines in domestic use, but more sizable declines in exports. Under the \$200/mt scenario, export declines are 4 percent and less for corn and soybeans, but reach 8.5 percent for barley and 17 percent for rice.

Effects on Crop Acreage: Charging a carbon permit price increases the costs of production and tends to reduce acreage planted across crops, regions, and cropping practices in proportion to how much carbon is embodied in the production process. The \$14/mt carbon permit price leads to an

acreage decline of about 0.2 percent, relative to the baseline case, for the 10 major field crops (corn, sorghum, barley, oats, wheat, cotton, rice, soybeans, hay and silage). At \$100/mt, acreage for these ten crops declines about 1.6 percent; acreage declines 3.1 percent at \$200/mt carbon prices. For all three carbon price scenarios, acreage declines are proportionally larger than average in the Mountain and Pacific regions. The largest declines occur in those regions, such as the South Plains, with substantial irrigated acreage.

Effects on Livestock Price and Production: Increasing carbon prices affects livestock production on the supply side through direct energy cost impacts and through indirect cost impacts such as higher feed costs. The \$14/mt carbon permit charge affects livestock products negligibly, with prices increasing less than one half of a percent and production declining a tenth of a percent or less. The \$100/mt carbon price causes dairy, hog and broiler prices to rise about 1 percent and beef cattle prices to rise 2 to 3 percent. The \$200/mt carbon charge doubles these impacts. Production declines remain small: less than 1 or 2 percent in both the \$100/mt and \$200/mt scenarios.

Income and Expense Effects: Increasing carbon prices increases the costs of production, which boosts commodity prices. Higher prices increase value of production, but also reduce quantity demanded and hence produced. The net effect on value of production depends on input supply and commodity demand markets, but given the inelastic demand for food in general, farm production costs are likely to rise. The \$14/mt carbon price affects crop and livestock income by less than a half percent. Total variable costs and value of production rise \$502 and \$277 million, netting out to a net cash returns decline of \$225 million. With the \$100/mt carbon charge, net cash returns decline \$1.6 billion (2.1 percent), of which \$1.4 billion comes from crops and \$213 million from livestock.

The decline in crop net returns results from the \$1.9 billion rise in total variable costs which is only partly offset by the \$572 million rise in value of production. At a carbon charge of \$200/mt, net cash returns decline \$3.0 billion (about 4 percent relative to the baseline case), again with the major portion of the decline in crops (\$2.6 billion) as opposed to livestock (\$0.4 billion). The \$200/mt scenario sees value of production rise \$3.7 billion, only half offsetting the \$6.7 billion rise in total variable costs.

Effects on Agricultural Inputs. Carbon price increases raise agricultural input prices proportionally with carbon content. Farmers' responses to higher input prices will determine the shifts in input uses and the ultimate effects of carbon charges on farmer expenditures. Increased input prices result in reduced input use and reduced carbon embodied in inputs and agricultural production. Over time, carbon charges would stimulate development of new technology that would reduce the energy requirements for agricultural production and its embedded carbon.

Crop and livestock expenses for all energy increase by 1.4 percent under \$14/mt carbon permit prices. Energy expenses increase by 9.8 percent and 19.2 percent with \$100/mt and \$200/mt carbon prices. The input industry as a whole, incurs a sales volume reduction of 0.6 percent with \$14/mt carbon permits. Reductions of 4 and 7 percent are incurred with \$100/mt and \$200/mt carbon prices. These changes in input use and energy expenditures reflect farmers' adjustments to carbon permit changes.

Direct fuel and lubricant use by farmers and that embodied in custom use are affected most directly by carbon price increases. Direct use of fuel and lubricants by farmers declines by 0.9 percent with \$14/mt carbon permits. Reductions of 5.4 and 9.3 percent are incurred in fuel and lubricant use with

\$100/mt and \$200/mt carbon prices. Custom service use declines by 2.8 percent with \$14/mt carbon permits. Custom use reductions of 16.5 and 28 percent are incurred with \$100/mt and \$200/mt carbon prices.

Fertilizers, particularly nitrogen, and chemicals are energy intensive inputs. About 1.6 pounds of carbon are embedded in each pound of nitrogen fertilizer and we estimate that about 5.6 pounds of carbon are embedded in each pound of chemical pesticide. Fertilizer use declines by 0.2 percent with \$14/mt carbon permits. Fertilizer reductions of 1.8 and 3.5 percent are incurred with \$100/mt and \$200/mt carbon prices. Chemical (pesticide) use declines by 0.3 percent with \$14/mt carbon permits. Reductions of 2.2 and 4.3 percent in chemical use are incurred with \$100/mt and \$200/mt carbon prices. Electricity use increases by 0.1 percent with \$14/mt carbon permits, reflecting electricity's smaller carbon content relative to fossil fuels. Increases of 2.3 and 5.0 percent are incurred with \$100/mt and \$200/mt carbon prices.

Input Expense Effects. Farmers' direct expenditures for fuel and lubrication increase by \$203.9 million or 2.2 percent with \$14/mt carbon permits. Fuel and lubricant expenditure increases of 15.5 and 30.4 percent are incurred with \$100/mt and \$200/mt carbon prices. Farmers' expenditures for custom services increase by \$1.5 million or 0.2 percent with \$14/mt carbon permits, reflecting the increase in fuel and lubricant costs. Custom operations expenditures increase 1.6 and 3.1 percent with 100/mt and \$200/mt carbon prices. Farmers' expenditures for fertilizers increase by \$154.2 million or 1.3 percent with \$14/mt carbon permits. Fertilizer expenditure increases of 8.8 and 17.3 percent are incurred with \$100/mt and \$200/mt carbon prices. About 75 percent of the changes are attributed to nitrogen, higher in carbon content than potash and phosphates. Chemical expenditures

increase by \$57.8 million or 0.7 percent with \$14/mt carbon permits. Chemical expenditure increases of 4.9 and 9.7 percent are incurred with \$100/mt and \$200/mt carbon prices. Expenditures on relatively lower cost electricity increase by \$14.3 million or 1.5 percent with \$14/mt carbon permits. Expenditure increases of 12.7 and 26.3 percent are incurred with \$100/mt and \$200/mt carbon prices.

Changes in Environmental Indicators. Higher carbon prices leads to a reduction in soil erosion and nitrogen loss to surface and ground waters. The reductions are brought about primarily by declines in acreage planted, rather than substitution of less carbon intensive conservation tillage practices for conventional practices. With a low carbon price (\$14/mt), both erosion and nitrogen loss decline less than 0.5 percent and are fairly uniform across production regions. The insignificant changes in the indicators reflects the negligible impact low carbon prices have on acreage planted and technology (tillage practices) used.

Effects on Competitiveness. The Kyoto Protocol calls for participation by Annex-I countries. This means that, at least to start, the direct costs of mitigating carbon emissions will be borne by Annex-I countries. Some have expressed concerns that increasing the costs of fossil fuels only in Annex-I countries will increase the likelihood that agricultural production (primary and/or processing) will shift to non-Annex-I regions. The validity of such concerns may depend on the time frame under consideration. In the short-run, increases in costs of energy-intensive inputs may initially hurt the competitiveness of some U.S. producers in some commodity markets. Over time, however, increasing energy prices only in Annex-I countries could result in agricultural production shifting from non-Annex-I countries to Annex-I countries. This is because production of commodities and

processed foods in Annex 1 countries is less energy intensive per unit of output than many other economic sectors and it is in these sectors that non-Annex-I countries are likely to expand production.

Carbon sequestration. Carbon sequestration activities in the Kyoto Protocol are limited to those considered in Article 3.3—afforestation, reforestation, and deforestation. Article 3.4 provides for future consideration of other human induced carbon sequestering activities such as those associated with agricultural soils. The rate of carbon accumulation/release in agricultural soils varies with many site specific factors — including chemical and physical characteristics of the soil, precipitation, above- and below-ground biology, temperature, solar radiation, atmospheric chemistry and processes, landscape characteristics, site history (including past management practices), time, and current land use. Developing a framework that accounts for these influences in a systematic and verifiable fashion across national and international regions is an important step in including agricultural soils in the Kyoto Protocol.

Soils having the greatest potential to sequester carbon are those that are below their carbon carrying capacity, meaning young soils and soils that have been depleted of carbon due to management practices. Because the large majority of U.S. cropland has been in production for several decades, their large initial releases of carbon have already occurred and current releases are now very low — estimates are typically under 15 million mt annually. Collectively then, U.S. agricultural soils have a relatively high potential for being managed to store additional carbon.

The potential to offset U.S. GHG emissions by shifting marginal agricultural lands into forests and

permanent grasses, and by changing farm management practices been the subject of several analyses and is currently an active area of research. For example, recent results suggest that a program encouraging tree planting on marginal lands could sequester about 48.6 MM tons of carbon per year (or 44.2 MM mt) and require some 22.2 million acres. The carbon sequestered is a little over 3 percent of current U.S. carbon emissions and about 7.9 percent of the emissions reduction that would be needed to comply with the Protocol in 2010, assuming no mitigation activities are undertaken until then. With respect to cultivated lands, a number of production practices exist that if adopted could increase soil carbon levels. These include conservation tillage, elimination of summer fallow, use of winter cover crops, and adding organic amendments to soils.

I. Climate Change and Agriculture

Agriculture's contribution to GHG emissions

In 1990, U.S. emissions of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride were on the order of 1,633 million metric tons in carbon equivalents (MMTCEs) (EPA, 1998). The Kyoto Protocol would require the U.S. to reduce its emissions of these greenhouse gases (GHGs) 7 percent below this level (to about 1,518 MMTCE) between 2008 and 2012. U.S. GHG emissions have risen since 1990 (table I.1). If emissions continue to rise at the rate shown in table I.1, by 2010 the United States will need to reduce its annual GHG emissions by 632 MMTCE to comply with the Protocol. Relative to a situation where no emissions restrictions are implemented, this implies a need to reduce 2010 GHG emissions by almost 30 percent.¹

The major GHGs associated with U.S. crop and livestock production are CO₂, CH₄, and N₂O. On a carbon equivalent basis, agriculture accounts for between 9.2 and 10.5 percent of U.S. emissions of these gases (table I.1). Agricultural emissions of CO₂ are primarily related to the burning of fossil fuels (e.g., gasoline, diesel, and LP gas) in farm operations, the use of fossil fuels in the manufacturing, and distribution of nitrogen fertilizers and other farm chemicals, the use of fossil fuels to generate electricity used on farms, and the release of carbon from soils when land is tilled or subjected to other field operations. Table I.1 indicates that CO₂ emissions from these sources are on the order of 38 to 51 million metric tons annually. While agriculture accounts for 2.5 to 3.5 percent of U.S. CO₂ emissions, CO₂ accounts for between 23 and 30

¹ Some studies have estimated this reduction at considerably more than 30 percent. Assuming no actions are taken to reduce GHG emissions, WEFA (1998) estimates that by 2010 the United States will need to reduce emissions 37 percent to comply with the Kyoto Protocol.

percent of GHG emissions from U.S. agriculture.

Annual U.S. emissions of CH₄ and N₂O are currently estimated at about 179 MMTCE and 103 MMTCE, respectively. Agricultural sources account for 30 percent of national CH₄ emissions (or 54 MMTCE) and 69 percent of national N₂O emissions (or 72 MMTCE). The primary agricultural sources of CH₄ emissions are enteric fermentation (35 MMTCE) and manure management (17 MMTCE). Lesser sources are rice cultivation and crop residue burning, which together emit another 2.7 MMTCE of CH₄ per year. Annual N₂O emissions from agriculture include about 69 MMTCE from soil management practices (primarily applications of nitrogen fertilizers) and 3.1 MMTCE from manure management and crop residue burning.

The Effects of Climate Change on Agriculture

Global changes in climate and the level of atmospheric carbon dioxide (CO₂) could have a major impact on the location and level of agricultural production (see Box). A number of studies have evaluated the effects of global climate change on agriculture in the United States (Adams and others, 1988, 1990, and 1995; Darwin, 1999; Darwin and others, 1994 and 1995; Easterling and others, 1992; Kaiser and others, 1993; Kane, Reilly, and Tobey, 1991; Mendelsohn, Nordhaus, and Shaw, 1994). These studies relied on results from equilibrium climate change scenarios in which atmospheric carbon dioxide (CO₂) is doubled. Such results showed relatively large global mean changes in temperature (2.8 °C to 5.2 °C) and precipitation (7.8 percent to 15.0 percent) compared with more recent Intergovernmental Panel on Climate Change (IPCC) conclusions on how climate is likely to change through 2100. Most of this section of the report represents a summary of these studies (other recent summaries include Adams, Hurd, and Reilly,

1999; IPCC, 1996; Lewandrowski and Schimmelpfennig, 1999; and Schimmelpfennig and others, 1996). Recent ERS research, however, relies on results from transient climate change scenarios that are consistent with emissions of greenhouse gases and tropospheric aerosols projected by the IPCC business-as-usual scenario, IS92a, assuming a 2.5°C increase in global mean surface temperature in response to a doubling of atmospheric CO₂ (Greco and others, 1994; Schlesinger and others, 1997). In these scenarios, increases in global mean temperature range from 1.0°C to 1.8°C in 2050 relative to 1990, while increases in global mean precipitation range from 1.3 percent to 2.8 percent. Summaries of results from this research have been included when they provide additional insight.

At higher latitudes and in alpine areas where temperatures are relatively cool, warming will increase the quantity of land suitable for agriculture, but warming in areas where agriculture faces periodically low rainfall may reduce soil moisture, thereby causing decreases in farm production. This is complicated by the fact that although precipitation generally increases, it may decrease in some areas. Recent projected changes in temperature and precipitation patterns induced by increased emissions of CO₂ and other greenhouse gases may reduce soil moisture and shorten growing seasons in one or more of the U.S.'s highly productive regions such as the Corn Belt, Lake States, Northern Plains, and Southern Plains by 2050. In other regions, however, soil moisture and growing seasons are likely to increase. The net effects of climate change on U.S. agriculture, therefore, are likely to be small and have little or no impact on the ability of the United States to produce enough food to feed itself through the next century. Nevertheless, regional impacts may be significant.

Changes in temperature and precipitation patterns affect the various agricultural sectors differently as well. Studies generally indicate that the production of grains in the U.S. is likely to

decline. U.S. production of non-grains is likely to increase. U.S. production of livestock, which relies heavily on grain production (primarily maize) also declines. U.S. production of processed foods, i.e., fish-meat-milk and other processed foods, is also likely to decline. These changes are reenforced by expected changes in the international competitiveness of U.S. agriculture and food production. Canada and northern Europe, for example, are likely to become relatively more competitive in grain and livestock production, while agricultural production in tropical regions, which tend to specialize in non-grains products, is likely to decline.

How these climate-induced production changes will affect the welfare of U.S. farmers and consumers is uncertain. Studies indicate that either producers or consumers may win or lose depending on the change in climate. One result that generally appears, however, is that the benefits or losses generated by climate change in the agricultural sector accrue to consumers, not farmers. In fact, if farmers benefit, then consumers are likely to lose and vice versa.

Studies show that the agricultural effects of climate change are less negative or more positive when the beneficial physiological effects on plant growth of higher levels of atmospheric CO₂ are included. For the world as a whole, production of agricultural commodities and processed food products is likely to rise, while prices fall. For the U.S., decreases in world agricultural prices induce declines in agricultural production. These effects combine to depress returns to U.S. agricultural land, labor, and capital. Total U.S. welfare, however, increases as gains by consumers outweigh producers' losses. These results also indicate that rising levels of atmospheric CO₂ (about 1 ppmv per year from 1950 to 1990) may also have contributed to the general trend in declining agricultural prices during the past 40 years.

A few studies have considered how climate change might affect water resources and land use in conjunction with agricultural production. Those that do show that U.S. water prices may

either increase or decrease depending on the climate scenario. Including the effects of higher levels of atmospheric CO₂ does not affect results. This indicates that conflicts over water resources could intensify in some U.S. regions under global climate change. There is much to be learned about water resources and climate change, however, especially with regard to erosion, flooding, water-logging, the availability of irrigation water, and sea level rise. Land-use changes that accompany climate-induced shifts in cropland and permanent pasture are also likely to raise additional social and environmental issues.

Farmer adaptations will be the main mechanisms for maintaining U.S. agricultural and processed food production under global climate change. The most important adaptations are selecting the most profitable mix of inputs and outputs on existing cropland as well as changing the amount of land under cultivation. The ability of U.S. farmers to adapt, however, will be determined by how well they can foresee the climatic future, the costs of adapting, and government programs. In the studies summarized here, farmers and other economic agents are assumed to know what the future climate will be at all locations and movement toward that climate is assumed to proceed in a slow and smooth manner. In fact we do not know what the future climate will be in a given location, changes could occur relatively rapidly, and the transition may not be smooth, (i.e., locations that might be wetter in, say, 2050 might become drier at some point before then). We know even less about future changes in seasonal variability and extreme weather events.

The studies reported here also generally ignore adjustment costs. It takes resources, for example, to convert forest land into agricultural land or to add or expand irrigation and flood control systems. The costs associated with these adaptations may be negligible if changes in climate occur slowly enough so that the rate of capital turnover assumed under some base case

scenario is sufficient to make climate-induced adaptations without incurring additional costs. It is more likely, however, that climate change would render at least some capital obsolete before it is fully depreciated. Also, social adjustment costs are likely to be high for those communities where the only viable adaptation will be to abandon farming.

Last but not least, government policies and programs ranging from crop insurance and disaster assistance to acreage reduction programs, tariffs and quotas, and the level of agricultural research and extension will influence the farm sector's response to climate change by providing the economic incentives (or disincentives) for farmers and other economic agents to adapt and by expanding the number of technological options with which they can adapt. Given the greater uncertainty about weather variability under global climate change, farmers need as much flexibility in choices of farming practices and crops as possible. Policy changes like those embedded in the 1996 Federal Agriculture Improvement and Reform Act which removed many restrictions and allows farmers to adjust to changing conditions without penalty are steps in the right direction.

Box: Climate Change, Atmospheric Gases, and Agricultural Productivity

Climate is the average meteorological conditions, i.e., temperature, precipitation, wind, etc., that prevail in a region. Climate change may refer to any change in climate over time whether due to natural variability or as a result of human activity. There are three major sources of natural variability that affect climate--changes in Earth's orbit, changes in ocean currents due to shifting continents or large-scale melting of continental ice, and changes in the composition of the global atmosphere (especially water vapor and greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O)). Human activity also may change the composition of the global atmosphere. As of 1992, for example, atmospheric concentrations of

CO₂, CH₄, and N₂O have grown by about 30%, 145%, and 15%, respectively, since preindustrial times (about 1750). Major sources include combustion of fossil fuel, deforestation, and agricultural production (rice and livestock). Anthropogenic aerosols (microscopic airborne particles) resulting from combustion of fossil fuels, biomass burning, and other sources tend to offset the warming effects of greenhouse gases.

Climate and Agriculture

Climate is a major factor in potential agricultural productivity and farming is located in those areas where potential agricultural productivity is consistently high. The two most important climate-related indicators of agricultural productivity are length of growing season and temperature regime (Food and Agriculture Organization of the United Nations, 1996). Length of growing season is the length of time during the year that soil temperature and soil moisture conditions are continuously suitable to crop growth. Temperature regime is the average temperature during the growing season. Crops vary in their requirements for these two variables, which depend on local temperature, precipitation, and solar radiation. In areas where soil moisture is a limiting condition, irrigation may be used to extend the length of the natural growing season. The source of the water used in such localities may depend on local precipitation, precipitation in some distant location, or precipitation from the distant past.

Climate also affects livestock production. Temperatures that are too high or too low can generate stress that lowers livestock productivity. Livestock also require a daily source of drinking water, which like irrigation water depends on precipitation. Livestock production also depends on the availability of crop feeds, such as hay or grain. Climate is also related to extreme weather events such as floods, wind storms, and droughts; to seasonal variability of frost-free periods, cold

temperatures, and rainfall patterns; and to the incidence and distribution of pests and pathogens. Changes in these variables also affect agricultural productivity. Extreme weather events involving heavy precipitation are especially important as they are responsible for most water-related soil erosion and to offsite deposition of agricultural pollutants such as livestock wastes and chemicals leached from agricultural lands. Global changes in climate, therefore, could have a major impact on the location and level of agricultural production in many areas.

Carbon Dioxide and Agricultural Productivity

The level of CO₂ in the atmosphere also affects agricultural productivity directly. Plants combine solar energy with water (generally from the soil) and CO₂ from the air to photosynthesize glucose, a simple sugar. Stomata, primarily on the leaves, control the passage of water vapor and other gases to and from the plant to the atmosphere and vice versa. Stomatal opening sizes are negatively correlated with the atmospheric concentration of CO₂, that is, the higher the level of CO₂, the smaller the stomatal openings and the slower the rate of transpiration (the loss of water vapor from the plant). Hence, elevated CO₂ increases plant water use efficiency and would tend to reduce water requirements and yield loss due to water stress. Leaf temperatures also rise. Crops are generally classified into two groups--C3 or C4--depending on the number of carbon atoms in the first compound into which CO₂ is incorporated during photosynthesis (IPCC, 1996). Experimental yield responses for C3 crops (e.g. wheat, rice, barley, oats, potatoes, and most other crops) to a doubling of atmospheric CO₂ averages +30%, with a range of -10% to +80%. Factors known to affect the magnitude of the response include the crop species, availability of water and plant nutrients, environmental factors such as temperature, and differences in experimental technique. The yield response of C4 crops (corn,

millet, sorghum, and sugar cane) to a doubling of atmospheric CO₂ is, on average, estimated to be around 7 percent.

There remains considerable debate about whether such CO₂-induced increases will be observed under commercial conditions. Also, although higher levels of atmospheric CO₂ may have a beneficial effect on plant growth, other gases released by burning fossil fuels (particularly ozone, sulfur dioxide, and nitrogen dioxide) have detrimental effects on plant growth. In addition, differential effects on C3 versus C4 crops could alter the competitive advantage between crops and weeds--C3 weeds could become more competitive with C4 crops. Finally, reduced transpiration and higher leaf temperatures could affect climate, i.e., temperatures could be higher and precipitation lower than those projected by general circulation models (Sellers and other, 1996).

Box References

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II. Economic Impacts of Climate Change Policies

Literature Review

The GHG mitigation literature contains two types of studies relevant for assessing the potential economic impacts of the Kyoto Protocol on U.S. agriculture. In one category are a set of macroeconomic studies that assess the potential impacts of reducing U.S. GHG emissions via some type of permit or tax applied to the use of carbon or energy in production. These studies typically focus on estimating the level of carbon or energy price increase that would be necessary to reduce U.S. GHG emissions to some specified level. In the other category are a set of microeconomic studies that assess how specified increases in the prices of energy intensive inputs would affect farm production costs, output prices, income, and welfare. In this section, we review both sets of studies. Our goals are to explain the variations and similarities in the reported results and to put the CEA assessment into context with the existing literature.

Macroeconomic Studies

This section compares results reported in the CEA (1998) assessment of the Kyoto Protocol with the results reported in five other studies that estimate the macroeconomic impacts of reducing U.S. greenhouse gas (GHG) emissions by adopting a system of carbon taxes or emissions permits. Our main conclusion is that differences in the estimated impacts reported in various studies are more related to differences in the underlying assumptions concerning the degrees of emissions trading and developing country participation that would occur rather than to differences in the methodologies. To help readers follow our discussion, we summarize key features, assumptions, and results of the CEA study in table II.1 and the other studies in table

II.2.

To start, the studies described in tables II.1 and II.2 do not all consider the same emissions reduction targets. CEA (1998), WEFA (1998), and CRA (1998) were done after the Kyoto meeting and they assess the actual Kyoto target for the U.S. of 1990-7%. The other studies were done prior to Kyoto and they consider emissions reductions targets that were commonly discussed at that time—namely, reducing emissions to 1990 and 1990-10% levels by 2010. In terms of actual emissions reductions, however, the CEA and CRA assessments consider larger reductions than the other studies. Apparent contradiction is due to the use of different forecasts regarding the magnitude carbon emissions in 2010 assuming no reduction efforts are undertaken. All the studies use emissions forecasts from DOE's Energy Information Agency (EIA) but the forecast used by CEA and CRA is more recent and higher—by about 81 million metric tons of carbon (MM mt C) per year—than the forecasts used in the other studies. The effect then is that the results reported by DRI (1997), EIA (1997), and Edmonds et al. (1997) for 1990-10% reflect emissions reductions that, with respect to quantity, are relatively close to those implied by Kyoto's 1990-7% (see table II.2).

Next, CEA emphasizes the potential importance of the "when," "what", and "where" flexibilities in reducing the costs of meeting the Kyoto target. Its quantitative analysis, however, is primarily limited to the "where" flexibility—that is the ability to trade emission reduction commitments internationally and the ability of nations to form groups and jointly meet their commitments.

CEA's discussions of the "when" flexibility (i.e., allowing for a multi-year commitment period and for the banking of emissions reductions) and the "what" flexibility (i.e., allowing for carbon sinks and for reductions in emissions of one greenhouse gas—or GHG—to offset emissions of other GHGs) are primarily qualitative. Other assessments of reducing GHG

emissions also tend ignore the factors encompassed in the "when" and "where" flexibilities.

None of the studies summarized in table II.2 considers carbon sinks, emissions banking, or non-CO₂ gases.

The CEA report focuses on the three scenarios that feature global trading of emissions obligations including with key developing countries (KDCs). The Administration has stated that it will not send to the Senate for ratification a treaty that does not have "meaningful" participation on the part of developing countries. Defining "meaningful participation" as the KDCs accepting emissions targets equal to their 2010 baselines and then engaging in normal emissions trading, CEA estimates a global carbon price of between \$14 and \$23 per mt and a direct economic cost to the U.S. economy between \$7 billion and \$12 billion annually (depending on how Annex 1 countries form trading blocs). Although not discussed explicitly by CEA, results in Table II.1 allow one to estimate a permit price of between \$190 and \$200 per mt C and an annual U.S. economic cost of between \$53 and \$60 billion when the CEA analysis is conducted assuming no international emissions trading.

Focusing on table II.2 and the scenarios where emissions are reduced to either 1990-7% or 1990-10% levels, estimated carbon prices range between \$14 and \$270 per mt C. The highest prices, \$270 and \$265 per mt C are reported by, respectively, DRI and WEFA. These analyses employ similar econometric macroeconomic forecasting models and assume no international trade in emissions. At the same time, the DRI model is used to generate the carbon price in the EIA assessment and in this case the price needed to return emissions to the 1990-10% level is about \$200 per mt C (again assuming no international emissions trading). Hence, while not apparent from the text, it seems likely that something in the underlying assumptions leads to the DRI and WEFA assessments estimating carbon prices that are considerably higher than those

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reported in EIA. Along with EIA, Edmonds et al. and CRA also estimate carbon prices in the neighborhood of \$173 to \$200 per mt C when international emissions trading is not allowed. For this scenario, CRA also reports a direct economic impact on the U.S. economy of \$60 billion. Assuming full global trading in emissions permits Edmonds et al. estimate a global carbon price of \$38 per mt; allowing for global emissions trading and duplicating other CEA assumptions, CRA replicates CEA's carbon price of \$14 per mt. The differences then, in the estimated costs of complying with the terms of the Kyoto Protocol reported in tables II.1 and II.2 appear to be primarily a function of differences in the underlying assumptions employed in the various studies and scenarios.

The key assumption distinguishing the various economic impacts shown in tables II.1 and II.2 is the degree of international trade in emissions obligations allowed for in the associated studies and scenarios. Among and within studies, costs are highest when such trade is not allowed, lowest when all countries participate in emissions trading, and somewhere in between when trading is limited to Annex 1 countries. The Protocol explicitly allows for trading of emissions obligations between Annex 1 countries (Article 6) and, to a limited extent, between Annex 1 and non-Annex 1 countries through the Clean Development Mechanism (Article 12). Hence, while the structure and procedures of an international emissions trading system have yet to be negotiated, scenarios that assume no such trading are probably overly pessimistic regarding the costs of implementing the Kyoto Protocol.

At the same time, within the Kyoto framework there remains the question of whether or not there will be a cap on the quantity of emissions reduction that a country or a region will be allowed to purchase internationally. CEA does not address this issue explicitly, but results in Edmonds et al. and CRA suggest it should not be ignored. Allowing only for emissions trading

among Annex 1 countries, Edmonds et al. estimate that the U.S. would purchase permits equal to 209 MM mt C annually (at price of \$109 per mt) from countries in Eastern Europe and the former USSR in 2010; allowing for full global emissions trading, U.S. permit purchases increase to 316 MM mt C annually (at price of \$38 per mt). Given their U.S. target of 510 MM mt C by 2010 implies the U.S. would purchase 41.0%-62.0% of its emissions reduction obligations from other countries. CRA claims that at carbon prices of \$14-\$23 per mt, the model used by Edmonds et al. (and also CEA) indicates the U.S. would purchase 82%-88% of its emissions reduction target internationally. Hence, if there are significant restrictions placed on the quantity of emissions reductions a country may obtain internationally, the various trading scenarios shown in tables II.1 and II.8 may understate the costs of implementing the Kyoto Protocol.

Agriculture Sector Studies

Crop and livestock production employ a variety of energy intensive inputs. A permit price or tax on carbon or energy use then, would almost certainly raise farm production costs. Here we, review 3 recent studies dealing with the potential impacts of a such a tax on these costs. Key features, assumptions, and results of the studies are summarized in table II.3. The common approach used to model a carbon/energy tax is to exogenously specify some level of tax and then estimate the how that tax would affect the prices of energy intensive farm inputs. Table II.4

summarizes these impacts by study

Francel (1997)

Francel uses a partial budgeting² approach to analyze the effects of “high” and “low” energy cost increases. The “high” energy cost increase scenario assumes 50 percent price increases for gasoline, diesel fuel, and electricity, citing an American Petroleum Institute (API) assessment of meeting emissions reductions targets associated with the United Nations Framework Convention on Climate Change. The “low” energy cost increase scenario is based on a Department of Commerce statement that capping U.S. GHG emissions at 1990 levels would require a 25 cent per gallon fuel tax. The “low” and “high” input cost increases are applied to 1994 enterprise budgets and to 1995 U.S. Farm Production Expenses to estimate ranges for the potential increase in U.S. farm production costs and the potential decrease in U.S. farm income. Francel states his basis for calculating input cost increases (see table II.4) as:

“..energy (natural gas typically accounts for 75% of the cash cost of manufacturing anhydrous ammonia, a basic feedstock or ingredient for all nitrogen fertilizer products. Nearly all the manufactured inputs have cost structures for which energy is equivalent to 50% or more of the underlying cash production costs.”

Francel applies the estimated input cost increases to 1995 U.S. farm production expenses to estimate cost increases of \$10.251 billion (5.8 percent) under the “low” scenario and \$20.537 billion (11.7 percent) under the “high” scenario. Dividing these cost increases by the average 1991-95 U.S. net farm income of \$42.7 billion, Francel estimated decreases in net farm income of 24 percent in the “low” scenario and 48 percent in the “high” energy price increase scenario. The increases in energy costs shown in table II.4 yield increases in manufactured input costs of 20

² Partial budgeting analysis addresses an enterprise’s revenue components, cost components, and the difference between these—net returns. It is partial in the sense that if, say a cost component changes, then net returns are simply recomputed without changing anything else.

percent and 40 percent; purchased feed and seed costs are assumed to increase by 6 and 12 percent; interest charges, capital consumption, and taxes are assumed to increase by 5 and 10 percent; and purchase livestock and poultry and net rent to nonoperator landlords decline by 5 and 10 percent.

To assess how the effects of a carbon/energy tax might differ within the farm sector, Franc1 applies the estimated cost increases to firm level production data for corn, cotton, soybeans, wheat, hogs, and milk to estimate impacts on net revenue for specific commodities. Assuming constant gross value of production, the estimated decreases in net revenues for the “high” scenario are 47 percent for corn, 49 percent for cotton, 21 percent for soybeans, 57 percent for wheat, 85 percent for hogs, and 53 percent for milk.

Franc1 computes increases in production expenses and assumes that gross cash income remains constant, implying that farmers do not adjust business plans in response to rising costs of production. This assumption is reasonable within a single production period (i.e. farmers have limited flexibility once crops are planted), but not so reasonable beyond the single production period. It is generally accepted that faced with rising production costs, producers reduce quantities supplied which leads to rising market prices. In the case of many agricultural commodities, demand is “inelastic” with the result that increases in production costs can actually lead to increases in net returns. Since farmers would likely respond to higher energy prices by reducing output and shifting marginal resources to other uses, commodity markets would clear at higher prices for the reduced quantities. The farm and farm sector income losses estimated by Franc1 are probably overstated.

Sparks Companies, Inc. (1997)

Sparks released a new version of this study on February 16, 1999. The new version has been quickly reviewed and it appears to be consistent with version reviewed here. It is expected that the new version will be reviewed for the final version of this report.

Sparks employs a partial budgeting approach to estimate the effects of carbon permit prices on the U.S. farm sector. Sparks draws on the DRI model (see Table II.2) to estimate the macroeconomic impacts associated with implementing carbon permits to reduce U.S. GHG emissions. For the case of issuing carbon permits to equal 1990 emissions, Sparks uses the estimated carbon price of \$180-\$190 per mt and other key macro impacts in a partial budgeting assessment of potential effects on 1997 farm income.

Sparks' estimated impacts of carbon permit prices of \$180-\$190 per mt on agricultural balance sheet items are presented in Table II.5. Sparks draws on the DRI analysis for a 33.1 percent increase in fuels and oils costs and 129.6 percent increase in natural gas costs.

Sparks estimates the percentage net cost change of energy intensive inputs as the product of the assumed energy share of the input, the assumed input's energy cost increase from the carbon permit, and the effect of assumed producer response to the higher price, or

$$\text{Net cost change} = \text{Energy share} * \text{Cost change} * (1 - \text{Usage response}).$$

Sparks states their basis for calculating manufactured input cost increases as:

“...natural gas typically amounts to 75% of the cash cost of manufacturing anhydrous ammonia, a basic component of nitrogen fertilizers. For nearly all manufactured farm inputs, energy costs are equivalent to 50% or more of the cash production costs.”

Sparks estimates that manufactured input costs (fuels, oils, and chemicals) increase by \$11.3 billion or 43 percent from 1997 levels. Sparks estimates that operating expenses (repair and maintenance, machine hire and custom work, transportation, and miscellaneous) increase by \$2.3 billion or 3.7 percent of 1997 levels. Overall, Sparks projects that total farm production costs increase about \$15.9 billion (about 8.5 percent over the 1997 level).³

Sparks estimates that agricultural revenues decline \$5 billion--\$1.4 billion from domestic consumption declines and \$3.6 billion in lost exports. Sparks estimated the \$1.4 billion decrease in domestic consumption of agricultural products based DRI macro model projections of a 2 percent decline in GDP, and assuming an income elasticity of 0.35. Sparks assumed that U.S. agricultural exports would decline by \$3.6 billion, because "Increased production costs for the United States likely would stimulate production in areas with underused production resources, especially in Latin America, parts of Asia and Africa where substantial amounts of land are available for development."

Summing their estimated \$5 billion revenue decline and \$15.9 billion production expense increase, Sparks projects that \$180-\$190 per mt carbon permit prices would reduce net farm income by \$21 billion (or 46 percent relative to 1997). Extending the analysis to specific production systems, Sparks estimates decreases in net farm returns of 43 percent for "typical" North Central corn-soybean operations, 50 percent for North Central hog operations, 70 percent for Upper Midwest dairy operations, and 121 percent for Florida tomato operations.

Sparks computes increases in production expenses and projects revenue declines from reduced domestic consumption and exports. Farmers in their analysis, however, do not adjust

³ The \$15.9 billion figure includes the \$11.3 billion in increased manufactured input costs, \$2.3 billion in higher "other operating expenses", and \$2.3 billion in additional charges for "overhead and farm origin inputs."

business plans in response to rising costs of production. Since farmers would likely respond to higher energy prices by reducing output and shifting marginal resources to other uses, commodity markets would clear at higher prices for the reduced quantities supplied. The farm and farm sector income losses estimated by Sparks are therefore probably overstated.

McCarl, Gowen, and Yeats (1997)

McCarl et al. (MGY) use the Agricultural Sector Model (ASMSOIL) to assess the farm sector impacts of carbon permits prices of \$25, \$50, and \$100 per short ton (2,000 lbs) implemented in years 2000, 2005, 2010, 2015, 2020.⁴ ASMSOIL is a spatial equilibrium nonlinear programming model with multiple input and output regions and thousands of production related variables. The model assumes that economic agents have sufficient time to adjust consumption and production decisions in response price or policy shocks (i.e. adjustment paths are not modeled). The simulation results reflect movements between market equilibriums.

Impacts of carbon permits on the costs of fertilizers and other chemicals are calculated using information in the transactions matrix of the IMPLAN input-output model and incorporating price increases for key energy inputs in the production of farm chemicals. Price increases for diesel, gasoline, and natural gas are roughly consistent with those estimated by Sparks. For various farm chemicals, however, MGY estimate prices increases that are all less than one percent. Hence, for farm chemicals, the cost increases associated with carbon permits in MGY are significantly less than would be suggested by the embodied fuel or carbon content of the inputs.

⁴ The study reviewed here is a "Draft Technical Memo." As such, it probably contains material that has been changed or corrected.

MGY report that the major farm sector adjustment to higher energy costs would be a shift to conservation tillage (particularly no till). In the \$100 carbon permit simulation, for example, quantities used of cropland, water, and labor all decline by less than 1 percent as do expenditures for nitrogen, potassium, and phosphorous; expenditures for other chemicals increase less than 1 percent.

MGY present welfare impacts associated with the various carbon permit prices in terms of changes in consumer, producer, and foreign surplus relative to a scenario where no taxes are imposed. The results indicate that consumers will pay a significantly larger absolute share of any carbon/energy tax, while producers will pay a larger relative share. For example, the loss in producer surplus associated with a \$100 carbon permit begun in 2000 is \$256 million, while the loss in consumer surplus is \$1.134 billion. In percentage terms, however, the loss in producer surplus is about 5 times larger than the loss in consumer surplus (0.09 percent vs 0.50 percent).

With respect to the U.S. farm sector, MGY estimate that carbon permit prices of \$25, \$50, and \$100 per ton would cost (producer surplus loss), respectively, \$450 million, \$850 million, and \$1.6 billion annually, for years 2000 through 2020. Given that 1996 gross farm income was \$49 billion, they conclude U.S. agriculture would not be very sensitive to the level of any carbon taxes or permits aimed at reducing U.S. GHG emissions. Additionally, MGY note that these costs could be largely offset by returning carbon tax revenues collected from the farm sector to producers in the form of lump-sum transfers. For carbon permit prices of \$25, \$50, and \$100 per ton, these revenues are estimated at \$450 million, \$800 million, and \$1.5 billion, respectively.

Summary

Francel and Sparks conduct partial budgeting analyses of the effects of carbon permits on the U.S. agriculture sector, and conclude that annual net farm income will decline by 46-48 percent. Sparks explicitly analyzes the effects of carbon permit prices at \$180-\$190 per metric ton. The large projected decline in net farm income is largely the result of assuming that farmers do not respond to changes in input costs and net returns. It is more likely that rising input costs lead to reduced quantities supplied which leads to rising market prices and value of production. The effects of carbon permits on farm income are likely to be overestimated by these studies.

McCarl, et al. use an agricultural sector model to analyze the effects of carbon permit prices. MGY's calculation of effects of carbon prices on fuel costs are consistent with Francel and Sparks, but their calculation of carbon price effects on fertilizer and pesticide costs--less than one percent rise--is low. The MGY analysis allows producers and markets to respond to higher input costs, and projects that income declines--less than 3.3 percent with a \$100/mt carbon price--would not significantly affect the sector. MGY further note that the income effects could be largely offset by returning carbon revenues to the farm sector. Since the MGY analysis seems to underestimate chemical cost increases, their estimated shifts of crop acreage into chemical intensive conservation tillage is likely to be overestimated. (If this is the case, the decline in farm income estimated by MGY would be underestimated, but this is limited in significance since they demonstrated that most of this income loss could be avoided by returning carbon revenues to the farm sector.)

Economic Analysis of the Kyoto Protocol on U.S. Agriculture

Because the bulk of the impact of a Kyoto protocol commitment will be met through some mechanism which assigns a price to carbon emissions, we focus on carbon dioxide emissions rather than the full set of greenhouse gases covered by the protocol. This is consistent with the CEA and other analyses of the protocol.

Policies to reduce carbon emissions will lead to increases in input prices, effectively taxing inputs based on their carbon emissions (in manufacture and use). Producers and consumers will be impacted according to how much carbon they are absorbing in production and consumption. Products and inputs containing relatively more carbon are likely to decline in use as producers and consumers respond to price signals. Costs of fuels, electricity, fertilizers and chemicals, and transportation services would all be affected. All sectors of the economy would likely be affected, including agriculture. The magnitude of the change in agricultural input costs will depend on three factors: how the policy is implemented, on how much carbon emissions need to be reduced, and on how much carbon is embodied in the sector's inputs.

We analyze the effects of the Kyoto protocol on agriculture in several steps. First, since many impacts important to agriculture depend on the carbon price and since views differ as to what the correct carbon price is, we identify from the literature three carbon prices which span the likely range of prices. Second, to accurately capture the effects of carbon charges, we estimate carbon embodied in agricultural production in great detail for many alternative crop and livestock production processes by region across the U.S. and use this to calculate change in input prices associated with each scenario. Fourth, in order to estimate what happens if producers must pay for carbon use we introduce the changes in input prices into a detailed model of the

U.S. agricultural sector, which estimates the corresponding impacts on agricultural commodity price, supply, demand, income, erosion, nitrogen loss, and other important agriculture sector indicators.

Carbon Emission Policies and Their Impacts

A carbon emissions reduction policy could be implemented as a tax on energy or carbon, a system of tradeable permits in carbon emissions, or through direct regulation. An instrument based directly on carbon content will generally be the most efficient, hence for a given desired level of carbon emissions reduction, input costs would rise less with a carbon charge than with an energy charge. The burden, or redistribution of income, resulting from the carbon reduction policy would depend on how the policy was designed and implemented. The value of tradeable carbon permits auctioned by the government, or the revenues collected from sale of permits, or the revenues from a carbon tax could be returned entirely to the agriculture sector. Permit values or revenues could be redistributed to agricultural producers according to historical carbon use, or according to some environmental or stewardship “good,” or on some other basis. Thus, the ultimate impact of the different mechanisms on consumer and producer welfare would depend on how the revenues were employed (returned to consumers or producers, or otherwise used).⁵

For simplicity and because these design questions haven’t been resolved, we model a generic policy which for a given carbon price raises input prices by the amount of carbon

⁵The specific emissions reduction mechanism used will also affect the calculation of changes in agriculture sector net benefits. We currently treat the increase in input costs paid by agriculture producers as a transfer payment from farmers to the government or permit holders completely outside agriculture. The design of a carbon pricing program goes beyond the agriculture sector. It is possible that under a scheme where carbon permits are allocated to producers based on current carbon emission rates, that agriculture producers could receive transfer payments from other sectors of the economy. These payments could be greater than the associated increases in energy costs, resulting in an increase rather than decrease in producer net benefits.

embodied in them. While the mechanism used could affect the price of carbon associated with a specific emission targets the resulting impact of these prices on agriculture can be modeled through the impact they have on input prices or unit costs.

Carbon Price Scenarios

We evaluate three Carbon Permit Price Scenarios which—based on our review of existing macro analyses—represent the range of likely carbon prices to emerge from implementation of the protocol. These prices selected are consistent those obtained by the CEA in their analysis of Kyoto with full emissions trading, limited emissions trading, and no emissions trading. The permit prices associated with these scenarios are \$14 per metric ton of carbon under full emissions trading, \$100 per metric ton of carbon under limited emissions trading, and \$200 per metric ton of carbon under no trading.

Estimates of Impact of Carbon Prices on Input Costs

The increase in input costs for each of the scenarios is calculated by multiplying the carbon embodied in each input by the prevailing carbon price. This was done by calculating the physical quantity of each input used in a production activity and then multiplying this quantity by physical science estimates of the amount of carbon embodied per unit of input. Input price increases for each of the carbon scenarios are presented in Table II.6. Economic Research Service (ERS) Cost of Production (COP) survey data were applied to calculate the physical quantity for each input used in the crop and livestock production enterprises.

Direct and Indirect Sources of Carbon in Crop and Livestock Budgets

Fuel (diesel, gasoline, natural gas, LP gas) lubrication and electricity expenses in both crop and

livestock budgets are generally referred to as direct carbon costs. The carbon embodied in other inputs such as chemicals, are collectively referred to as indirect carbon costs (see Appendix 1, Energy Use in Agriculture).

Direct carbon costs for crops represented in the COP budgets include expenditures on diesel, gasoline, LP gas, natural gas, lubricants, and electricity used for the operation of machinery, vehicles, irrigation systems, and crop drying. The most important categories of indirect carbon costs are “fertilizer, lime, and gypsum”, “chemicals” (pesticides), and “custom operations”. “Custom operations” includes custom field and other operations, often involving machinery that farmers contract for. It can also include technical services, and commercial drying as well. Other important categories are “Other variable cash expenses” which can include purchased irrigation water, baling, and so on. Remaining categories of interest include “Ginning” for cotton and “Drying” for rice.

Direct energy costs for livestock include expenses for diesel, gasoline, LP gas, natural gas, lubricants, and electricity used for machinery, vehicles, equipment, manure handling systems, feed systems, housing, and dairy parlor operation. Indirect energy cost sources include “Hauling,” “Marketing,” and “Custom services and supplies.”

Modeling Carbon Price Impacts

To capture the full effects of carbon permits on the agriculture sector we apply our estimates of the increase in input prices to each of the nearly 1,000 production systems contained in the ERS regional agricultural model, USMP. We then solve the model to return commodity and input markets to equilibrium. The supply, use, acreage, price and other market indicators which result then form the basis for determining the impacts of Kyoto on the agriculture sector.

The USMP regional agricultural model represents agricultural markets and production enterprises in considerable detail with commodity, spatial, production practice and other particulars of the model validated to the latest baseline, geographic, and cost of production data sources available (see Appendix 2, USMP Regional Agricultural Model). The USMP model accounts for the most important effects of the carbon charges on U.S. agriculture.⁶

We evaluate the impacts of the emissions reduction policy in 2010, the midpoint of the 2008-2012 period established for compliance with the Kyoto Protocol. U.S. agriculture sector conditions in 2010 are based on the USDA Long-Term Agricultural Baseline (February 1998). The official USDA baseline provides projections through the year 2007; for this analysis we extended the baseline estimates to 2010 with linear trends (of acreage planted, prices, and other market variables).⁷ The USMP model is then calibrated to crop and livestock supply, demand, production, acreage, government program, input cost and other conditions for 2010. USMP employs crop multi year rotation system enterprises and livestock enterprise budgets based on ERS 1996 cost-of-production (COP) budgets (<http://www.econ.ag.gov/briefing/fbe/car/car.htm>). These costs are indexed to baseline projections of variable costs for 2010.

The analysis is "comparative static" which means that it compares conditions in the initial,

⁶ The model results are "partial equilibrium" because they omit effects on agriculture which pertain to interaction between the agriculture sector and the rest of the U.S. economy. These interaction effects are minor enough that they are routinely ignored when evaluating policy impacts on agriculture. They would include, for example, effects of changes in consumer good and production input prices which result from how the carbon permit scenarios affect agriculture and non-agriculture sector producers and consumers. If carbon permits reduce non-agriculture sector income somewhat, specific examples might include declines in non-agriculture sector purchases of, e.g., food and fertilizer for non-agriculture use. These changes would reduce agriculture sector product sales revenue and input expenses somewhat, but the magnitudes are so small relative to the direct impacts that they may be safely ignored.

⁷ This procedure to extend the baseline to 2010 was based on recommendations from ERS baseline analysts.

base year, equilibrium situation with conditions after the economy has had several years to adjust to a new, medium-run, equilibrium. This analysis follows the Baseline assumptions that no other policy or market changes take place, so we can isolate the unique effects of implementing carbon permit charges. In this analysis farmers can respond to carbon permit-related increases in input costs by changing production levels or quantities, by changing products produced, and by shifting among current production practices actually observed in agricultural survey data. Producer response to changes in product and input prices is ultimately determined by all producers adjusting so that the revenue and returns from their last items produced just equal one another. Shifts among production practices--for example reducing acreage in moldboard plow and increasing acreage in no-till tillage--incur costs of acquiring new implements and learning new management practices which all enter into the process of adjusting to the new equilibrium. We hold energy efficiency of available production technology constant. This means in particular that we do not allow new technologies to come into use, nor do we allow for increases in energy efficiency of production processes in response to increased energy costs--because we are uncertain as to how much energy efficiency will increase. Failing to account for anticipated increases in energy efficiency is somewhat unrealistic since producers are routinely observed to economize on scarce or more expensive inputs. On the other hand, since carbon permits most likely will affect agriculture negatively, our approach is a conservative one which will not underestimate negative impacts on U.S. agriculture.

We now turn to a comprehensive analysis of how carbon permit prices--spanning the range likely under the Kyoto Protocol--would affect U.S. agriculture. We examine the most important indicators of agriculture economic and environmental performance.

Effects on Crop Prices, Supply and Use

Charging a carbon permit price causes crop costs of production to rise, which reduces quantity demanded, boosts crop price and leads to declines in production. Relative crop impacts are influenced on the supply side by carbon intensity in production. A \$14/mt carbon price leads to crop price increases of less than 1 percent, averaging around 1 cent per bushel for feedgrains and wheat (table II.7). With a \$100/mt carbon permit price, feedgrain, wheat and rice prices rise 1 to 4 percent. A \$200/mt carbon price boosts feedgrain, wheat and rice prices 2 to 7 percent. Relative changes among feedgrains (corn, sorghum, barley, oats) on the supply side depend on their relative energy and carbon intensity in production, and on the demand side depend on their relative protein and energy content in constituting animal feed rations. Rice price rises more than other crops owing to its greater energy and carbon intensity in production. Soybean, silage and hay prices rise less than 1 percent in all scenarios owing to lesser carbon intensity in production: soybean production, in the Corn Belt for example, uses only about 40 percent of the carbon per acre (134 lbs) as does corn (309 lbs).

Declines in crop production are greater as the charge for carbon is greater. The \$14/mt permit price leads to negligible output declines of 0.6 percent or less. \$100/mt permit prices lead to feedgrain and wheat production declines of 1 to 2 percent, while \$200/mt permit prices double that to declines of 2 to 4 percent. Soybean production impacts are half those of feedgrains owing to the lesser carbon intensity in production, while rice production declines are greater due to its greater carbon intensity in production.

Crop domestic use declines negligibly (less than 0.5 percent) with the \$14/mt carbon charge (table II.8). Crop export impacts are similarly negligible except that rice and barley exports

decline 1 percent. The \$100/mt and \$200/mt carbon scenarios see minimal declines in domestic use, but more sizable declines in exports. Under the \$200/mt scenario, export declines are 4 percent and less for corn and soybeans, but reach 8.5 percent for barley and 17 percent for rice.

Effects on Crop Acreage

Charging a carbon permit price will increase crop costs of production and will tend to reduce acreage planted across crops, regions, and cropping practices in proportion to how much carbon is embodied in the production process. The \$14/mt carbon permit price leads to a decline of 800 thousand acres planted to the 10 major field crops (corn, sorghum, barley, oats, wheat, cotton, rice, soybeans, hay and silage) (table II.10). Feedgrain (corn, sorghum, barley and oats) acreage declines about 200 thousand acres, while wheat and hay acreage decline 200 thousand acres each. Proportionally, acreage declines are larger than average in the Mountain and Pacific regions and particularly large in the South Plains—regions with substantial irrigated acreage (table II.12). Virtually all of the acreage decline occurs in acres farmed under conventional tillage as opposed to conservation tillage.

The \$100/mt and \$200/mt carbon permit prices lead to 5.4 and 10.7 million acre declines in acreage planted (table II.10). About a third of the acreage planted decline occurs in feedgrains, and about a quarter occurs in wheat. Three quarters of the decline in acreage planted occurs in the North and South Plains, and Mountain regions—owing to the energy use in the substantial irrigated acreage in these regions. The Pacific region—also with substantial irrigation, but with slightly lower embodied carbon per acre since more of its irrigation energy tends to come from hydroelectric power—sees a decline in acreage similar in proportion to the North Plains and Mountain regions, but a lesser absolute decline since it accounts for only 9 million acres of the

10 major crops in 2010.

Nearly 90 percent of the decline in acreage planted occurs in conventional plus moldboard plow tillages—4.9 and 9.6 million acres with the \$100/mt and \$200/mt scenarios. Reduced tillage accounts for 0.5 and 1.1 million of the acreage declines in these scenarios. Reduced tillage practices use less fuel and lubrication energy than conventional tillage, but tend to use more chemicals than conventional tillage.

Effects on Livestock Price and Production

Charging a carbon permit price affects livestock production on the supply side both through direct energy cost impacts and indirect cost impacts including higher feed costs. The \$14/mt carbon permit charge affects livestock products negligibly, with prices increasing less than a half percent and production declining a tenth of a percent or less (table II.9). The \$100/mt carbon charge causes dairy, hog and broiler prices to rise about 1 percent and beef cattle prices to rise 2 to 3 percent. The \$200/mt carbon charge doubles these impacts with dairy, hog and broiler prices gaining 1 to 2 percent and beef cattle prices rising 4 to 5 percent. Production declines remain small: less than 1 or 2 percent in both the \$100/mt and \$200/mt scenarios.

Income and expense effects

Value of production and total variable costs are the major components of farm income affected by the carbon charge scenarios. Charging for carbon increases costs of production, which boosts commodity

Income Accounting Concepts

+	Value of Production
+	Conservation Reserve Payments
+	Production Flexibility Payments
–	<u>Total Variable Costs</u>
=	Net Cash Returns

prices. Higher prices increase value of production, but also reduce quantity demanded and hence produced, which serves to reduce value of production. The net effect on value of production depends on input supply and commodity demand markets, but—given inelastic demand—agricultural product values typically rise when production costs rise.

The \$14/mt carbon permit charge affects crop and livestock income by less than a half percent. Total variable costs and value of production rise \$502 and \$277 million, netting out to a net cash returns decline of \$225 million (table II.11) assuming that carbon permit revenues are not returned to the agriculture sector. With the \$100/mt carbon charge, net cash returns decline \$1.6 billion (2.1 percent, table II.13), of which \$1.4 billion comes from crops and \$213 million from livestock. The decline in crop net returns results from the \$1.9 billion rise in total variable costs which is only partly offset by the \$572 million rise in value of production. At a carbon charge of \$200/mt, net cash returns decline \$3.0 billion, again with the major portion of the decline in crops (\$2.6 billion) as opposed to livestock (\$0.4 billion). The \$200/mt scenario sees value of production rise \$3.7 billion, only half offsetting the \$6.7 billion rise in total variable costs.

Regional changes are minor with the \$14/mt carbon charge: net cash returns decline an average of 0.3 percent, except for the North and South Plains with declines of 0.7 and 1.4 percent. With the \$200/mt carbon charge, regional net cash return declines average 4.1 percent and in the North and South Plains decline 9 and 10 percent.

Carbon Used in Production

Tracking total and per production unit amounts of carbon used in crop and livestock

production⁸ helps in understanding why some differential impacts are noticed across crops and regions, and suggests the extent to which different policy implementations--for example, charges applied to energy--would be less efficient than the carbon charge policy. The model estimates total carbon used in crop and livestock production in 2010 at 40.5 million metric tons (table II.14). Of this, about half is used for fuel, lubricants and electricity, totaling 20.3 million metric tons. Fertilizer use accounts for 13 million metric tons. Crops account for 31.7 million metric tons or over three fourths of total carbon used in production.

Carbon used in crop production averages 204 pounds per acre (table II.15). The highest users of carbon are rice and cotton at 812 and 383 pounds per acre—owing to their use of energy in irrigation. Rice use of carbon reaches a regional high of 856 pounds per acre in the South Plains and cotton a high of 593 pounds per acre in the Mountain region. Regionally the Delta States score the highest crop carbon use at 302 pounds per acre, owing to the predominance of irrigated rice and cotton.

Across all crops, the average 204 pounds of carbon per acre is principally composed of nitrogen use at 62 pounds per acre, chemical (pesticide) use at 37.7 pounds per acre, and diesel fuel use at 39.5 pounds per acre (table II.16). Corn production use of carbon is more than 50 percent higher than the average crop at 345 pounds per acre (table II.17). Corn's carbon use is principally composed of nitrogen, diesel, and chemical use at 123.5, 58.1, and 57.7 pounds per acre.

The adjustments in carbon total and per acre use (tables II.14-II.17) reflect changes in acreage planted or animal numbers, regional shifts in production, and changes in usage among

⁸The major field crops and livestock (beef, dairy, swine, poultry) represented in the USMP model.

currently observed (in surveys) production techniques. Since these scenario analyses assume use of current, already-in-use production technology, they overestimate impacts of changes (such as price increases and income declines) to the extent that crop and livestock producers, and input suppliers would act on incentives to develop and shift to technologies more efficient in carbon use. Investigation of carbon and energy saving technology adjustments and analysis of how such technologies would mitigate impacts of carbon permit charges are important topics for further research.

Effects on Agricultural inputs

A system of carbon permits will increase the prices of agricultural inputs proportionally with carbon content. Farmers' responses to higher input prices will determine the shifts in input uses and the ultimate effects of carbon charges on farmer expenditures. Increased input prices result in reduced input use and reduced carbon embodied in inputs and agricultural production. Over time, carbon charges would stimulate development of new technology that would reduce the energy requirements for agricultural production and its embedded carbon.

The effects of carbon permits on carbon content and energy-intensive input use and on energy expenses by input are presented in Table II.18. Crop and livestock expenses for all energy increase by 1.4 percent under \$14/mt carbon permit prices. Energy expenses increase by 9.8 percent and 19.2 percent with \$100/mt and \$200/mt carbon prices. The input industry as a whole, using "Crops and livestock all energy" as a proxy⁹, incurs a sales volume reduction of 0.6 percent with \$14/mt carbon permits. Reductions of 4 and 7 percent are incurred with \$100/mt

⁹For this analysis the carbon content of inputs used in the available technologies (production practices) is fixed, enabling reductions in carbon to be used to estimate reductions in input use. The percent changes in each input's use can be approximated by its percent change in embedded carbon.

and \$200/mt carbon prices. These changes in input use and energy expenditures reflect farmers' adjustments to carbon permit charges (discussed above in "Crop price, supply, and use," "Livestock price and production", and "Crop acreage planted").

Input demand impacts

Direct fuel and lubricant use by farmers and that embodied in custom use are affected most directly by carbon permits. Direct use of fuel and lubricants by farmers declines by 0.9 percent with \$14/mt carbon permits. Reductions of 5.4 and 9.3 percent are incurred in fuel and lubricant use with \$100/mt and \$200/mt carbon prices. Custom service use declines by 2.8 percent with \$14/mt carbon permits. Custom use reductions of 16.5 and 28 percent are incurred with \$100/mt and \$200/mt carbon prices.

Fertilizers, particularly nitrogen, and chemicals are energy intensive inputs. About 1.625 pounds of carbon are embedded in each pound of nitrogen fertilizer and we estimate that about 5.633 pounds of carbon are embedded in each pound of chemical pesticide. Fertilizer use declines by 0.2 percent with \$14/mt carbon permits. Fertilizer reductions of 1.8 and 3.5 percent are incurred with \$100/mt and \$200/mt carbon prices. Chemical (pesticide) use declines by 0.3 percent with \$14/mt carbon permits. Reductions of 2.2 and 4.3 percent in chemical use are incurred with \$100/mt and \$200/mt carbon prices.

Electricity use increases by 0.1 percent with \$14/mt carbon permits, reflecting electricity's smaller carbon content relative to fossil fuels. Increases of 2.3 and 5.0 percent are incurred with \$100/mt and \$200/mt carbon prices.

Input expense effects

Input expenses change due to the rise in per unit input costs and decline (or increase) in aggregate input use. Farmers' direct expenditures for fuel and lubrication increase by \$203.9 million or 2.2 percent with \$14/mt carbon permits. (The expense effects on income were discussed previously in "Income and expense effects".) Fuel and lubricant expenditure increases of 15.5 and 30.4 percent are incurred with \$100/mt and \$200/mt carbon prices. Farmers' expenditures for custom increase by \$1.5 million or 0.2 percent with \$14/mt carbon permits, reflecting the increase in fuel and lubricant costs. Custom expenditure increases of 1.6 and 3.1 percent are incurred with 100/mt and \$200/mt carbon prices.

Farmers' expenditures for fertilizers increase by \$154.2 million or 1.3 percent with \$14/mt carbon permits. Fertilizer expenditure increases of 8.8 and 17.3 percent are incurred with \$100/mt and \$200/mt carbon prices. About 75 percent of the changes are attributed to nitrogen, higher in carbon content than potash and phosphates. Chemical expenditures increase by \$57.8 million or 0.7 percent with \$14/mt carbon permits. Chemical expenditure increases of 4.9 and 9.7 percent are incurred with \$100/mt and \$200/mt carbon prices.

Expenditures on relatively lower cost electricity increase by \$14.3 million or 1.5 percent with \$14/mt carbon permits. Expenditure increases of 12.7 and 26.3 percent are incurred with \$100/mt and \$200/mt carbon prices.

Changes in surplus measures and net social benefit

Imposition of a carbon charge causes net social benefit from agriculture to decline, along with consumer and producer surpluses, reflecting the adverse effects the resulting increases in

Box B2—Measures of social benefit

Change in net farm income (cash returns) accurately measures the economic effects of carbon permit prices on agricultural producer welfare. It tells us little, however, about how changes in crop and livestock prices affect consumers or society as a whole. There is, unfortunately, no comparably direct measure for changes in consumer or social welfare as exists for producers. As a result, economists typically rely on measures of willingness to pay such as consumer surplus, producer surplus and net social benefit, to gauge the effect of economic changes on consumers and society.

Willingness to pay measures the intensity of economic agents' preferences for a change. It is based on the amount an individual or firm is willing to pay or accept to let the change take place. While willingness to pay is not directly related to changes in personal utility, it does provide a common measure (money) for measuring the gains or losses that consumers, producers and society face. As such, it is used to evaluate the tradeoffs involved in changes in government policy and the potential for the losers from these changes in policy to be compensated by the gainers so that everyone could be made at least as well off as before.

Producer surplus represents total revenues minus total variable costs and is equivalent to net income. **Consumer surplus**, while not equivalent to consumers willingness to pay, does provide a satisfactory approximation when analyzing changes in sectors, such as agriculture, where consumer expenditures on its commodities represent only a small share of consumer income. **Net social benefit** is equal to the sum of consumer and producer surplus plus changes in revenues transferred in or out of the market. It represents the potential of gainers in the market to compensate the losers so that the losers are no worse off after a change than before it.

production costs and food prices have on both consumers and agricultural producer welfare (table II.19).¹⁰ If the carbon price is low, \$14/mt, losses to both consumers and agricultural producers are relatively small, declining by \$482 million. The losses are split fairly evenly between consumers and producers, with consumer surplus declining by \$229 million and producer surplus declining by \$253 million. Net domestic benefit (consumer surplus plus producer surplus plus

¹⁰The various surplus and social benefit measures used in this analysis represent only partial gains or losses from the imposition of carbon charges. They represent changes in consumer and social welfare caused by changes in the agriculture sector alone. They don't take into account the effect of increased energy prices on consumer income or the prices consumers pay for other goods. As a result, the demand for agriculture products is only affected by changes in agricultural prices. It also assumes that all input prices, excepting land and those directly affected by changes in energy prices remain unchanged. It also leaves out any environmental benefits which may result from reductions in acreage planted and conventional tillage and reduction in GHG emissions.

revenues transferred out of sector) which measures the net impact on agriculture or deadweight loss, declines by \$40 million. This is considerably less than the direct losses to consumers and agricultural producers, and indicates the potential for significantly reducing agriculture sector losses by recycling revenues transferred out of the sector by the carbon charge back to consumers and agriculture producers in the form of a lump sum transfer.

At high permit prices (\$100/mt and \$200/mt) losses to consumers and agricultural producers are 10 and 15 times higher than observed at the lower permit price, reflecting consumers' strong preferences (inelastic demand) for food and limits to agriculture producers' ability to substitute to less carbon intensive technologies.

Changes in environmental indicators

The imposition of carbon permit prices leads to a reduction in soil erosion (sheet, rill and wind) and nitrogen loss to water (surface runoff and leach) (table II.20). The reductions are brought about primarily by declines in acreage planted, rather than substitution of less carbon intensive conservation tillage practices for conventional practices. With a low carbon price (\$14/mt), both erosion and nitrogen loss decline imperceptibly (less than 0.5 percent) and are fairly uniform across production regions. The insignificant changes in the indicators reflects the negligible impact low carbon prices have on acreage planted and technology (tillage practices) used.

At the high carbon prices (\$100/mt and \$200/mt) declines in erosion and nitrogen loss to water are greater and more regionally concentrated. Declines in soil erosion and water related nitrogen losses are consistent with associated declines in planted acres. The decline in soil erosion is more heavily concentrated in Northern Plains and Mountain regions, while erosion in

the Corn Belt is remains relatively unchanged from its base value. Reductions in nitrogen loss under the higher carbon prices are concentrated in the Northern and Southern Plains.

Societal benefits (improved water quality) from reductions in erosion and nitrogen loss largely accrue downstream (off-site)¹¹ from the agricultural production activities causing them. As a result, they are not included in calculations of consumer surplus, producer surplus or net social benefits. None the less, the off-site benefits from carbon charges could conceivably be large enough to offset the direct costs to the agriculture sector.

Declines in the estimated offsite damages from soil erosion, range from \$3 million for the low carbon price scenario (\$14/mt) to \$49 million for the high carbon price (\$200/mt) scenario. While not complete, the estimates suggest that the added environmental benefits from the charging of carbon permit prices, while important, will not offset the loss to consumers and producers caused by the carbon charge.

Exports and Competitiveness Effects

U.S. commodity exports both depend on and influence market prices.¹² U.S. commodity exports also depend on the costs of producing crops and livestock elsewhere in the world. It is

¹¹Reduced water quality has negative effects on navigation, recreational and commercial fishing, and water for drinking, industrial, and irrigation uses. Reduced quality results in costs incurred by individuals in avoiding or treating sub-quality water. Damage in dollar terms per ton of erosion for these categories by agricultural region have been estimated by analysts at ERS using procedures which approximate the physical, chemical, biological and economic links between soil erosion and water quality. The estimates of off-site damage used in this report were derived by multiplying the estimated damage per ton of erosion times tons of erosion for each production region.

¹² Changes in crop exports in USMP are determined by the price change evaluated and the export demand elasticities specified in the model. The export demand elasticities used in this analysis are: corn, -0.53; sorghum, -1.17; barley, -0.65; oats, -0.65; wheat, -1.44; rice, -2.41; soybeans, -0.73; and cotton, -1.26. These capture the medium-run impacts of a shock occurring 10 years in the future.

logical to assume then, that the demand for U.S. agricultural exports could shift under a fully implemented Kyoto Protocol. While this analysis does model the effects of U.S. commodity price changes on exports, it does not model shifts in export demand due to changes in production costs in other global regions.

If, as a result of implementing the Protocol, foreign producers incur smaller carbon charges than domestic producers, U.S. agricultural commodities could become less competitive in global markets and U.S. commodity export demands would fall. On the other hand, if foreign producers incur higher production costs under the Protocol, U.S. competitiveness would be enhanced and U.S. commodity export demands would increase. Lacking accurate estimates of the likely effects of implementing the Protocol on the competitiveness of U.S. agricultural products, we do not shift U.S. export demands from the levels projected in the extended USDA Long-Term Baseline.

At the same time, we acknowledge the concerns that some have expressed about the possibility that increasing energy prices only in Annex-I countries will increase the likelihood of agricultural production (primary and/or processing) shifting to non-Annex-I regions. Recent evidence, however, suggests that the validity of such concerns may depend on the time-frame being considering -- specifically, whether or not one is allowing for limited or full adjustments on the part of regional and world economies to the higher energy prices (i.e. a partial versus a general equilibrium framework).

Initially, the Kyoto Agreement calls for participation by Annex-I countries. At least to start then, the direct costs of mitigating carbon emissions will be borne by Annex-I countries. This suggests

that in the short-run (i.e., before all global adjustments can occur), increases in the costs of energy-intensive inputs may initially hurt the competitiveness of some U.S. producers in some commodity markets. Over time, however, increasing energy prices only in Annex-I countries could result in agricultural production shifting from non-Annex-I countries to Annex-I countries. This is because production of commodities and processed foods in Annex I countries is relatively less energy intensive per unit of output than many other economic sectors and it is in these sectors that, over time, non-Annex-I countries would likely expand production.

This long-run shift of agricultural production to Annex I countries can be qualitatively illustrated with the Future Agricultural Resources Model (FARM) (Darwin *et al.*, 1995, 1996; Darwin, 1999) by imposing a 10 percent tax on the price of coal-oil-gas consumed in the U.S., Canada, European Community, Japan, and Australia/New Zealand. These regions include all Annex I countries except those in the former Soviet Union and those European countries not in the European Community as of 1990. The tax is collected in the region where the fossil fuel is consumed. As a result, production of agricultural commodities and processed foods generally increases in regions where the tax is levied (table II.21). The four exceptions—wheat in the U.S. and wheat, other grains, and non-grains in Canada—are attributable to greater production of these commodities in other regions where the tax is imposed.¹³ When the tax on fossil fuels is imposed in all regions, however, production of agricultural commodities and processed foods in the U.S., Canada, European Community, Japan, and Australia/New Zealand generally declines (table II.22). Welfare losses in the U.S. agricultural sector are also smaller when fossil fuels

¹³ Similar results were obtained in an Australian study of uniform emissions reductions imposed only in Annex I countries (Australian Bureau of Agricultural and Resource Economics, 1997).

taxes are confined to the developed regions.¹⁴

Summary and Conclusions

Policies to reduce GHG emissions will likely include some form of carbon permits, effectively introducing a price for carbon into producers' and consumers' marginal decisions. Costs of agricultural production inputs--fuels, electricity, fertilizers and chemicals, transportation services, and so on--would all be affected. We evaluated the agricultural impacts of three scenarios which span the range of likely carbon permit prices reported by the CEA and supported by other macro analyses. The permit prices used were \$14, \$100, and \$200 per metric ton of carbon.

We found that the effects of the Kyoto Protocol on the U.S. agriculture sector, depending on the extent to which the United States meets its emissions targets through international trading, will range from slight to moderate. If the CEA's best case scenario prevails and the carbon permit price is low (\$14 per metric ton), then the impact on the U.S. agriculture sector will be slight. Crop and livestock prices will increase by less than one percent and farm income will fall about one-half percent. Agriculture exports will be largely unaffected. What impact there is will be fairly evenly spread across all commodities and regions of the country.

Even if CEA's worst case scenario comes true and no trading in carbon emissions occurs and the carbon permit prices reach \$200 per metric ton, impacts of this on the agriculture sector will be fairly moderate. Crop and livestock prices will increase from two to seven percent and farm

¹⁴This analysis assumes 1990 economic conditions without any climate change. It also does not consider 1) potential long-term dynamic changes that differential prices in fossil fuels might generate or 2) methods for mitigating agricultural emissions of greenhouse gases, like methane or nitrous oxide.

income will fall by only 4 percent. Exports of most crops decline by less than 4 percent. In this case, however, the impacts are not spread evenly. Exports of rice fall by nearly 23 percent. Declines in production and farm income are concentrated in the Northern and Southern Plains and the Mountain states in areas where irrigation use predominates.

All and all farm income can be expected to decline by 2 percent for each \$100 per metric ton of carbon permit cost. Under all scenarios, reductions in farm income and losses to consumers of agricultural products can be almost completely offset by recycling the revenues transferred out of the sector by the implementation of Kyoto.

The conclusions of this study are consistent with the study by MGY, but differ significantly from those of the Francel and Sparks studies. Both of those studies project substantial declines in farm income as a result of Kyoto. While their estimates of the increase input prices is similar to ours, neither study takes into account the response of producers or agriculture markets to the increase in input costs. As a result they significantly overestimate, as our analysis demonstrates, the impact of Kyoto on the agriculture sector. MGY on the other hand did account for producers response to increased input costs and obtained results similar to those presented here.

We believe the agriculture sector impacts of the carbon price scenarios reported here to be conservative. That is we err towards overestimating the costs borne by the agriculture sector. In part, this follows because we assume that farmers do not adopt new technologies to increase the efficiency of their carbon use. More significantly, we do not account for the benefits that could accrue to agriculture producers from carbon sequestration activities.

III. Carbon Sequestration

Carbon sequestration in the Kyoto Protocol

The quantitative analyses of CEA and the studies described in section II do not account for the potential use of terrestrial carbon sinks in helping the U.S. to meet its emissions reduction target under the Kyoto Protocol. U.S. agriculture could benefit from a national program to implement the Kyoto Protocol if terrestrial carbon sinks are allowed to play a significant role in the mitigation of GHG emissions. Specifically, farms account for almost half of all land in the contiguous 48 states and given appropriate economic inducements, significant areas could be managed to increase the quantity of carbon stored in the soils and above ground biomass. In this section we consider the potential for U.S. agriculture to serve as a GHG sink within the framework of the Kyoto Protocol and the set of policies that could be used to develop this potential.

The Kyoto Protocol has largely left the issue of terrestrial carbon sinks to future negotiation. Currently carbon sequestration activities are limited to those considered in Article 3.3—afforestation, reforestation, and deforestation. Article 3.4 provides for future consideration of other human induced carbon sequestering activities such as those associated with agricultural soils.

Implications for U.S. agriculture

Numerous studies of agricultural sites in North America have documented changes in soil carbon levels with changes in tillage practices (see Paustian et al, 1996; Reicosky, 1995; Reicosky et al., 1995; Kern and Johnson, 1993). For undisturbed soils first brought into

production using conventional tillage practices, soil carbon losses typically range from 30%-50% over the first 20 years of cultivation, after which, soil carbon levels generally stabilize at a new equilibrium. In the Great Plains, soil carbon losses due to cultivation have been estimated to range from 24%-60% and take as long as 30 to 43 years to stabilize. In studies of sites that have been shifted out of conventional tillage and into permanent grasses or no-till systems, results show rates of soil carbon buildup between 0 and 2,000 lbs. per acre with accumulation typically taking 5 to 12 years to become measurable. Studies of former cropland sites either abandoned or reseeded with natural grasses indicate that about 50 years is needed to return soils to their maximum carrying capacity (Gephart et al., 1994; and Lal et al., 1998).

The rate of carbon accumulation/release in agricultural soils varies with many site specific factors—including chemical and physical characteristics of the soil, precipitation, above- and below-ground biology, temperature, solar radiation, atmospheric chemistry and processes, landscape characteristics, site history (including past management practices), time, and current land use (Johnson and Kern, 1990). Developing a framework that accounts for these influences in a systematic and verifiable fashion across national and international regions is an important step in including agricultural soils under Article 3.4 of the Kyoto Protocol.

Soils having the greatest potential to sequester carbon are those that are below their carbon carrying capacity, meaning young soils and soils that have been depleted of carbon due to management practices (Johnson and Kern, 1990). Because the large majority of U.S. cropland has been in production for several decades, their large initial releases of carbon have already occurred and current releases are now very low—estimates range between 2.7 and 15 MM mt annually (Gephart et al., 1994; and Lal et al., 1998). Collectively then, U.S. agricultural soils have a relatively high potential for being managed to store additional carbon.

Converting agricultural lands to forests

For 1996, EPA estimates that due to improved management practices and regeneration, U.S. forests represented a net carbon sink of about 208.6 MM mt. This is about 14% of total U.S. carbon emissions and 12% of total emissions of gases (in carbon equivalents) covered in the Kyoto Protocol. The potential to further offset U.S. GHG emissions by shifting millions of acres of marginal cropland and pasture into forests has been analyzed by Moulton and Richards (1990), Adams et al. (1993), and Parks and Hardie (1995 and 1996). We focus here on the works by Parks and Hardie because the studies by Moulton and Richards, and, Adams et al., while frequently cited, are now understood to have significantly overstated the amount of carbon sequestered in new forests (Richards, 1992).

Table III.1 (part A) presents selected results from Parks and Hardie (1995). These results suggest that a CRP type program, funded at a level of \$456.2 million annually, would sequester about 48.6 MM tons of carbon per year (or 44.2 MM mt) and require some 22.2 million acres. The carbon sequestered is a little over 3 percent of current U.S. carbon emissions and about 7.9 percent of the emissions reduction CEA estimates will be required to meet our obligations under the Kyoto Protocol in 2010. Also clear in Table III.1 is that most of the land converted to forests would be pasture land—note that when only cropland is considered, acres enrolled fall to 9.4 million, carbon sequestered drops to 21.6 MM tons, and per acre costs more than double (to \$48.53). Parks and Hardie (1996), consider the goal of sequestering 10 percent of U.S. carbon emissions in new forests. Achieving this level of sequestration by converting marginal croplands and pasture to new forests is estimated to require 116.1 million acres and cost \$8.31 billion annually.

Converting cropland to grasses

While forest generally have more primary production and above ground biomass than grasslands, grassland soils often have more carbon than forest soils (Johnson and Kern, 1991). This is because soil carbon in grasslands is mostly a function of root mortality and because the roots of grasses are thin, compact, and often extend to a depth of a meter or more. Carbon in forest soils, on the other hand is primarily a function of fine root turn-over near the surface and tree litter. For areas that were once prairie or are otherwise poorly suited to forests, conversion of cropland to grasses may be a more efficient carbon sink than conversion to trees.

Paustian et al. look at soil carbon accumulation on 25 million acres of CRP land in Great Plains. Over the 10 year contract period they estimate an aggregate increase in below ground soil carbon (i.e. carbon in soil organic matter, roots, and soil litter) of 57.6 MM mt—or 5.76 MM mt per year. For CRP acres put into grasses at five locations in the Great Plains, Gebhart et al. estimate carbon accumulation in the top 120 inches at 1,000 lbs. per acre per year—implying a 25 million acre program would sequester a total of 11.36 MM mt of carbon per year. Splitting the estimates of Paustian et al. and Gebhart et al., suggests a 25 million acre CRP like program to convert marginal cropland to grasses would sequester carbon on the order of 8.56 MM mt per year. This represents about 1.5 percent of the CEA's Kyoto emissions reduction target for the US in 2010 (i.e., 559 MM mt).

For the most recent CRP enrollment period, mean rental payments for land in the Great Plains ranged between \$32 and \$40 per acre. Given a CRP type program then, a rough cost estimate of shifting 25 million acres of cropland to grasslands would be \$800 million-\$1 billion.

Increasing Soil Carbon in Cultivated Soils

With respect to cultivated lands, a number of production practices exist that if adopted could increase soil carbon levels. These include conservation tillage (particularly no-till), elimination of summer fallow, use of winter cover crops, and adding organic amendments to soils. To date, virtually no economic analysis has been done on the potential costs and benefits of encouraging farmers to adopt these practices as an approach to mitigating GHG emissions. We can, however, draw on the literature to establish a rough estimate of the potential to sequester carbon in cultivated soils for one practice—conservation tillage.

Kern and Johnson (1993) estimate changes in soil carbon and energy use for various levels of adoption of minimum tillage and no-till systems for the period 1990-2020. Their results are reproduced in part B of Table III.1 and suggest that in moving from 60 million acres in no-till (scenario 2, line c) to 80 million acres (scenario 3, line c), soil carbon would increase between 206 MM mt and 339 MM mt (i.e. 286-80 and 468-129, respectively) over a 30 year period. This suggests that shifting 20 million acres into no-till would result in between 6.9 MM mt and 11.3 MM mt of carbon being sequestered annually—or between 1.2% and 2.0% of the CEA's target for complying with the Kyoto Protocol in 2010.

How much a program to induce farmers to put 20 million acres into no-till would cost is, at this point, speculative. While conservation tillage increased from 2% of US cropland in 1968 to 36% in 1996, acreage over the period 1992-1996 was almost constant—although acres under no-till increased from 9.9% of all cropland to 14.5% (ERS, 1998). Conservation tillage is used

mostly on soybeans, corn, and small grains, which indicates that conservation compliance has probably been a major factor affecting adoption rates. This suggests that economic incentives would probably be a significant component of any effort to mitigate GHG emissions via the expanded use of conservation tillage.

Additionally, it is worth noting that conservation tillage has been linked to a variety of environmental benefits and these may also help justify additional government actions to promote its use with respect to mitigating GHG emissions. ERS, for example, has estimated the benefits of reduced erosion from switching 22.4 million acres of highly erodible land now under conventional tillage to conservation tillage at between \$30.5 million and \$99.1 million with a best guess of \$49.6 million annually.

Policy Considerations for Increasing Carbon Sequestration in Agriculture

If shifting lands from commodity production to forests or grasses, or moving from conventional tillage to conservation tillage are to be considered carbon sinks in the context of the Kyoto Protocol, the affected lands will have to stay in their new uses for extended periods of time (perhaps a minimum of 20 years). That is, managing land to sequester carbon for a few years and then returning it to production, or resuming conventional tillage in the case of land put into no-till, would quickly release any carbon that had been added to soils or biomass by sequestration activities (Paustian et al., 1996; ERS, 1998a). A key focus then of policies to promote agricultural carbon sinks will need to be ensuring that conditions exist under which producers are willing to enter relatively long-run commitments regarding the management of land resources.

To assess how government policies might facilitate and encourage such commitments, it is

helpful to view land ownership as a bundle of separate interests, each conveying the right to use a parcel of land in a particular way (Weibe, 1996). The set of interests associated with any given parcel may be held by one agent or may be distributed among multiple agents (public and private). From this perspective, the market value of any subset of interests reflects expectations about the present value of all current and future uses that subset allows the holder to legally undertake. Hence, the effect of establishing agricultural GHG sinks within the framework of the Kyoto Protocol would be to create a new economic interest in farm land—namely the right to manage it for increased carbon content. Giving sequestered carbon a positive market value would mean farmers could treat it as another commodity. Profit maximizing producers would then choose to sequester carbon when the present value of its net returns exceeded similar streams associated with other commodities over some relevant time horizon.

At present, the details of any future market for carbon sequestration are largely uncertain since many of the factors that would define this market are still being debated by the Parties to the Kyoto Protocol. One often discussed possibility, however, is that firms with high emissions reductions costs would mitigate the environmental impacts of their emissions by contracting with farmers to engage in specific sequestration activities. If the price of carbon were sufficiently high, it is conceivable that the farm sector would produce enough sequestration to significantly offset national GHG emissions. In the extreme, the government's role in promoting agricultural carbon sinks would be limited to maintaining the legal environment in which sinks are defined, measured, verified, and sequestration contracts enforced.

At lower carbon prices, or for activities that sequester relatively small quantities of carbon, it may be the case that the benefits to agricultural producers are not adequate to attract enough acreage out of commodity production (or to generate shifts to production practices that increase

carbon sequestration) to significantly offset national GHG emissions. In this case, it may be necessary to assess whether or not the social benefits of carbon sequestration (including the associated environmental side benefits) are sufficient to justify government expenditures to promote or enhance agricultural carbon sinks. If it is deemed that such expenditures are justified, then carbon sequestration could become an explicit conservation objective of farm policy.

In recent years, conservation has become an increasingly important component of farm policy. Conservation programs authorized in the Federal Agricultural Improvement and Reform (FAIR) Act of 1996 (i.e., the last Farm Bill), for example, encourage farmers and ranchers to take actions that reduce soil erosion, protect wetlands, improve water quality, and enhance wildlife habitat.¹⁵ USDA conservation programs typically feature economic incentives to encourage voluntary participation on the part of private landowners. Frequently used incentives include annual rental payments to landowners in exchange for retiring environmentally sensitive lands from production, cost-share assistance to establish practices that help reduce environmental damages, conservation compliance, education, and technical assistance. If promoting carbon sequestration does become an explicit goal of USDA conservation policy, then these tools could be modified or expanded to encourage the adoption of agricultural practices that increase the quantity of carbon stored in soils and biomass.

¹⁵The expanding role of conservation in farm policy is evident in the last three Farm Bills. The Food Security Act of 1985 targeted problems associated with soil erosion by establishing the Conservation Reserve Program. It also introduced conservation compliance, which made participation in a wide range of farm programs conditional on abiding by restrictions on farming highly erodible lands and wetlands (i.e., the sodbuster and swampbuster provisions of the Bill). The Food, Agriculture, Conservation, and Trade Act of 1990 expanded the policy focus to include protecting and restoring wetlands on private farm lands by establishing the Wetlands Reserve Program. In addition to the Conservation Reserve and Wetlands Reserve Programs, the FAIR Act authorizes the Wildlife Habitat Incentives Program, the Environmental Quality Incentives Program, and the Conservation of Private Grazing Lands Program.

To highlight the potential role for farm policy in establishing and enhancing agricultural carbon sinks, consider the net effect on GHG emissions associated with any given land-use or production practice as a difference between carbon input to a sink and carbon output to the atmosphere. Formally:

$$\text{Carbon Input} - \text{Carbon Output} = \text{Net Carbon Gain}.$$

For lands shifted from commodity production to forests or permanent grasses, it is generally accepted that this relationship will be positive. Hence, the potential use of policy to expand forest and grassland sinks would be to establish inducements such that shifting lands out of commodity production would be viewed as economically rational by some set of producers or land owners.

For lands that remain in production, the carbon input variable is affected by the level of crop residue left on and in the field, which in turn, is a function of crop choice (including rotation system), fertilizer use, timing of field operations (e.g., planting, harvesting, and irrigation), and climate. All but climate are largely management variables. The *carbon output* variable is affected by the level of biomass removed, the rate of biological oxidation, and the rate of soil erosion. These factors can also be influenced by farm management decisions. Switching from conventional tillage to no-till, for example, increases crop residues left on and in the soil (reducing biomass removal and erosion) and decreases soil mixing (reducing biological oxidation). Table IV.1 presents a list of selected management practices that could be used to enhance agricultural carbon sinks. With each practice is an assessment as to its relative potential to store carbon as well as a list of policy tools that could be used to promote the practice.

Tables

Table I.1: Emissions of CO₂, CH₄, and N₂O 1989-96: US and Agricultural Sector

Year	1990	1991	1992	1993	1994	1995	1996
Total Emissions (MMT carbon equivalent -- MMTCE)							
Carbon	1348.3	1333.2	1353.4	1385.6	1408.5	1419.2	1471.1
Methane	169.9	171.1	172.5	171.9	175.9	179.2	178.6
Nitrous Oxide	92.3	94.4	96.8	97.1	104.9	101.9	103.7
Total*	1632.7	1620.2	1645.7	1678	1715.3	1731.1	1788.0
Agric. Sources (low)	151.12	153.09	158.56	157.55	168.55	163.57	NA
Percent agric.	9.26	9.45	9.63	9.39	9.83	9.45	NA
Agric. Sources (high)	163.42	165.39	170.86	169.85	180.85	175.87	NA
Percent agric.	10.01	10.21	10.38	10.12	10.54	10.16	NA
U.S. Methane Emissions from Agricultural Sources (MMTCE)							
Enteric Fermentation	32.7	32.8	33.2	33.6	34.5	34.9	34.5
Dairy Cattle	8.4	8.4	8.4	8.4	8.4	8.4	8.5
Beef Cattle	22.6	2.8	23.1	23.6	24.5	24.9	24.6
Manure Management	14.9	15.4	16.0	16.1	16.7	16.9	16.6
Swine	7.8	8.2	8.6	8.6	9.1	9.2	8.8
Dairy Cattle	4.3	4.3	4.4	4.4	4.5	4.5	4.5
Rice Cultivation	2.5	2.5	2.8	2.5	3.0	2.8	2.5
Crop Residue Burning	0.2	0.2	0.2	0.2	0.2	0.2	0.2
All Agric. Sources	50.3	50.9	52.2	52.4	54.4	54.8	53.8
Percent Agric.	29.6	29.7	30.3	30.5	30.9	30.6	30.1
U.S. Nitrous Oxide Emissions from Agricultural Sources (MMTCE)							
Soil Management	62.4	63.4	65.2	64.1	70.4	67.2	68.6
Manure Management	2.6	2.8	2.8	2.9	2.9	2.9	3.0
Crop Residue Burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1
All Agric. Sources	65.1	66.3	68.1	67.1	73.4	70.2	71.7
Percent Agric.	70.5	70.2	70.4	69.1	70.0	68.9	69.1
U.S. Carbon Emissions from Agricultural Sources (MMT of carbon)							
Gas, Diesel, LP gas **	11.83	11.87	13.6	13.38	14.44	13.48	NA
N,P,K (man. & distr.) **	16.55	16.74	17	16.95	18.56	17.33	NA
Electricity **	2.81	2.75	3.13	3.19	3.22	3.23	NA
Pesticide (man. & dsitr) **	1.83	1.83	1.83	1.83	1.83	1.83	NA
C from Ag soils (low) ***	2.7	2.7	2.7	2.7	2.7	2.7	2.7
C from Ag soils (high) ***	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Total Agric. C (low)	35.72	35.89	38.26	38.05	40.75	38.57	NA
Total Agric. C (high)	48.02	48.19	50.56	50.35	53.05	50.87	NA

Source: Except as noted below, EPA (1998).

* Includes emissions of hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

** In house estimates based on assorted published sources. Estimates for N,P,K, Pesticides, and Electricity reflect carbon used in manufacture and delivery. Estimates for gas, diesel, and LP gas reflect carbon in gallons consumed on farms.

*** low estimate is from Gephart et al. (1994); high estimate is from Lal et al. (1998)

Table II.1: Summary of CEA (1998) Analysis of Implementing the Kyoto Protocol

Emissions Reduce U.S. greenhouse gas (GHG) emissions to 7% below 1990 levels between

Target: 2008 and 2012. Gases covered are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆).

Methodology

1. Construct regional "business as usual" (BAU) GHG emissions scenarios for 2010.
2. Develop regional marginal abatement cost curves for reducing GHG emissions.
3. Use the Second Generation Model (SGM) to calculate the world carbon prices that equate marginal abatement costs across regions for various trading scenarios. For each scenario, assess the impacts on U.S. energy prices, energy consumption, GDP, investment, and consumption. (SGM is a 12 region - 9 sector computable general equilibrium model designed to analyze energy markets)

Key Assumptions

1. efficient trading of emissions allowances within regions and across specified trading blocs.
2. carbon sinks not considered
3. autonomous gain in energy efficiency for the US economy set at 0.96% annually
4. no banking of emissions allowances for later periods
5. no emissions mitigation related to electricity sector restructuring, the Climate Change Technology Initiative, the Energy Efficiency Initiative, or voluntary industry actions.
6. Reduction in carbon emissions needed to meet 1990-7% target = 559 MMT carbon.
7. specified trade blocs:
 - Annex 1: Unrestricted trade of emissions credits among Annex 1 countries.
 - Umbrella 1: Unrestricted trade of emissions credits among Annex 1 countries minus Eastern Europe and the European Union (EU).
 - Umbrella 2: Unrestricted trade of emissions credits among Annex 1 countries minus the EU.
 - CDM: Developing countries sell emissions credits via Clean Development Mechanism.
 - KDC: Key developing countries adopt emissions targets equal to their 2010 baseline and participate in normal trading:

Scenario results (% reductions relative to case where all countries reduce emissions domestically):

Scenario	reduction in permit price	reduction in U.S. economic cost	Permit Price (1996 \$s)	U.S. Economic Cost (1996 \$s)
Annex1	72%	57%		
Umbrella1	75%	61%		
Umbrella2	85%	74%		
Annex1+KDC	88%	80%	\$23/metric ton	\$12 billion/year
Umbrella1+KDC	91%	83%		
Umbrella2+KDC	93%	87%	\$14/metric ton	\$ 7 billion/year
Annex1+CDM	79%	66%		
Umbrella1+CDM	82%	71%		
Umbrella2+CDM	88%	80%		

Table 1: (continued)

Results for permit price = \$14 per metric ton (relative to the BAU scenario in 2010)

- a. raise household energy prices 3% and annual household energy costs \$70,
- b. raise both electricity and gasoline prices 3% (for gasoline this is about 4 cents per gallon);
- c. decrease GDP \$1 billion (about 0.01%) and increase investment \$1 billion;
- d. decrease consumption and employment insignificantly.

Results for permit price = \$23 per metric ton (relative to the BAU scenario in 2010)

- a. raise household energy prices 5% and annual household energy costs \$110,
- b. raise electricity prices 5% and gasoline prices 4% (about 6 cents per gallon),
- c. decrease GDP \$5 billion and increase investment \$3 billion,

d. decrease consumption \$4 billion and decrease employment slightly.

Table II.2: Assumptions, Features, and Results of Selected Macroeconomic Studies on Reducing U.S. Carbon Emissions

Study	Selected Emissions targets*	Price of Carbon in 2010 (\$ per mt)	Key Assumptions and Features	Key Results
DRI (1997): results in 1995 \$'s	1990 by 2010	\$192 (firms given permits equal to 1990 emissions)	1. Econometric macroeconomic forecasting model of the U.S. economy with 1 foreign. Partial equilibrium structure with 245 sectors.	1. Permits prices rise over the period 2010-2020. Price increases range from \$ 5 0 to \$ 9 0 across scenarios.
	1990-10% by 2010	\$270 (firms given permits equal to 90% of 1990 emissions)	2. No international permit trading. 3. When permits are auctioned, revenues are used to reduce the Federal deficit. 4. No carbon sinks or emissions credits banking. 5. All policies phased in over 2000-2010.	2. In 2010, relative to the base case: a. US GDP drops 1.6% to 2.5%, b. US economy loses 0.8-1.4 million jobs (mostly in energy intensive sectors).
	1990 by 2010	\$180 (emissions permits auctioned)	6. All Annex 1 countries have similar policies. 7. Analysis limited to CO ₂ emissions. 8. Needed reduction in carbon emissions: 556 MM mt C for 1990-10% target.	c. producer energy prices rise 68%-80%.
Edmonds et al (1997): results in 1992 \$'s	1990 by 2010	\$108 if no emissions trading \$ 72 if Annex 1 trading \$ 26 if global trading	1. Second Generation Model (SGM); a 12 region, 9 sector general equilibrium framework designed to analyze energy markets. SGM run with with some prices fixed so 2. With Annex 1 (global) trading, U.S. buys 209 (316) Tg of carbon permits in 2010 and 244 (436) m Eastern Europe and former USSR.	1. Reducing emissions reduces U.S. GDP relative to the baseline. In all scenarios these decreases are less than 1%.
	1990-10% by 2010	\$173 if no trading \$109 if Annex 1 trading \$38 if global trading	2. No phase-in period. 3. Permits allocated to regions based on 1990 emissions levels. All tax revenues recycled via lump-sum transfers. 4. No carbon sinks or emissions credits banking. 5. Analysis limited to CO ₂ emissions. 6. Needed reduction in carbon emissions: 510 MM mt C for 1990-10% target.	3. Price of carbon permit falls 20%-85% if Eastern Europe the former USSR can sell "hot air" credits. **
EIA (1997) results in 1995 \$'s	1990 by 2010	\$130 (domestic permit trading only)	1. DRI model to estimate macroeconomic effects & EIA's National Energy Modeling System to assess U.S. energy sector impacts.	1. Relative to base case, U.S. GDP decreases 1.0% to 1.8% across scenarios.
	1990 by 2010	\$40 (global trading with world carbon	2. Assesses 5 and 10 year phase-in periods ending in 2010, 2015, & 2020.	2. With no global trade in emissions permits U.S. energy prices rise significantly.

	price specified exogenously)	3. Global trading scenario results of limited value because: a. DRI model has 1 foreign region b. world carbon price set exogenously	By 2010, prices for coal, natural gas, gasoline, and electricity rise 252%, 73%, 25%, and 36%, respectively (relative to the baseline).
1990-10% by 2010	\$200 (estimated from graph)	4. No carbon sinks or banking of emissions credits. 5. Analysis limited to CO ₂ emissions. 6. Needed reduction in carbon emissions: 506 MM mt C for 1990-10% target.	3. Increasing phase-in period from 5 to 10 years decreases yearly GDP losses but lengthens period over which losses occur.
WEFA 1990-7% results in 1996 \$'s	\$265 by 2010	1. Econometric macroeconomic forecasting model of the U.S. economy (similar to DRI model- partial equilibrium structure. 2. carbon sinks not included 3. carbon tax revenues returned via lump-sum transfers 4. no trading in emissions permits or other forms of international cooperation 5. Analysis limited to CO ₂ emissions. 6. Needed reduction in carbon emissions: 466 MM mt C for 1990-7%	Meeting the Kyoto emissions target would (1998): 1. nearly double the prices of energy and electricity (gasoline prices would rise \$0.48 per gallon by 2010) 2. decrease U.S. GDP \$300 billion (3.2%) 3. cost the U.S. economy 2.4 million jobs 4. decrease mean annual household income \$2,728 by 2010 and \$1,876 by 2020. 5. hurt US competitiveness in world markets 6. Price of carbon would rise to \$360 per metric ton in 2020
Charles River Assoc. (1998) results in 1997 \$'s	1990-7% \$14-\$193 per mt depending on assumptions	1. Charles River Associates (CRA) model. Model not described but stated to be similar to SGM in structure and capabilities. 2. Goal is to replicate results of CEA analysis and then assess how relaxing the CEA assumptions affect the price of emissions permits and the economic costs associated with emissions permits. 3. Needed reduction in carbon emissions: 559 MM mt C for 1990-7%.	1. Using CEA assumptions in the CRA yields similar results -- a global carbon price of \$14 per metric ton and an annual cost to the U.S. economy of \$7 billion. 2. Not allowing global trading increases the U.S. cost to \$27 billion annually. 3. Not allowing Annex 1 trading increases the U.S. cost to \$53 billion annually. 4. Not allowing international emissions trading increases the price of carbon to \$193 per metric ton. 5. Allowing Annex 1 trading but less fuel substitution and smaller energy efficiency gains results in a carbon price of \$170 per mt. Related impacts (for 2010) are a

1.1% fall in GDP (\$110 billion) and an
additional \$0.50 per gallon for gasoline.

* not all scenarios included here

Table II.3: Assumptions, Features, and Results of Selected Farm-Level Studies on Reducing U.S. Carbon Emissions

Study	Emissions targets*	Price of Carbon (\$ permit)	Key Assumptions and Features	Key Results
Francel (1997) results in 1994 \$'s	1990	low scenario: \$0.25 per gallon of fuel high scenario: \$0.50 per gallon of fuel	1. Estimates how fuel taxes would affect input prices and production cost of selected commodities. 2. Tax rates based on a literature review 3. All price changes occur in year 1. 4. Effects relative to 1994 5. No producer supply response that would raise commodity prices.	1. Total farm production expenses increase 5.8% in the low scenario and 11.7% in the high scenario. 2. See Table II.4 for impacts on agricultural input prices
Sparks (1997): results in 1995 \$'s	See DRI study (table II.2)	See DRI study	1. Uses DRI model to define baseline and assess macroeconomic impacts of each scenario. No phase-in period. 2. Estimates how carbon tax would affect the prices energy intensive farm inputs. 3. Input cost increase reflects producer response to higher prices, domestic consumer response limited to income effect. 4. Technology, commodity production patterns, and systems of food processing and marketing assumed constant through 2010. 5. No producer supply response that would raise commodity prices.	1. Higher energy costs would: a. increase farm production costs \$15.9 billion (8.5%) and food processing and marketing costs \$17 billion (2.6%). b. reduce domestic food demand 0.7% c. decrease farm income nearly 50% (relative to average for since 1990) d. increase farm consolidation e. increase food imports and decrease food exports.
McCarl et al. (1997)	no specific target	Considers taxes of 25, \$50, and \$100 per short ton of carbon	1. taxes put in place all at once & all economic adjustments occur immediately 2. Changes in relative prices of diesel, natural gas, fertilizer and electricity are estimated exogenously and imposed on the model. 3. Considers imposing carbon tax in 2000, 2005, 2010, 2015, and 2020.	1. U.S. agriculture is not very sensitive to carbon taxes. 2. Carbon taxes of \$25, \$50, and \$100 / ton would cost the farm sector, respectively, \$450, \$850, and \$1,600 million annually. Annual tax revenues from the farm sector would be \$450, \$800, and \$1,500 million. 3. Farmers would pass most of any input price increases on to consumers.

Table II.4: Input Cost Increases Estimated in Various Studies, by Carbon Tax Scenario

Study	Input	Policy Scenario		
Francel		Fuel Price Increase Scenario		
		Low	High	
		--percent--		
	Fuel and electricity	25	50	
	Pesticides/chemicals	20	40	
	Fertilizer	15 to 20	30 to 40	
	Custom operations/hauling	15	30	
	Other Expenses	5	10	
Sparks, Inc.		Emissions Permit Price (1995 \$'s per metric ton of Carbon)		
		\$180		
		--percent--		
	Fuels and Oil	33.1		
	Natural Gas	129.6		
	Fertilizer	106		
	Pesticides	55		
McCarl et al.	Input	Carbon Permit Price (1997 \$'s per short ton of Carbon)		
		\$25	\$50	\$100
		--percent--		
	Gasoline	4.52	9.04	18.08
	Diesel	8.26	16.53	33.06
	Natural Gas	13.13	26.26	52.53
	Electricity	8.26	16.53	33.06
	Nitrogen	0.22	0.44	0.87
	Phosphorous	0.08	0.16	0.33
	Potassium	0.22	0.44	0.87
	Chemicals	0.08	0.16	0.33

**Table II.5: Farm Expenditure Increases with \$180-\$190/MT Carbon Price, 2010;
estimated by Sparks Companies, Inc.**

Item	Assumptions				Expense	Cost
	Energy	Cost	Usage	Net Cost	1997	Impact
	Component	Change	Response	Change		
	percent	percent	percent	percent	\$ bil.	\$ bil.
<u>Manufactured inputs</u>						
Fertilizer & Lime	65.0	106	-20	55	11.2	6.2
Fuel & oils	95.0	33	-3	30	6.3	1.9
Pesticides	70.0	55	-5	37	8.8	3.2
Total					26.3	11.3
<u>Farm origin inputs</u>						
Feed purchased	12.0	40	-5	5	24.2	1.1
Livestock & poultry purchased	7.5	40	-1	3	13.3	0.4
Seed purchased	15.0	40	-1	6	6.3	0.4
Total					43.8	1.9
<u>Interest charges</u>						
Short-term interest				-1.5	7.0	-0.1
Real-estate interest				-1.8	6.4	-0.1
Total					13.4	-0.2
<u>Other operating expenses</u>						
Repair & Maintenance	5.0	55	-2	3	10.6	0.3
Contract & hired labor	0.0	33		0	17.7	0.0
Mach. hire & cust. work	9.0	33	-2	3	5.0	0.1
Mktg, stor., trans.	20.0	33	-2	6	7.2	0.5
Misc. op. Expenses	12.0	55	-2	6	22.2	1.4
Total					62.7	2.3
<u>Other overhead</u>						
Capital consumption				4	19.7	0.8
Taxes				5	7.1	0.4
Net rent				-4	13.9	-0.6
Total					40.7	0.6
<u>Total Production Expenses</u>					186.9	15.9

Source: Sparks, Table 13, p.18.

Net Cost Calculation for Fertilizer & Lime = $.65 \times 1.06 \times (1 - .20) = .55$.

Table II.6: 2010 Agricultural input price increases under alternative carbon price scenarios*

Table 11.6. 2010 Agricultural input price increases under alternative carbon price scenarios									
Item	Unit	Unit Price	Carbon Content pounds / unit	Input Price Increases Given Carbon Permit Prices per Metric Ton					
				\$14		\$100		\$200	
				\$ / unit	percent	\$ / unit	percent	\$ / unit	percent
Fuels									
Diesel fuel	Gallon	1.21	6.026	0.04	3.2	0.27	22.6	0.55	45.3
Gasoline	Gallon	1.65	5.233	0.03	2.0	0.24	14.4	0.47	28.7
LP gas	Gallon	1.06	3.200	0.02	1.9	0.15	13.8	0.29	27.5
Natural gas	100 Cu.Ft.	0.45	3.300	0.02	4.7	0.15	33.3	0.30	66.7
Electricity									
Northeast	Kwh.	0.11	0.087	0.00	0.5	0.00	3.8	0.01	7.5
Lake States	Kwh.	0.06	0.150	0.00	1.6	0.01	11.5	0.01	23.0
Corn Belt	Kwh.	0.06	0.150	0.00	1.7	0.01	12.1	0.01	24.2
Northern Plains	Kwh.	0.06	0.150	0.00	1.7	0.01	12.1	0.01	24.2
Appalachian	Kwh.	0.08	0.105	0.00	0.8	0.00	6.0	0.01	11.9
Southeast	Kwh.	0.06	0.129	0.00	1.4	0.01	10.2	0.01	20.3
Delta	Kwh.	0.05	0.135	0.00	1.8	0.01	12.6	0.01	25.1
Southern Plains	Kwh.	0.05	0.127	0.00	1.5	0.01	10.7	0.01	21.4
Mountain	Kwh.	0.06	0.127	0.00	1.5	0.01	10.5	0.01	20.9
Pacific	Kwh.	0.07	0.042	0.00	0.4	0.00	2.8	0.00	5.5
Chemicals									
Nitrogen	Pound	0.38	1.420	0.01	2.4	0.06	16.9	0.13	33.8
Phosphate	Pound	0.29	0.296	0.00	0.7	0.01	4.7	0.03	9.3
Potash	Pound	0.17	0.236	0.00	0.9	0.01	6.3	0.02	12.5
Pesticides	Pound	3.49	5.633	0.04	1.0	0.26	7.3	0.51	14.6

* Input cost changes under USMP alternative carbon permit price model runs.

Table II.7: 2010 crop price and production under alternative carbon price scenarios

Crop Unit		Commodity Price				Commodity Production			
		Base 2010	Carbon price scenario			Base 2010	Carbon price scenario		
			\$14/mt	\$100/mt	\$200/mt		\$14/mt	\$100/mt	\$200/mt
		-- dollars per unit --				-- million units --			
Corn	Bushel	3.20	3.21	3.28	3.36	11,776.2	11,764.3	11,691.0	11,604.2
	Change		0.01	0.08	0.17		-11.9	-85.2	-172.0
	% change		0.38	2.60	5.16		-0.1	-0.7	-1.5
Sorghum	Bushel	3.00	3.01	3.10	3.20	770.0	767.6	753.3	736.4
	Change		0.01	0.10	0.20		-2.4	-16.7	-33.6
	% change		0.48	3.31	6.65		-0.3	-2.2	-4.4
Barley	Bushel	2.85	2.87	2.96	3.04	450.0	448.4	441.0	433.7
	Change		0.02	0.11	0.19		-1.7	-9.1	-16.3
	% change		0.70	3.78	6.75		-0.4	-2.0	-3.6
Oats	Bushel	1.90	1.91	1.96	2.02	293.7	293.2	289.1	284.8
	Change		0.01	0.06	0.12		-0.6	-4.6	-9.0
	% change		0.39	3.14	6.07		-0.2	-1.6	-3.1
Wheat	Bushel	4.65	4.66	4.70	4.76	2,828.0	2,824.2	2,796.7	2,758.4
	Change		0.01	0.05	0.11		-3.9	-31.4	-69.6
	% change		0.13	1.08	2.39		-0.1	-1.1	-2.5
Rice	Hundred-weight	12.87	12.94	13.34	13.79	206.4	205.2	198.0	189.8
	Change		0.07	0.47	0.92		-1.2	-8.4	-16.6
	% change		0.51	3.63	7.17		-0.6	-4.1	-8.0
Soybeans	Bushel	7.55	7.56	7.58	7.61	3,144.2	3,142.2	3,130.0	3,115.6
	Change		0.00	0.03	0.05		-2.0	-14.2	-28.5
	% change		0.06	0.38	0.71		-0.1	-0.5	-0.9
Cotton	Bale	NA ¹	NA	NA	NA	21.3	21.3	20.9	20.5
	Change		0.76	5.65	12.18		-0.1	-0.4	-0.8
	% change		0.21	1.53	3.30		-0.2	-1.8	-3.9
Silage	Ton	21.66	21.67	21.70	21.73	95.6	95.5	94.5	93.5
	Change		0.01	0.04	0.07		-0.1	-1.1	-2.1
	% change		0.02	0.16	0.33		-0.2	-1.1	-2.2
Hay	Ton	60.53	60.58	60.74	60.84	155.6	155.2	153.6	152.4
	Change		0.05	0.21	0.30		-0.4	-2.0	-3.2
	% change		0.08	0.35	0.50		-0.3	-1.3	-2.0

¹ USDA is prohibited from publishing cotton price projections.

Table II.8: 2010 crop domestic use and exports under alternative carbon price scenarios

Crop Unit		Domestic Use				Commodity Exports			
		Base 2010	Carbon price scenario \$14/mt \$100/mt \$200/mt			Base 2010	Carbon price scenario \$14/mt \$100/mt \$200/mt		
		-- dollars per unit --				-- million units --			
Corn	Bushel	1,675.0	1,674.6	1,672.0	1,669.0	3,250.6	3,244.0	3,205.8	3,161.7
	Change		-0.4	-3.0	-6.1		-6.5	-44.7	-88.9
	% change		0.0	-0.2	-0.4		-0.2	-1.4	-2.7
Sorghum	Bushel	35.0	34.9	34.0	33.0	335.0	333.1	322.1	309.0
	Change		-0.1	-1.0	-2.0		-1.9	-13.0	-26.1
	% change		-0.4	-2.8	-5.6		-0.6	-3.9	-7.8
Barley	Bushel	172.0	171.7	170.3	169.0	70.0	69.4	66.7	64.0
	Change		-0.3	-1.7	-3.0		-0.6	-3.3	-6.0
	% change		-0.2	-1.0	-1.8		-0.9	-4.8	-8.5
Oats	Bushel	102.0	102.0	101.7	101.4	2.0	2.0	2.0	1.9
	Change		0.0	-0.3	-0.6		0	0	-0.1
	% change		0.0	-0.3	-0.6		-0.3	-2	-3.9
Wheat	Bushel	1,146.0	1,145.9	1,144.9	1,143.5	1,625.0	1,621.6	1,596.8	1,562.3
	Change		-0.1	-1.1	-2.5		-3.5	-28.3	-62.7
	% change		0.0	-0.1	-0.2		-0.2	-1.7	-3.9
Rice	Hundred-weight	7.0	7.0	6.9	6.8	85.4	84.3	77.9	70.5
	Change		0.0	-0.1	-0.2		-1.1	-7.5	-14.9
	% change		-0.2	-1.2	-2.4		-1.2	-8.8	-17.4
Cotton	Bale	152.2	152.1	152.0	151.8	1,149.7	1,149.3	1,146.6	1,143.8
	Change		0.0	-0.2	-0.4		-0.5	-3.2	-6.0
	% change		0.0	-0.1	-0.3		0	-0.3	-0.5
Soybeans	Bushel	13.2	13.2	13.0	12.8	8.0	8.0	7.8	7.7
	Change		0.0	-0.2	-0.4		0	-0.2	-0.3
	% change		-0.2	-1.6	-3.4		-0.3	-1.9	-4.2
Silage	Ton	27.5	27.5	27.1	26.7	0	0	0	0
	Change		-0.1	-0.4	-0.8		0	0	0
	% change		-0.2	-1.5	-3.0		0	0	0
Hay	Ton	79.2	78.9	77.7	77.0	0	0	0	0
	Change		-0.4	-1.5	-2.2		0	0	0
	% change		-0.5	-1.9	-2.8		0	0	0

Table II.9: Selected 2010 livestock price and production under alternative carbon price scenarios

Product Unit		Commodity Price				Commodity Production			
		Base 2010	Carbon price scenario			Base 2010	Carbon price scenario		
			\$14/mt	\$100/mt	\$200/mt		\$14/mt	\$100/mt	\$200/mt
		-- dollars per unit --				-- million units --			
Milk	Hundred-weight	15.25	15.27	15.4	15.54	1,705.0	1,703.9	1,697.5	1,690.1
	Change		0.02	0.15	0.29		-1.1	-7.5	-14.9
	% change		0.14	0.96	1.9		-0.1	-0.4	-0.9
Hog slaughter	Hundred-weight*	49.80	49.88	50.37	50.92	255.2	255.2	255.1	254.9
	Change		0.08	0.57	1.12		0	-0.1	-0.2
	% change		0.17	1.14	2.24		0	0	-0.1
Beef yearlings	Hundred-weight*	90.64	90.97	92.92	95.23	185.9	185.8	184.8	183.7
	Change		0.32	2.28	4.59		-0.2	-1.1	-2.2
	% change		0.35	2.51	5.06		-0.1	-0.6	-1.2
Fed beef	Hundred-weight*	80.61	80.89	82.62	84.63	329.5	329.2	327.3	325
	Change		0.29	2.01	4.02		-0.3	-2.3	-4.5
	% change		0.36	2.5	4.99		-0.1	-0.7	-1.4
Broilers	Pounds	0.39	0.39	0.39	0.39	37,863.5	37,857.2	37,819.7	37,777.4
	Change		0	0	0.01		-6.3	-43.9	-86.1
	% change		0.13	0.91	1.79		0	-0.1	-0.2

* live weight.

Table II.10: 2010 acreage planted and acreage change under alternative carbon price scenarios

	Base/ Change	North East	Lake States	Corn Belt	North Plains	Appa- lachie	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
Selected crops												
-- million acres --												
Feed- grains	2010 base	4.0	15.5	43.6	24.5	4.8	2.2	1.0	6.4	4.4	1.4	107.7
	\$14/mt	0	0	0	-0.1	0	0	0	-0.1	0	0	-0.2
	\$100/mt	-0.1	-0.1	-0.1	-0.6	-0.1	0	0	-0.6	-0.2	-0.1	-1.8
	\$200/mt	-0.2	-0.2	-0.2	-1.2	-0.1	0	0	-1.3	-0.3	-0.2	-3.6
Wheat	2010 base	0.7	3.9	6.5	29.0	1.5	0.4	0.7	21.4	10.7	2.8	77.5
	\$14/mt	0	0	0	-0.1	0	0	0	-0.1	0	0	-0.2
	\$100/mt	0	0	0	-0.4	0	0	0	-0.8	-0.2	0	-1.4
	\$200/mt	0	0	0	-0.7	0	0	0	-1.6	-0.5	0.1	-2.9
Soybeans	2010 base	1.1	8.4	36.1	8.4	5.0	2.9	8.2	0.3	0	0	70.3
	\$14/mt	0	0	0	0	0	0	0	0	0	0	-0.1
	\$100/mt	0	0	-0.1	-0.1	-0.1	0	-0.1	0	0	0	-0.4
	\$200/mt	0	-0.1	-0.2	-0.2	-0.1	-0.1	-0.2	0	0	0	-0.8
Hay	2010 base	7.8	10.5	11.4	10.9	6.3	1.1	0.8	1.2	9.3	3.2	62.5
	\$14/mt	0	0	0	0	0	0	0	0	-0.1	0	-0.2
	\$100/mt	-0.1	-0.1	-0.1	-0.3	0	0	0	-0.1	-0.3	0	-0.8
	\$200/mt	-0.2	-0.2	-0.1	-0.4	0	0	0	-0.1	-0.3	0	-1.3
10 major crops	2010 base	15.0	40.0	98.6	74.3	19.0	7.6	17.0	36.4	25.1	9.0	342.1
	\$14/mt	0	0	0	-0.2	0	0	0	-0.3	-0.1	0	-0.8
	\$100/mt	-0.2	-0.3	-0.3	-1.3	-0.1	-0.1	-0.1	-2.1	-0.7	-0.2	-5.4
	\$200/mt	-0.4	-0.7	-0.5	-2.5	-0.3	-0.1	-0.3	-4.4	-1.1	-0.4	-10.7
Tillage Types												
Conven- tional	2010 base	3.3	16.0	45.2	37.2	7.7	6.6	15.6	28.0	13.5	5.4	178.4
	\$14/mt	0	0	0	-0.2	0	0	0	-0.3	-0.1	0	-0.8
	\$100/mt	-0.1	-0.2	-0.1	-1.3	0	-0.1	-0.1	-2	-0.7	-0.2	-4.8
	\$200/mt	-0.2	-0.4	-0.2	-2.1	-0.1	-0.1	-0.3	-3.9	-1.0	-0.4	-8.8
Mold- board	2010 base	8.3	13.3	12.2	15.0	6.2	1.1	0.8	6.4	8.8	3.4	75.5
	\$14/mt	0	0	0	0.1	0	0	0	0	0	0	0
	\$100/mt	0	-0.1	0	0.3	0	0	0	-0.4	0.1	0	-0.1
	\$200/mt	0	-0.2	0	0.3	0	0	0	-1	0.1	0	-0.8
Mulch	2010 base	1.3	7.6	20.7	15.7	1.7	0	0	2.0	2.9	0.2	52.1
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	0	-0.1	-0.1	-0.1	-0.1	0	0	0.3	-0.1	0	-0.2
	\$200/mt	-0.1	-0.1	-0.2	-0.2	-0.1	0	0	0.5	-0.2	0	-0.5
No-Till	2010 base	2.1	3.0	20.5	5.0	3.5	0	0.7	0	0	0	34.7
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	0	0	0	-0.2	0	0	0	0	0	0	-0.3
	\$200/mt	-0.1	0.1	-0.1	-0.5	-0.1	0	0	0	0	0	-0.6
Ridge-Till	2010 base	0	0.1	0	1.4	0	0	0	0	0	0	1.5
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	0	0	0	0	0	0	0	0	0	0	0
	\$200/mt	0	0	0	0	0	0	0	0	0	0	0
All Tillage Types	2010 base	15.0	40.0	98.6	74.3	19.0	7.6	17.0	36.4	25.1	9.0	342.1
	\$14/mt	0	0	0	-0.2	0	0	0	-0.3	-0.1	0	-0.8
	\$100/mt	-0.2	-0.3	-0.3	-1.3	-0.1	-0.1	-0.1	-2.1	-0.7	-0.2	-5.4
	\$200/mt	-0.4	-0.7	-0.5	-2.5	-0.3	-0.1	-0.3	-4.4	-1.1	-0.4	-10.7

Table II.12: 2010 acreage planted and percent change under alternative carbon price scenarios

	Base/ %Change	North East	Lake States	Corn Belt	North Plains	Appa- lachia	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
Selected crops												
-- million acres/percent change --												
Feed- grains	2010 base	4.0	15.5	43.6	24.5	4.8	2.2	1.0	6.4	4.4	1.4	107.7
	\$14/mt	-0.2	-0.1	0	-0.3	-0.1	-0.1	-0.3	-0.9	-0.7	-0.8	-0.2
	\$100/mt	-1.9	-0.5	-0.2	-2.4	-1.1	-1.0	-2.0	-9.1	-4.3	-5.6	-1.7
	\$200/mt	-3.9	-1.1	-0.5	-4.8	-2.3	-2.2	-4.1	-19.6	-6.4	-11.2	-3.3
Wheat	2010 base	0.7	3.9	6.5	29.0	1.5	0.4	0.7	21.4	10.7	2.8	77.5
	\$14/mt	-0.1	-0.1	0	-0.2	-0.2	-0.1	0	-0.5	-0.1	0.1	-0.2
	\$100/mt	-0.9	-0.5	-0.3	-1.3	-1.1	-0.9	-0.2	-3.8	-2.0	0.8	-1.9
	\$200/mt	-1.6	-0.9	-0.5	-2.5	-2.2	-1.8	-0.3	-7.3	-5.0	1.8	-3.7
Soybeans	2010 base	1.1	8.4	36.1	8.4	5.0	2.9	8.2	0.3	0	0	70.3
	\$14/mt	-0.1	-0.1	0	-0.1	-0.1	-0.2	-0.2	-0.5	0	0	-0.1
	\$100/mt	-0.5	-0.4	-0.2	-1	-1	-1.2	-1.3	-3	0	0	-0.6
	\$200/mt	-1.1	-0.8	-0.4	-2	-2	-2.5	-2.5	-5.4	0	0	-1.1
Hay	2010 base	7.8	10.5	11.4	10.9	6.3	1.1	0.8	1.2	9.3	3.2	62.5
	\$14/mt	-0.1	-0.1	0	-0.4	0	0	0	-0.8	-0.9	0.1	-0.3
	\$100/mt	-1.0	-0.9	-0.4	-2.3	-0.1	-0.2	-0.2	-4.9	-3.0	0.3	-1.3
	\$200/mt	-2.2	-2.0	-1.0	-3.8	-0.3	-0.4	-0.4	-6.9	-3.3	0.5	-2.1
10 major Crops	2010 base	15	40	98.6	74.3	19	7.6	17	36.4	25.1	9	342.1
	\$14/mt	-0.1	-0.1	0	-0.3	-0.1	-0.1	-0.1	-0.7	-0.5	-0.3	-0.2
	\$100/mt	-1.2	-0.8	-0.3	-1.8	-0.7	-0.9	-0.9	-5.8	-2.7	-2.3	-1.6
	\$200/mt	-2.5	-1.7	-0.5	-3.4	-1.4	-1.8	-1.7	-12.1	-4.5	-4.5	-3.1
Tillage Types												
Conven- Tional	2010 base	3.3	16.0	45.2	37.2	7.7	6.6	15.6	28.0	13.5	5.4	178.4
	\$14/mt	-0.6	-0.2	0	-0.6	-0.1	-0.1	-0.1	-0.9	-1.1	-0.6	-0.4
	\$100/mt	-3.9	-1.4	-0.2	-3.5	-0.6	-1.0	-1.0	-7.0	-4.8	-4.0	-2.7
	\$200/mt	-7.1	-2.7	-0.4	-5.6	-1.3	-2.0	-1.9	-14.0	-7.4	-7.8	-4.9
Mold- board	2010 base	8.3	13.3	12.2	15.0	6.2	1.1	0.8	6.4	8.8	3.4	75.5
	\$14/mt	0.1	-0.1	0	0.4	0	0	0	-0.7	0.2	0	0.1
	\$100/mt	0.2	-0.5	0.1	1.9	0.2	-0.2	-0.4	-6.1	0.8	0.1	-0.1
	\$200/mt	-0.2	-1.3	0	1.8	0.4	-0.4	-0.8	-14.9	1.1	0.1	-1
Mulch	2010 base	1.3	7.6	20.7	15.7	1.7	0	0	2.0	2.9	0.2	52.1
	\$14/mt	-0.3	-0.1	-0.1	-0.1	-0.4	0	0	1.9	-0.2	0.4	0
	\$100/mt	-2.0	-0.9	-0.6	-0.7	-3.2	0	0	12.6	-3.5	3.3	-0.4
	\$200/mt	-3.9	-1.8	-1.2	-1.3	-6.4	0	0	23.6	-8.0	6.7	-0.9
No-Till	2010 base	2.1	3.0	20.5	5.0	3.5	0	0.7	0	0	0	34.7
	\$14/mt	-0.2	0.2	0	-0.5	-0.2	0	0	0	0	0	-0.1
	\$100/mt	-1.7	1.1	-0.2	-4.4	-1.3	0	0.5	0	0	0	-0.9
	\$200/mt	-3.3	2.3	-0.4	-9.4	-2.6	0	1.1	0	0	0	-1.8
Ridge-Till	2010 base	0	0.1	0	1.4	0	0	0	0	0	0	1.5
	\$14/mt	0	0.1	0	0	0	0	0	0	0	0	0
	\$100/mt	0	0.5	0	0.2	0	0	0	0	0	0	0.2
	\$200/mt	0	0.9	0	0.4	0	0	0	0	0	0	0.4
All Tillage Types	2010 base	15.0	40.0	98.6	74.3	19.0	7.6	17.0	36.4	25.1	9.0	342.1
	\$14/mt	-0.1	-0.1	0	-0.3	-0.1	-0.1	-0.1	-0.7	-0.5	-0.3	-0.2
	\$100/mt	-1.2	-0.8	-0.3	-1.8	-0.7	-0.9	-0.9	-5.8	-2.7	-2.3	-1.6
	\$200/mt	-2.5	-1.7	-0.5	-3.4	-1.4	-1.8	-1.7	-12.1	-4.5	-4.5	-3.1

Table II.11: 2010 income/expense: base and change under alternative carbon price scenarios

	Base/ Change	North East	Lake States	Corn Belt	North Plains	Appa- lachia	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
-- million dollars --												
Crops												
Value	2010 base	3,503	11,034	38,477	16,835	5,595	2,496	7,577	6,299	5,218	3,497	100,530
Of	\$14/mt	2	19	79	0	5	3	11	-17	-12	-6	84
Production	\$100/mt	7	118	527	6	32	18	83	-133	-40	-45	572
	\$200/mt	7	224	1,033	19	62	37	176	-322	-46	-92	1,098
Conserva- tion	2010 base	5	104	268	214	29	30	20	118	108	38	933
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
Reserve	\$100/mt	0	0	0	0	0	0	0	0	0	0	0
Payments	\$200/mt	0	0	0	0	0	0	0	0	0	0	0
Production	2010 base	92	357	1,029	857	152	83	411	642	227	160	4,010
Flexibility	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
Payments	\$100/mt	0	0	0	0	0	0	0	0	0	0	0
	\$200/mt	0	0	0	0	0	0	0	0	0	0	0
Total	2010 base	2,485	5,868	16,580	10,141	3,498	1,516	4,272	5,409	3,049	2,220	55,038
Variable	\$14/mt	8	36	127	52	19	9	29	2	-6	-4	274
Costs	\$100/mt	53	254	898	385	134	63	210	-67	21	-29	1,922
	\$200/mt	97	498	1,786	767	264	124	419	-247	97	-66	3,739
Net	2010 base	1,115	5,627	23,195	7,764	2,278	1,093	3,736	1,649	2,505	1,474	50,435
cash	\$14/mt	-6	-18	-48	-52	-14	-6	-18	-19	-6	-2	-190
Returns	\$100/mt	-46	-136	-371	-379	-102	-45	-127	-67	-61	-15	-1,350
	\$200/mt	-91	-275	-753	-749	-202	-86	-243	-75	-142	-26	-2,641
Livestock												
Value	2010 base	8,816	11,676	17,889	18,416	8,488	8,156	5,741	19,701	8,901	9,545	117,329
Of	\$14/mt	4	6	96	53	3	1	1	-111	84	56	193
Production	\$100/mt	24	40	435	395	13	5	4	-654	642	426	1,331
	\$200/mt	46	77	531	881	18	1	2	-727	998	792	2,619
Total	2010 base	5,163	7,882	15,398	18,306	6,293	5,082	3,558	17,370	8,035	6,464	93,550
Variable	\$14/mt	11	16	94	53	6	5	4	-74	68	43	228
Costs	\$100/mt	76	113	452	390	41	33	24	-427	518	328	1,545
	\$200/mt	147	221	598	844	72	57	41	-399	819	609	3,010
Net	2010 base	3,653	3,794	2,491	109	2,195	3,074	2,184	2,331	866	3,081	23,780
cash	\$14/mt	-7	-10	1	0	-4	-4	-3	-37	16	13	-36
Returns	\$100/mt	-51	-73	-17	6	-27	-28	-20	-227	125	98	-213
	\$200/mt	-102	-145	-68	38	-54	-56	-39	-328	179	183	-391
Crops and Livestock												
Value	2010 base	12,319	22,710	56,366	35,250	14,083	10,652	13,318	26,000	14,120	13,042	217,859
Of	\$14/mt	6	25	174	53	8	4	12	-128	73	50	277
Production	\$100/mt	31	158	962	401	46	23	87	-787	602	381	1,903
	\$200/mt	53	300	1,564	900	80	38	178	-1,048	952	700	3,717
Total	2010 base	7,648	13,750	31,977	28,447	9,790	6,598	7,830	22,778	11,084	8,685	148,587
Variable	\$14/mt	19	53	221	106	26	14	33	-72	62	40	502
Costs	\$100/mt	129	367	1,350	775	175	95	234	-494	539	298	3,466
	\$200/mt	245	720	2,385	1,611	335	181	460	-646	915	543	6,748
Net	2010 base	4,768	9,422	25,686	7,874	4,474	4,167	5,919	3,981	3,371	4,555	74,215
cash	\$14/mt	-13	-28	-47	-52	-18	-10	-21	-56	10	11	-225
Returns	\$100/mt	-97	-209	-388	-374	-129	-73	-147	-293	64	83	-1,563
	\$200/mt	-192	-419	-821	-711	-256	-142	-282	-402	37	157	-3,032

Table II.13: 2010 income/expense: base and percent change under alternative carbon price scenarios

	Base/ %Change	North East	Lake States	Corn Belt	North Plains	Appa- lachia	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
-- million dollars/percent change --												
Crops												
Value	2010 base	3,503	11,034	38,477	16,835	5,595	2,496	7,577	6,299	5,218	3,497	100,530
Of	\$14/mt	0.1	0.2	0.2	0	0.1	0.1	0.1	-0.3	-0.2	-0.2	0.1
Production	\$100/mt	0.2	1.1	1.4	0	0.6	0.7	1.1	-2.1	-0.8	-1.3	0.6
	\$200/mt	0.2	2	2.7	0.1	1.1	1.5	2.3	-5.1	-0.9	-2.6	1.1
Conserva- Tion	2010 base	5	104	268	214	29	30	20	118	108	38	933
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
Reserve	\$100/mt	0	0	0	0	0	0	0	0	0	0	0
Payments	\$200/mt	0	0	0	0	0	0	0	0	0	0	0
Production	2010 base	92	357	1,029	857	152	83	411	642	227	160	4,010
Flexibility	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
Payments	\$100/mt	0	0	0	0	0	0	0	0	0	0	0
	\$200/mt	0	0	0	0	0	0	0	0	0	0	0
Total	2010 base	2,485	5,868	16,580	10,141	3,498	1,516	4,272	5,409	3,049	2,220	55,038
Variable	\$14/mt	0.3	0.6	0.8	0.5	0.5	0.6	0.7	0	-0.2	-0.2	0.5
Costs	\$100/mt	2.1	4.3	5.4	3.8	3.8	4.1	4.9	-1.2	0.7	-1.3	3.5
	\$200/mt	3.9	8.5	10.8	7.6	7.5	8.1	9.8	-4.6	3.2	-3	6.8
Net	2010 base	1,115	5,627	23,195	7,764	2,278	1,093	3,736	1,649	2,505	1,474	50,435
cash	\$14/mt	-0.6	-0.3	-0.2	-0.7	-0.6	-0.6	-0.5	-1.2	-0.2	-0.1	-0.4
Returns	\$100/mt	-4.1	-2.4	-1.6	-4.9	-4.5	-4.1	-3.4	-4	-2.4	-1	-2.7
	\$200/mt	-8.1	-4.9	-3.2	-9.6	-8.9	-7.9	-6.5	-4.5	-5.7	-1.8	-5.2
Livestock												
Value	2010 base	8,816	11,676	17,889	18,416	8,488	8,156	5,741	19,701	8,901	9,545	117,329
Of	\$14/mt	0	0.1	0.5	0.3	0	0	0	-0.6	0.9	0.6	0.2
Production	\$100/mt	0.3	0.3	2.4	2.1	0.2	0.1	0.1	-3.3	7.2	4.5	1.1
	\$200/mt	0.5	0.7	3	4.8	0.2	0	0	-3.7	11.2	8.3	2.2
Total	2010 base	5,163	7,882	15,398	18,306	6,293	5,082	3,558	17,370	8,035	6,464	93,550
Variable	\$14/mt	0.2	0.2	0.6	0.3	0.1	0.1	0.1	-0.4	0.9	0.7	0.2
Costs	\$100/mt	1.5	1.4	2.9	2.1	0.6	0.6	0.7	-2.5	6.4	5.1	1.7
	\$200/mt	2.9	2.8	3.9	4.6	1.1	1.1	1.1	-2.3	10.2	9.4	3.2
Net	2010 base	3,653	3,794	2,491	109	2,195	3,074	2,184	2,331	866	3,081	23,780
cash	\$14/mt	-0.2	-0.3	0	-0.2	-0.2	-0.1	-0.1	-1.6	1.8	0.4	-0.1
Returns	\$100/mt	-1.4	-1.9	-0.7	5.1	-1.2	-0.9	-0.9	-9.7	14.4	3.2	-0.9
	\$200/mt	-2.8	-3.8	-2.7	34.3	-2.4	-1.8	-1.8	-14.1	20.7	5.9	-1.6
Crops and Livestock												
Value	2010 base	12,319	22,710	56,366	35,250	14,083	10,652	13,318	26,000	14,120	13,042	217,859
Of	\$14/mt	0	0.1	0.3	0.2	0.1	0	0.1	-0.5	0.5	0.4	0.1
Production	\$100/mt	0.3	0.7	1.7	1.1	0.3	0.2	0.7	-3	4.3	2.9	0.9
	\$200/mt	0.4	1.3	2.8	2.6	0.6	0.4	1.3	-4	6.7	5.4	1.7
Total	2010 base	7,648	13,750	31,977	28,447	9,790	6,598	7,830	22,778	11,084	8,685	148,587
Variable	\$14/mt	0.3	0.4	0.7	0.4	0.3	0.2	0.4	-0.3	0.6	0.5	0.3
Costs	\$100/mt	1.7	2.7	4.2	2.7	1.8	1.4	3	-2.2	4.9	3.4	2.3
	\$200/mt	3.2	5.2	7.5	5.7	3.4	2.7	5.9	-2.8	8.3	6.3	4.5
Net	2010 base	4,768	9,422	25,686	7,874	4,474	4,167	5,919	3,981	3,371	4,555	74,215
cash	\$14/mt	-0.3	-0.3	-0.2	-0.7	-0.4	-0.2	-0.4	-1.4	0.3	0.2	-0.3
Returns	\$100/mt	-2	-2.2	-1.5	-4.7	-2.9	-1.7	-2.5	-7.4	1.9	1.8	-2.1
	\$200/mt	-4	-4.5	-3.2	-9.0	-5.7	-3.4	-4.8	-10.1	1.1	3.5	-4.1

Table II.14: 2010 carbon embodied in crop and livestock production under alternative carbon price scenarios¹

		Carbon							
		Base	Carbon price scenario			Base	Carbon price scenario		
		2010	\$14/mt	\$100/mt	\$200/mt	2010	\$14/mt	\$100/mt	\$200/mt
		Crops				Crops & Livestock			
		-- million metric tons --				-- million metric tons --			
Fuel		11.0	10.9	10.4	9.9	19.4	19.2	18.3	17.6
	Change		-0.1	-0.6	-1.0		-0.2	-1	-1.8
	% change		-0.9	-5.3	-9.4		-0.9	-5.4	-9.3
Electricity		0.5	0.5	0.5	0.5	0.9	0.9	0.9	0.9
	Change		0	0	0		0	0	0
	% change		-0.5	0.5	2.1		0.1	2.3	5
Custom		1.4	1.3	1.1	1.0	1.4	1.3	1.1	1.0
	Change		0	-0.2	-0.4		0	-0.2	-0.4
	% change		-2.8	-16.5	-28.0		-2.8	-16.5	-28
Fertilizer		13.0	13	12.8	12.5	13.0	13.0	12.8	12.5
	Change		0	-0.2	-0.5		0	-0.2	-0.5
	% change		-0.2	-1.8	-3.5		-0.2	-1.8	-3.5
Chemicals		5.9	5.8	5.7	5.6	5.9	5.8	5.7	5.6
	Change		0	-0.1	-0.3		0	-0.1	-0.3
	% change		-0.3	-2.2	-4.3		-0.3	-2.2	-4.3
All Energy		31.7	31.5	30.5	29.6	40.5		40.2	38.9
	Change		-0.2	-1.2	-2.1		-0.3	-1.6	-2.8
	% change		-0.6	-3.7	-6.7		-0.6	-4.0	-7.0
		Livestock							
		-- million metric tons --							
Fuel		8.4	8.3	7.9	7.6				
	Change		-0.1	-0.4	-0.8				
	% change		-0.9	-5.4	-9.1				
Electricity		0.4	0.4	0.4	0.4				
	Change		0	0	0				
	% change		0.7	4.3	8.1				
All Energy		8.8	8.7	8.4	8.1				
	Change		-0.1	-0.4	-0.7				
	% change		-0.8	-4.9	-8.3				

¹ These estimates pertain to the 10 major field crops and major livestock enterprises included in the USMP model and cover most significant carbon use in agriculture. USMP does not model fruit, vegetable and other horticultural production which are energy intensive and use relatively more electricity than field crops. Horticultural electricity uses include irrigation, refrigeration and greenhouse operation.

Table II.15: 2010 crop production carbon use per acre under alternative carbon price scenarios

	Base/ Change	North East	Lake States	Corn Belt	North Plains	Appa- lachia	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
Selected crops --pounds per acre --												
Corn	2010 base	250.2	271.7	309.3	513.5	313.4	289.3	369.4	543.7	528.7	506.7	344.9
	\$14/mt	-0.4	-0.5	-0.4	-2.2	-0.5	-0.3	-0.3	-0.9	-1.7	-3.1	-0.9
	\$100/mt	-2.5	-2.6	-2.6	-10.7	-3	-1.8	-1.6	-4.3	-9	-17.9	-5
	\$200/mt	-4.2	-4.2	-4.2	-16.4	-5.3	-3	-2.5	-8.2	-13.8	-29.1	-8.2
Sorghum	2010 base	0	0	215.3	215.2	222.1	221.2	265.2	260.7	221.7	0	236.5
	\$14/mt	0	0	-0.3	-0.5	-0.3	-0.3	-0.3	-1.4	-0.9	0	-0.9
	\$100/mt	0	0	-1.5	-3.5	-1.9	-1.8	-1.7	-8.9	-6.1	0	-6.3
	\$200/mt	0	0	-2.4	-6.4	-3.1	-2.9	-2.6	-16.1	-7.3	0	-11.6
Barley	2010 base	144.9	105.8	0	124.5	141.6	0	0	216.3	186.5	154.7	151.9
	\$14/mt	-0.3	-0.2	0	-0.2	-0.3	0	0	-0.3	-1.9	-0.6	-1.1
	\$100/mt	-1.5	-1	0	-1	-1.5	0	0	-1.6	-8.6	-3.5	-4.9
	\$200/mt	-2.5	-1.7	0	-1.7	-2.5	0	0	-2.5	-13.3	-5.3	-7.6
Oats	2010 base	140.5	79.0	88.5	83.9	86.1	0	0	103.7	72.0	70.9	86.9
	\$14/mt	-0.2	-0.3	-0.3	-0.8	-0.3	0	0	-1	0	0	-0.5
	\$100/mt	-0.3	-1.5	-1.6	-4.8	-2	0	0	-5.9	0	0	-2.8
	\$200/mt	0.5	-2.3	-2.5	-7.4	-3.2	0	0	-7.6	0	0	-4.3
Wheat	2010 base	168.5	126.6	164.2	126.3	154.5	153.3	174.5	173.6	159.1	224.5	152.2
	\$14/mt	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.4	-0.5	-0.4	-1	-0.4
	\$100/mt	-0.9	-1	-1.1	-1.7	-1.8	-1.8	-2.2	-3.4	-2.3	-6.2	-2.4
	\$200/mt	-1.4	-1.7	-1.8	-2.9	-3	-2.9	-3.7	-6.3	-3.4	-10.4	-4.2
Rice	2010 base	0	0	815.5	0	0	0	819.8	855.5	0	774.1	811.7
	\$14/mt	0	0	-2.8	0	0	0	-2.6	-3.3	0	-6.5	-3.3
	\$100/mt	0	0	-15.9	0	0	0	-15.1	-18.9	0	-39.6	-19.2
	\$200/mt	0	0	-25.9	0	0	0	-24.6	-30.4	0	-68.8	-30.9
Soybeans	2010 base	133.4	133.1	133.9	117.0	171.5	164.1	156.1	125.4	0	0	138.2
	\$14/mt	-0.2	-0.2	-0.2	-0.3	-0.3	-0.2	-0.3	-0.7	0	0	-0.2
	\$100/mt	-1.3	-1.4	-1.3	-1.7	-1.8	-1	-1.5	-4.3	0	0	-1.5
	\$200/mt	-2.1	-2.3	-2.1	-2.8	-3.2	-1.7	-2.5	-7.3	0	0	-2.4
Cotton	2010 base	0	0	235.0	0	332.1	331	355.8	376.3	593.3	589.4	383.2
	\$14/mt	0	0	0	0	-0.2	-0.2	-0.3	-1.9	-3.3	-5	-1.6
	\$100/mt	0	0	0	0	-1.4	-1.2	-2.2	-17.4	-19.6	-31.1	-12.2
	\$200/mt	0	0	0	0	-2.4	-2.1	-3.8	-33.6	-32.6	-55	-22
Silage	2010 base	159.5	192	240.6	227.1	257.8	226	271.9	205.9	228.3	0	207.4
	\$14/mt	0	-0.1	0	0	0	0	0	0	0	0	0
	\$100/mt	0	-0.9	0	-0.1	0	0	0	0	0	0	-0.1
	\$200/mt	0	-1.7	-0.1	-0.3	0	0	0	0	0	0	-0.2
Hay	2010 base	68.2	105.0	130.2	80.2	66.4	52.2	52.2	168.8	59.6	74.0	88.1
	\$14/mt	-0.7	-0.6	-0.3	-2.3	-0.2	0	0	-1.8	-3.1	0	-1.1
	\$100/mt	-4.8	-4.4	-2.1	-10	-1.1	0	0	-11	-10.4	0	-5.2
	\$200/mt	-9.2	-8.5	-3.8	-13.5	-2.1	0	0	-14	-12.2	0	-7.8
All Crops	2010 base	132.6	172.2	211.3	205.9	180	206.3	301.6	236.4	151.9	249.7	204.1
	\$14/mt	-0.5	-0.4	-0.3	-1.1	-0.3	-0.2	-0.5	-1.2	-1.4	-2.5	-0.8
	\$100/mt	-3.5	-2.5	-1.9	-5.4	-2.1	-1.2	-3	-9.1	-6.3	-16	-4.4
	\$200/mt	-6.4	-4.4	-3.2	-8.7	-3.8	-1.9	-4.9	-17.6	-8.8	-28.7	-7.5

Table II.16:2010 major crop production carbon use by input under alternative carbon price scenarios

	Base/ Change	North East	Lake States	Corn Belt	North Plains	Appa- lachia	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
--pounds per acre --												
Diesel	2010 base	25.7	31.0	34.7	43.2	28.6	34.0	80.8	46.4	37.4	50.4	39.5
	\$14/mt	-0.3	-0.3	-0.3	-0.4	-0.2	-0.2	-0.5	-0.2	-0.6	-0.8	-0.3
	\$100/mt	-2.2	-1.7	-1.6	-2	-1.2	-1.1	-3.1	-0.5	-2.6	-4.9	-1.9
	\$200/mt	-4	-3.1	-2.8	-3.2	-2.1	-1.9	-5.3	-0.3	-4	-8.5	-3.1
Gasoline	2010 base	7.5	12.8	14.4	13.5	9.0	10.5	14.7	25.3	12.0	24.6	14.6
	\$14/mt	0	0	0.1	0	0	0.1	0.1	0.1	0	-0.2	0
	\$100/mt	-0.1	0.2	0.3	0.2	0.2	0.4	0.5	0.6	0.3	-1.5	0.2
	\$200/mt	-0.3	0.2	0.6	0.5	0.4	0.7	0.8	0.7	0.4	-2.9	0.3
Lp-Gas	2010 base	1.5	4.8	4.7	2.3	1.9	1.9	8.2	5.7	0.9	3.0	3.8
	\$14/mt	0	0	0	0	0	0	0.1	0	0	0	0
	\$100/mt	0	0.1	0.2	0.1	0.1	0.1	0.5	0.1	0	-0.1	0.1
	\$200/mt	-0.1	0.2	0.4	0.2	0.1	0.2	0.8	-0.1	0.1	-0.3	0.2
Natural Gas	2010 base	0	0.7	0.6	20.4	0	0	1.1	18.3	5.8	5.4	7.3
	\$14/mt	0	0	0	-0.4	0	0	0	-0.6	-0.1	-0.1	-0.2
	\$100/mt	0	-0.1	-0.1	-2	0	0	-0.1	-4.5	-0.5	-0.7	-1.1
	\$200/mt	0	-0.1	-0.1	-3.1	0	0	-0.2	-8.5	-0.8	-1.2	-1.8
Lube	2010 base	6.8	9.3	10.5	16.7	7.8	9.2	22.2	24.7	15.1	36.4	14.5
	\$14/mt	-0.1	-0.1	-0.1	-0.2	-0.1	-0.1	-0.3	-0.4	-0.4	-1	-0.2
	\$100/mt	-0.8	-0.9	-0.9	-1.3	-0.6	-0.6	-1.7	-2.3	-1.9	-5.9	-1.4
	\$200/mt	-1.4	-1.4	-1.4	-2.1	-1	-1.1	-2.8	-4.3	-2.8	-10.1	-2.4
Electricity	2010 base	0.1	1.9	2.0	5.2	0.8	1.4	6.1	3.4	3.4	3.7	3.0
	\$14/mt	0	0	0	0	0	0	0.1	0	-0.4	0	0
	\$100/mt	0	0.1	0.1	0.4	0.1	0.1	0.4	0	-1.3	0.2	0.1
	\$200/mt	0	0.1	0.2	0.7	0.2	0.2	0.7	-0.1	-1.4	0.2	0.2
Nitrogen	2010 base	39.7	53.9	75.3	56.8	58.7	58.2	59.6	79.9	39.3	47.8	62.3
	\$14/mt	0	0	0	0	0	0	0	-0.2	0.1	-0.2	0
	\$100/mt	-0.1	-0.1	0	-0.1	-0.2	0	0.1	-1.4	0.2	-1.3	-0.2
	\$200/mt	-0.2	-0.1	0	-0.4	-0.3	0.1	0.3	-2.5	0.1	-2.6	-0.5
Phosphate	2010 base	14.0	13.7	14.0	15.1	13.0	13.1	13.3	13.9	17.3	16.9	14.4
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	0	0	0	0	0	0	0	0.2	0.1	0.1	0
	\$200/mt	0	0	0	0.1	0	0	0	0.3	0.1	0.2	0.1
Potash	2010 base	13.0	9.4	9.1	3.3	13.1	13.4	3.7	1.0	7.6	7.4	7.1
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	0	0	0	0	0	0	0	0	0	0.2	0
	\$200/mt	0	0	0	0	-0.1	0	0	0.1	0.1	0.3	0.1
Chemical	2010 base	24.4	34.7	46.1	29.5	47	64.5	92.0	17.8	13.3	54.2	37.7
	\$14/mt	0	0	0	-0.1	-0.1	0	0	-0.1	-0.1	-0.3	0
	\$100/mt	-0.3	-0.1	0	-0.7	-0.4	0	0.3	-1.3	-0.6	-1.9	-0.2
	\$200/mt	-0.5	-0.1	0	-1.4	-0.9	0	0.7	-2.9	-0.6	-3.9	-0.5
Custom	2010 base	4.6	7.3	8.4	7.4	3.4	3.8	15.5	10.2	11.6	27.4	8.8
	\$14/mt	-0.1	-0.2	-0.2	-0.2	-0.1	-0.1	-0.4	-0.2	-0.3	-0.9	-0.2
	\$100/mt	-0.8	-1.1	-1.2	-1.1	-0.5	-0.6	-2.3	-1.4	-1.7	-5.6	-1.3
	\$200/mt	-1.4	-1.8	-2	-1.9	-0.9	-0.9	-3.9	-2.3	-2.9	-9.5	-2.3
Total Energy	2010 base	132.6	172.2	211.3	205.9	180.0	206.3	301.6	236.4	151.9	249.7	204.1
	\$14/mt	-0.5	-0.4	-0.3	-1.1	-0.3	-0.2	-0.5	-1.2	-1.4	-2.5	-0.8
	\$100/mt	-3.5	-2.5	-1.9	-5.4	-2.1	-1.2	-3	-9.1	-6.3	-16	-4.4
	\$200/mt	-6.4	-4.4	-3.2	-8.7	-3.8	-1.9	-4.9	-17.6	-8.8	-28.7	-7.5

Table II.17: 2010 corn production carbon use by input under alternative carbon price scenarios

	Base/ Change	North East	Lake States	Corn Belt	North Plains	Appa- lachia	South East	Delta States	South Plains	Moun- tain	Pacific	US Total
--pounds per acre --												
Diesel	2010 base	53.3	43.5	45.6	104	51.3	49.0	53.9	99.9	83.8	78.0	58.1
	\$14/mt	-0.4	-0.4	-0.4	-0.5	-0.3	-0.3	-0.3	0.2	-0.2	-0.9	-0.4
	\$100/mt	-2.4	-2.3	-2.2	-2.9	-1.9	-1.6	-1.8	2	-1.2	-5.4	-2.5
	\$200/mt	-4.1	-4	-3.7	-4.7	-3.1	-2.7	-3.1	2.2	-2.1	-9.2	-4.2
Gasoline	2010 base	15.4	17.9	18.8	27.7	16.5	15.8	17.9	28.4	13.7	18.3	20
	\$14/mt	0.1	0	0.1	0.2	0.1	0.1	0.1	-0.1	0.1	0.1	0.1
	\$100/mt	0.4	0.3	0.4	1	0.5	0.6	0.6	-1	0.8	0.5	0.4
	\$200/mt	0.7	0.5	0.7	1.8	1	1	1.1	-1	1.4	1	0.8
Lp-Gas	2010 base	2.9	7.0	6.5	8.7	4.5	4.6	4.8	9.7	7.7	8.6	6.7
	\$14/mt	0	0	0	0.1	0	0	0	0	0.1	0	0.1
	\$100/mt	0.2	0.3	0.3	0.6	0.2	0.2	0.3	-0.3	0.6	0.2	0.3
	\$200/mt	0.3	0.5	0.5	1.1	0.3	0.4	0.5	-0.1	1.1	0.4	0.6
Natural Gas	2010 base	0	0.9	0.9	91.8	0	0	0.2	101.7	121.7	61.1	20.5
	\$14/mt	0	0	0	-1.5	0	0	0	-1	-1.7	-1.5	-0.4
	\$100/mt	0	-0.1	-0.1	-7.8	0	0	0	-5.4	-9.4	-8.4	-2
	\$200/mt	0	-0.2	-0.2	-12.2	0	0	0	-9.2	-15	-13.5	-3.3
Lube	2010 base	14.2	13.1	13.7	48.9	14.1	13.5	14.9	52.6	49.3	60.8	21.3
	\$14/mt	-0.2	-0.2	-0.2	-0.6	-0.2	-0.2	-0.2	-0.6	-0.4	-1	-0.3
	\$100/mt	-1.1	-1.2	-1.2	-2.9	-1	-0.9	-1.1	-3.5	-2.6	-5.9	-1.7
	\$200/mt	-1.9	-1.9	-1.9	-4.7	-1.7	-1.5	-1.8	-5.4	-4.2	-9.6	-2.8
Electricity	2010 base	0.2	2.8	2.7	22.8	2.0	3.6	4.8	21.4	25.2	15.5	6.9
	\$14/mt	0	0	0	0.3	0	0	0	0.4	0.4	0.3	0.1
	\$100/mt	0	0.2	0.2	2	0.2	0.3	0.3	2.6	2.9	1.8	0.5
	\$200/mt	0.1	0.3	0.3	3.7	0.4	0.5	0.6	4.7	5.2	3.5	0.9
Nitrogen	2010 base	83.6	101.4	128.8	129.7	130.5	111.8	181.4	160.6	158.9	140.1	123.5
	\$14/mt	0.2	0.1	0	0.1	0	0	0	-0.1	0	0	0
	\$100/mt	1.6	0.6	0.1	0.3	-0.1	-0.3	0.2	-0.7	0.3	-0.3	0.2
	\$200/mt	3.1	1.2	0.1	0.4	-0.1	-0.7	0.4	-1.9	0.6	-0.7	0.3
Phosphate	2010 base	16.5	19.8	21.5	20.8	17.2	16.5	21	17.8	14.2	16.3	20.3
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	0	0	0	0	0	0.1	-0.1	0	0	0	0
	\$200/mt	0.1	0	0	0.1	0	0.1	-0.3	-0.1	-0.1	-0.1	0
Potash	2010 base	10.4	10.9	12.4	1.9	13.9	16.7	0	1.8	1.4	2.5	9.9
	\$14/mt	0	0	0	0	0	0	0	0	0	0	0
	\$100/mt	-0.2	-0.1	0	-0.2	-0.1	0	0	0.1	-0.1	0	0
	\$200/mt	-0.4	-0.1	0	-0.3	-0.3	0	0	0.2	-0.2	0	0
Chemical	2010 base	53.7	54.5	58.3	57.2	63.3	57.7	70.5	49.9	52.9	105.4	57.7
	\$14/mt	-0.1	0	0	-0.1	-0.1	0	0	0.3	0	-0.1	0
	\$100/mt	-1	-0.3	0	-0.8	-0.9	-0.1	0	2	-0.3	-0.5	-0.3
	\$200/mt	-2.1	-0.6	-0.1	-1.6	-1.8	-0.2	0.1	2.6	-0.5	-1	-0.6
Custom	2010 base	13.5	13.5	13.0	21.2	5.6	5.5	5.4	17.6	17.7	14.6	14.1
	\$14/mt	-0.4	-0.3	-0.3	-0.5	-0.1	-0.1	-0.1	-0.4	-0.5	-0.4	-0.3
	\$100/mt	-2.1	-2	-1.8	-3.1	-0.8	-0.8	-0.8	-2.4	-2.7	-2.2	-2.1
	\$200/mt	-3.6	-3.3	-3.1	-5.2	-1.4	-1.3	-1.3	-4.2	-4.5	-3.6	-3.5
Total Energy	2010 base	250.2	271.7	309.3	513.5	313.4	289.3	369.4	543.7	528.7	506.7	344.9
	\$14/mt	-0.4	-0.5	-0.4	-2.2	-0.5	-0.3	-0.3	-0.9	-1.7	-3.1	-0.9
	\$100/mt	-2.5	-2.6	-2.6	-10.7	-3.0	-1.8	-1.6	-4.3	-9.0	-17.9	-5.0
	\$200/mt	-4.2	-4.2	-4.2	-16.4	-5.3	-3	-2.5	-8.2	-13.8	-29.1	-8.2

Table II.18: Carbon embedded and energy expenses with carbon prices

Item	Carbon embodied in production				Energy expenses in production			
	Base	Carbon price scenario			Base	Carbon price scenario		
	2010	\$14/mt	\$100/mt	\$200/mt	2010	\$14/mt	\$100/mt	\$200/mt
-- Crops --		-- million mt --				-- million dollars --		
Fuel	11	10.9	10.4	9.9	5210.9	5328.6	6042.6	6823.9
Change		-0.1	-0.6	-1		117.7	831.8	1613.1
% Change		-0.9	-5.3	-9.4		2.3	16	31
Electricity	0.5	0.5	0.5	0.5	446.3	450.7	494.2	548.5
Change		0	0	0		4.4	47.9	102.2
% Change		-0.5	0.5	2.1		1	10.7	22.9
Custom	1.4	1.3	1.1	1	655.5	657	666	676.1
Change		0	-0.2	-0.4		1.5	10.6	20.6
% Change		-2.8	-16.5	-28		0.2	1.6	3.1
Fertilizer	13	13	12.8	12.5	12,275.3	12,429.5	13,357.8	14,402.1
Change		0	-0.2	-0.5		154.2	1082.5	2126.8
% Change		-0.2	-1.8	-3.5		1.3	8.8	17.3
Chemicals	5.9	5.8	5.7	5.6	8007.9	8065.7	8402.1	8784
Change		0	-0.1	-0.3		57.8	394.1	776.1
% Change		-0.3	-2.2	-4.3		0.7	4.9	9.7
Crops all energy	31.7	31.5	30.5	29.6	26,595.8	26,931.4	28,962.7	31,234.5
Change		-0.2	-1.2	-2.1		335.6	2366.9	4638.7
% Change		-0.6	-3.7	-6.7		1.3	8.9	17.4
-- Livestock --								
Fuel	8.4	8.3	7.9	7.6	4075.4	4161.6	4685	5287.7
Change		-0.1	-0.4	-0.8		86.2	609.5	1212.3
% Change		-0.9	-5.4	-9.1		2.1	15	29.7
Electricity	0.4	0.4	0.4	0.4	483.6	493.4	553.8	624.4
Change		0	0	0		9.9	70.2	140.9
% Change		0.7	4.3	8.1		2	14.5	29.1
Livestock all energy	8.8	8.7	8.4	8.1	4559	4655.1	5238.7	5912.1
Change		-0.1	-0.4	-0.7		96.1	679.7	1353.1
% Change		-0.8	-4.9	-8.3		2.1	14.9	29.7
--Crops and livestock--								
Fuel	19.4	19.2	18.3	17.6	9286.3	9490.2	10,727.6	12,111.6
Change		-0.2	-1	-1.8		203.9	1441.3	2825.3
% Change		-0.9	-5.4	-9.3		2.2	15.5	30.4
Electricity	0.9	0.9	0.9	0.9	929.8	944.1	1048	1172.9
Change		0	0	0		14.3	118.1	243.1
% Change		0.1	2.3	5		1.5	12.7	26.1
Custom	1.4	1.3	1.1	1	655.5	657	666	676.1
Change		0	-0.2	-0.4		1.5	10.6	20.6
% Change		-2.8	-16.5	-28		0.2	1.6	3.1
Fertilizer	13	13	12.8	12.5	12,275.3	12,429.5	13,357.8	14,402.1
Change		0	-0.2	-0.5		154.2	1082.5	2126.8
% Change		-0.2	-1.8	-3.5		1.3	8.8	17.3
Chemicals	5.9	5.8	5.7	5.6	8007.9	8065.7	8402.1	8784
Change		0	-0.1	-0.3		57.8	394.1	776.1
% Change		-0.3	-2.2	-4.3		0.7	4.9	9.7
All energy	40.5	40.2	38.9	37.6	31,154.8	31,586.5	34,201.5	37,146.7
Change		-0.3	-1.6	-2.8		431.6	3046.6	5991.8
% Change		-0.6	-4	-7		1.4	9.8	19.2

Table II.19: Social benefit measures under alternative carbon price scenarios

Measure		Base	Carbon price scenario		
		2010	\$14/mt	\$100/mt	\$200/mt
-- million dollars --					
Producer Surplus		1,096,957	1,096,704	1,095,136	1,093,405
	Change		-253	-1,821	-3,552
	% change		-0.02	-0.17	-0.32
Net farm cash		74,215	73,990	72,652	71,183
Returns ¹	Change		-225	-1,563	-3,032
	% change		-0.30	-2.11	-4.09
Consumer surplus		822,239	822,010	820,650	819,070
	Change		-229	-1,589	-3,169
	% change		-0.03	-0.19	-0.39
Consumer and producer		1,919,196	1,918,714	1,915,786	1,912,475
Surplus	Change		-482	-3,410	-6,721
	% change		-0.03	-0.18	-0.35
Revenue transfers out of agriculture sector ²		N/A	442	3,082	6,011
Net social benefit		1,919,196	1,919,156	1,918,868	1,918,486
	Change		-40	-328	-710
	% change		-0.00	-0.02	-0.04
Net foreign surplus		54,409	54,331	53,863	53,311
	Change		-78	-546	-1,097
	% change		-0.14	-1.00	-2.02

¹ Crop and live animal producers. Processing (food, feed and meat) not included.

² Revenues transferred out of agriculture sector based on carbon tax rate implied by carbon permit price.
Equal to tax revenues from imposition of a carbon tax.

Δ Net social benefit = Δ Consumer surplus + Δ Producer surplus + Tax revenue

Δ Net foreign surplus = Δ Export surplus + Δ Import surplus

Table II.20: Changes in erosion and water related nitrogen losses¹

Indicator			North East	Lake States	Corn Belt	North Plains	Appa- Lachia	South East	Delta States	South Plains	Moun- tain	Pacif ic	U.S. Total
			--- million tons---										
Soil	Base		48.9	224.3	471.7	307.1	102.2	47.0	85.3	285.2	326.4	89.5	1987.7
Erosion	\$14/mt	change	-0.06	-0.43	-0.16	-1.06	-0.14	-0.07	-0.13	-0.47	0.19	-0.02	-2.33
		% change	-0.12	-0.19	-0.03	-0.34	-0.14	-0.15	-0.15	-0.16	0.06	-0.03	-0.12
	\$100/mt	change	-0.45	-2.78	-1.24	-7.80	-0.97	-0.52	-0.81	0.20	-4.20	0	-18.57
		% change	-0.92	-1.24	-0.26	-2.54	-0.95	-1.10	-0.94	0.07	-1.29	0	-0.93
	\$200/mt	change	-0.91	-4.95	-2.57	-15.40	-2.01	-1.11	-1.69	-0.85	-13.01	0.11	-42.38
		% change	-1.86	-2.21	-0.54	-5.02	-1.97	-2.36	-1.98	-0.30	-3.99	0.13	-2.13
			--- million dollars---										
Nitrogen-	Base	million tons	0.23	0.36	1.96	1.10	0.46	0.17	0.47	-0.63	0.17	0.09	5.63
Loss to	\$14/mt	change	0	0	0	0	0	0	0	0	0	0	-0.01
Water		% change	-0.25	-0.20	-0.04	-0.34	-0.13	-0.16	-0.18	-0.68	-0.08	-1.10	-0.23
	\$100/mt	change	0	-0.01	-0.01	-0.03	0	0	-0.01	-0.03	0	-0.01	-0.09
		% change	-1.93	-1.47	-0.34	-2.34	-0.97	-1.14	-1.17	-4.18	-1.96	-7.55	-1.61
	\$200/mt	change	-0.01	-0.01	-0.01	-0.05	-0.01	0	-0.01	-0.06	-0.01	-0.01	-0.19
		% change	-3.90	-2.98	-0.72	-4.56	-2.00	-2.43	-2.47	-8.90	-4.64	-14.72	-3.30
			--- million dollars---										
Offsite	Base	mil. dollars	228.8	377.4	579.3	152.4	346.9	108.2	265.8	175.1	170.0	208.1	2612.0
Damages From Erosion	\$14/mt	change	-0.27	-0.57	-0.16	-0.39	-0.47	-0.17	-0.39	-0.62	-0.01	-0.16	-3.21
		% change	-0.12	-0.15	-0.03	-0.26	-0.14	-0.15	-0.15	-0.36	-0.01	-0.08	-0.12
	\$100/mt	change	-2.10	-4.02	-1.25	-2.39	-3.30	-1.19	-2.51	-3.42	-1.95	-0.77	-22.91
		% change	-0.92	-1.07	-0.22	-1.57	-0.95	-1.10	-0.94	-1.95	-1.15	-0.37	-0.88
	\$200/mt	change	-4.27	-7.39	-2.62	-4.60	-6.84	-2.55	-5.26	-8.68	-5.37	-1.28	-48.84
		% change	-1.87	-1.96	-0.45	-3.02	-1.97	-2.36	-1.98	-4.95	-3.16	-0.62	-1.87

¹ The environmental indicators reported in this table do not measure environmental quality, but rather changes in factors which influence environmental quality.

Table II.21: The Effects of Increasing Fossil Fuel Prices in Developed Regions on Per-Capita Utility, Income from Agricultural Land, Income from All Primary Factors in Agriculture, and Production of Goods and Services, by Region¹

Variable	Region							Rest of World
	United States	Canada	EC	Japan	OEA ²	SEA ³	ANZ ⁴	
	Percent change							
Per-Capita Utility ⁵	-0.005	-0.051	0.077	0.000	-0.019	-0.014	0.040	-0.005
Income								
Agricultural Land	-0.453	-0.540	-0.205	-0.143	-0.002	0.004	0.030	0.092
All Agricultural Factors	-0.494	-0.466	-0.224	-0.167	-0.008	0.014	-0.056	0.092
Goods and Services								
Wheat	-0.026	-0.219	0.027	0.109	-0.038	n/a	0.350	-0.002
Other Grains	0.009	-0.098	0.036	0.088	-0.026	-0.039	0.248	0.011
Non-Grains	0.057	-0.117	0.059	0.060	-0.021	-0.058	0.237	0.004
Livestock	0.014	0.057	0.004	0.026	-0.050	-0.102	0.256	-0.032
Fish-Meat-Milk	0.006	0.044	0.001	0.024	-0.062	-0.126	0.096	-0.035
Other Processed Foods	0.007	0.011	0.010	-0.002	-0.027	-0.091	-0.004	-0.029
Textiles-Clothing-								
Footwear	-0.083	0.337	0.082	0.034	-0.123	-0.347	0.416	-0.082
Forest Products	-0.550	-0.695	-0.152	0.039	0.115	0.153	-0.192	0.102
Coal-Oil-Gas	-0.342	-0.655	-1.465	0.214	0.193	0.104	-0.208	0.016
Other Minerals	0.117	0.239	0.008	0.003	0.026	-0.202	0.311	-0.051
Other Non-Metal								
Manufactures	-0.893	-0.812	-0.264	-0.040	0.638	0.757	-0.472	0.274
Other								
Manufactures	-0.247	0.407	0.070	-0.081	-0.312	-0.436	-0.112	-0.136
Services	0.063	0.065	0.042	0.018	-0.019	-0.030	0.016	-0.021

¹ Prices are increased by levying a 10 percent tax on coal-oil-gas consumed in the United States, Canada, European Community, Japan, and Australia/New Zealand. The tax is collected in the region where the coal-oil-gas is consumed.

² Other East Asia (China, including Taiwan; Hong Kong; and South Korea).

³ Southeast Asia (Thailand, Indonesia, Philippines, Malaysia, and Singapore).

⁴ Australia and New Zealand.

⁵ The population weighted change in per-capita utility for the world is -0.013 percent.

Table II.22: The Effects of Increasing Fossil Fuel Prices in All Regions on Per-Capita Utility, Income from Agricultural Land, Income from All Primary Factors in Agriculture, and Production of Goods and Services, by Region¹

Variable	Region							Rest of World
	United States	Canada	EC	Japan	OEA ²	SEA ³	ANZ ⁴	
	Percent change							
Per-Capita Utility ⁵	-0.005	0.046	0.001	0.007	-0.066	0.026	-0.039	0.003
Income								
Agricultural Land	-0.701	-0.844	-0.455	-0.210	-0.297	-0.391	-0.296	-0.517
All Agricultural Factors	-0.691	-0.649	-0.379	-0.213	-0.401	-0.403	-0.330	-0.628
Goods and Services								
Wheat	-0.153	-0.430	-0.091	0.111	0.290	n/a	0.370	0.086
Other Grains	-0.200	-0.391	-0.147	0.036	0.139	0.037	0.057	0.065
Non-Grains	-0.245	-0.496	-0.270	-0.052	0.165	0.059	-0.093	0.086
Livestock	-0.093	-0.134	-0.089	-0.053	0.170	0.093	-0.057	0.131
Fish-Meat-Milk	-0.065	-0.100	-0.071	-0.061	0.162	0.089	-0.121	0.131
Other Processed Foods	-0.055	-0.113	-0.065	-0.016	0.036	0.084	-0.094	0.101
Textiles-Clothing-Footwear	-0.302	0.113	-0.165	-0.055	0.087	0.100	0.190	0.134
Forest Products	-0.543	-0.368	-0.085	-0.012	0.107	-0.266	-0.239	-0.082
Coal-Oil-Gas	-0.011	0.051	-0.909	0.943	-1.520	0.973	0.653	-0.641
Other Minerals	-0.106	-0.406	-0.182	-0.010	-0.240	-0.322	-0.097	0.141
Other Non-Metal Manufactures	-0.684	-0.399	0.070	0.122	-0.057	-0.740	-0.215	-0.330
Other Manufactures	0.140	0.039	-0.045	-0.121	-0.145	-0.070	-0.152	0.151
Services	0.057	0.066	0.025	0.013	0.032	-0.032	0.009	0.080

¹ Prices are increased by levying a 10 percent tax on coal-oil-gas consumed in all regions. The tax is collected in the region where the coal-oil-gas is consumed.

² Other East Asia (China, including Taiwan; Hong Kong; and South Korea).

³ Southeast Asia (Thailand, Indonesia, Philippines, Malaysia, and Singapore).

⁴ Australia and New Zealand.

⁵ The population weighted change in per-capita utility for the world is -0.011 percent.

Table III.1: Potential Carbon Sequestration on U.S. Agricultural Lands**A. Selected Features of CRP Type Program to Sequester Carbon on Marginal Cropland and Pasture (from: Parks and Hardie, 1995)**

Objective:	---- Cropland and Pasture ----		----- Cropland -----	
	Minimize	Minimize	Minimize	Minimize
	<u>Cost per Acre</u>	<u>Cost per Ton C</u>	<u>Cost per Acre</u>	<u>Cost per Ton C</u>
Total land enrolled (million acres)	23.1	22.2	10.3	9.4
Annual Carbon Sequestered (million metric tons)	40.9	44.2	15.3	19.6
Annual cost (\$/acre)	19.75	20.54	44.29	48.53
Annual cost (\$/metric ton)	11.15	10.33	29.88	23.23

Length of Program: 10 years (assumes forests would then be highest value use)

Total Program Cost:\$3.7 billion total

Annual Program Cost: \$456.2 million

B. Estimated Changes in SOC and Fossil Fuel Use to the year 2020 for Select Changes in the Use of Minimum Tillage and No-Till systems in the United States (from: Kern and Johnson, 1993)

Tillage System	----- Scenario 1 -----				----- Scenario 2 -----				----- Scenario 3 -----			
	Mean	Min.	Max.	Fuel	Mean	Min.	Max.	Fuel	Mean	Min.	Max.	Fuel
	----- MMT C -----											
a. Conventional	-41	-31	-52	-121	-24	-18	-30	-87	-13	-9	-16	-67
b. Minimum	0	0	0	-30	0	0	0	-52	0	0	0	-66
c. No-till	0	0	0	-6	105	80	129	-10	377	286	468	-13
d. Totals	-41	-31	-52	-157	80	62	99	-149	364	277	452	-146
Net gain/loss	-198	-188	-209		-69	-87	-50		218	131	306	

Scenarios:

1. 27% of current cropland is in conservation tillage 27% (20% in minimum till and 7% in no-till)
2. Conservation tillage increases to 57% of all cropland (=> 60 million acres in conserv- tillage).
3. Conservation tillage increases to 76% of all cropland (=> 80 million acres in conserv- tillage).

Table IV.1: Relative Carbon Gain and Potential Policies Actions for Selected Management Practices

Management Practice	Relative Carbon Gain (per unit area)*	Possible Policy Actions**
Cultivated Land		
Adoption of reduced- or no-till	M	CS, E&TA, CC
Use of winter cover crops	L	CS, E&TA
Elimination of summer fallow	M	CS, E&TA
Use of forages in rotations	M	CS, E&TA
Use of improved varieties	M	CS, E&TA
Use of organic amendments	M	CS, E&TA
Irrigation	H	CS
Set-Aside Lands		
Establish perennial grasses	H	CS, LR,
Soil/water conservation measures	H	CS, E&TA, CC
Establish forest	H	CS, LR
Restore wetlands	H	CS
Pastureland		
Improved grazing methods	M	CS, E&TA
Fertilizer applications	M	CS, E&TA
Use of improved species/varieties	M	CS, E&TA
Irrigation	M	CS

Source: Except for restoring wetlands, assessments of relative carbon gain are from Bruce et al. (1998)

* H = high, M = medium, L = low

** CS = cost share (paying all or part of the costs of implementing the practice -- cost could be defined to include lost income)

CC= conservation compliance (requires land owner to participate in a market transition, commodity support, or other government program with economic benefits).

E&TA = education and technical support (requires that the practice be profitable)

LR = land retirement (providing payments, usually annual, for land to be put into specific uses).

TableA.1: Use of Energy Inputs in U.S. Agriculture; 1978 and 1990-94.

Year	Gasoline billion gallons	Diesel billion gallons	LP gas billion kWh	Electricity billion kWh	Nitrogen	Phosphate million pounds	Potash	Pesticide
1978*	3.6	3.2	1.3	47.6	10	5.1	5.5	0.29
1990	1.5	2.7	0.6	48.9	11.1	4.3	5.2	0.27
1991	1.4	2.8	0.6	47.9	11.3	4.2	5	0.27
1992	1.6	3.1	0.9	54.6	11.5	4.2	5	0.29
1993	1.4	3.3	0.7	55.6	11.4	4.4	5.1	0.28
1994	1.4	3.5	0.9	56.2	12.6	4.5	5.3	0.32

* 1976 pesticide value; 1980 electricity value.

Sources:

For electricity: estimated from farm expenditures data in ERS (1997; table 3.3.3, p.138) and electricity price data for industrial users in EIA (1996; table 8.11, p. 247).

For all other inputs see ERS (1997, table 3.1.1, p. 100; table 3.2.2, p.119; and table 3.3.1, p. 136).

Table A.2: Factors in U.S. farm demand for refined fuel, electricity, fertilizer, and pesticides

Item	1978	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Cropland											
million acres											
Cropland used for crops \1	na	331	327	341	341	337	337	330	339	332	346
Irrigated cropland \2	50.3	46.4	na	na	na	na	49.4	49.8	51.8	52	53.3
Farm Fuel Prices, U.S. Ave. \3											
dollars per gallon											
Gasoline	0.6	0.92	0.93	1.05	1.17	1.19	1.15	1.14	1.08	1.11	1.26
Diesel	0.46	0.71	0.73	0.76	0.95	0.87	0.82	0.82	0.77	0.77	0.92
LP gas	0.4	0.59	0.59	0.58	0.83	0.75	0.72	0.78	0.72	0.73	0.8
cents per Kwh.											
Electricity (Retail industrial rate) \4	2.8	4.8	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.7	4.6
Fertilizer \5											
dollars per ton											
Anhydrous ammonia (82%)	177	187	208	224	199	210	208	213	243	330	303
N solutions (30%)	118	109	137	142	132	138	141	137	137	169	182
Urea (45-46%)	169	161	183	212	184	212	198	202	207	266	278
Ammonium Nitrate (33%)	140	157	166	189	180	184	178	186	196	223	233
Ammonium Sulfate (21%)	109	144	140	154	154	151	151	157	170	182	184
Superphosphate (44-46%)	151	194	222	229	201	217	206	190	212	234	258
Potassium chloride (60% pot.)	96	115	157	163	155	156	150	146	146	155	153
Chemicals \6											
index (1990-92 = 100)											
Chemicals price indices						101	103	107	112	115	
Herbicides						101	102	106	110	113	
Insecticides						101	104	110	117	120	
Fungicides and others						101	105	111	109	117	

\1 USDA-ERS Ag. Resources and Environmental Indicators, 1996-97, Ag. HB 712 - Table 1.1.5 Major uses of cropland, U.S. 1986-96 , p6.; and Cropland Use in 1997, AREI update No. 5 Aug. 1997, Table 1.

\2 USDA-ERS Ag. Resources and Environmental Indicators, 1996-97, Ag. HB 712 -Table 2.1.3 Irrigated land in farms, by region and crop, selected years 1969-96, p.74.

\3 USDA-ERS Ag. Resources and Environmental Indicators, 1996-97, Ag. HB 712 - p. 137, Table 3.3.2 - Avg. U.S. farm fuel prices, 1974-95.

\4 Energy Info. Admn. Annual Energy Review - Table 8.11 Retail prices of Electricity Sold by Electricity Utilities, 1960-1996, p. 247.

\5 USDA-ERS Ag. Resources and Environmental Indicators, 1996-97, Ag. HB 712 - p.109, Table 3.1.8 - Average U.S. farm prices of selected fertilizers, 1960-96.

\6 USDA-ERS Ag. Resources and Environmental Indicators, 1996-97, Ag. HB 712 - p. 127, Table 3.2.6 Selected April pesticide prices, 1991- 1995.

Table A.3: Income statement and energy-related expenses for U.S. farm sector 1989-1998

Item	Unit	1989	1990	1991	1992	1993	1994	1995	1996	1997P	1998F	Ave.	St. Dev.
Cash income statement:													
1. Cash receipts	\$ Bil.	160.8	169.5	167.9	171.3	177.7	181.2	188.1	199.6	208.3	200.6	182.5	16.1
Crops 1/	\$ Bil.	76.9	80.3	82.1	85.7	87.5	93.1	101.0	106.6	111.7	105.8	93.1	12.4
Livestock	\$ Bil.	83.9	89.2	85.8	85.6	90.2	88.2	87.0	93.0	96.6	94.8	89.4	4.2
Livestock share	Pct.	52.2	52.6	51.1	50.0	50.8	48.6	46.3	46.6	46.4	47.3	49.2	2.5
2. Direct Government payments	\$ Bil.	10.9	9.3	8.2	9.2	13.4	7.9	7.3	7.3	7.5	7.4	8.8	2.0
3. Farm-related income 2/	\$ Bil.	8.6	8.2	8.2	8.2	9.0	9.2	10.1	10.9	11.8	11.5	9.6	1.4
4. Gross cash income (1+2+3)	\$ Bil.	180.3	187.0	184.3	188.7	200.1	198.3	205.4	217.8	227.6	219.5	200.9	16.4
Cash expenses 3/	\$ Bil.	127.5	134.2	134.0	133.6	141.2	147.6	153.6	161.4	166.9	166.2	146.6	14.7
Net cash income	\$ Bil.	52.8	52.8	50.3	55.1	58.9	50.7	51.8	56.4	60.7	53.4	54.3	3.5
Farm income statement:													
Total gross income 4/	\$ Bil.	192.0	198.2	191.9	200.5	203.7	215.8	210.1	235.8	237.9	230.0	211.6	17.6
Total expenses	\$ Bil.	146.7	153.4	153.3	152.9	160.5	167.4	174.0	182.3	188.0	187.4	166.6	15.5
Net farm income	\$ Bil.	45.3	44.8	38.6	47.6	43.2	48.3	36.1	53.5	49.9	42.5	45.0	5.2
Energy-related Expenses													
<u>Manufactured inputs</u>													
Fuels and oils	\$ Bil.	4.8	5.8	5.6	5.3	5.4	5.3	5.4	6.0	6.2	6.2	5.6	0.4
Electricity	\$ Bil.	2.6	2.6	2.6	2.6	2.7	2.7	3.0	3.2	3.0	2.9	2.8	0.2
Direct Energy Expenses	\$ Bil.	7.4	8.4	8.2	7.9	8.1	8.0	8.4	9.2	9.2	9.1	8.4	0.6
Share of Cash Expenses	Pct.	5.8	6.3	6.1	5.9	5.7	5.4	5.5	5.7	5.5	5.5	5.7	0.3
Share of Total Expenses	Pct.	5.0	5.5	5.3	5.2	5.0	4.8	4.8	5.0	4.9	4.9	5.0	0.2
Fertilizer & lime	\$ Bil.	8.2	8.2	8.7	8.3	8.4	9.2	10.0	10.9	10.9	11.0	9.4	1.2
Pesticides	\$ Bil.	5.0	5.4	6.3	6.5	6.7	7.2	7.7	8.5	8.8	8.8	7.1	1.4
Chemical Expenses	\$ Bil.	13.2	13.6	15.0	14.8	15.1	16.4	17.7	19.4	19.7	19.8	16.5	2.5
Share of Cash Expenses	Pct.	10.4	10.1	11.2	11.1	10.7	11.1	11.5	12.0	11.8	11.9	11.2	0.6
Share of Total Expenses	Pct.	9.0	8.9	9.8	9.7	9.4	9.8	10.2	10.6	10.5	10.6	9.8	0.6
Total Manufactured Inputs	\$ Bil.	20.6	22.0	23.2	22.7	23.1	24.4	26.2	28.7	29.0	28.9	24.9	3.1
Share of Cash Expenses	Pct.	16.2	16.4	17.3	17.0	16.4	16.5	17.1	17.8	17.4	17.4	16.9	0.5
Share of Total Expenses	Pct.	14.0	14.3	15.1	14.8	14.4	14.6	15.1	15.7	15.4	15.4	14.9	0.6
<u>Other expenses</u>													
Machine hire & custom work	\$ Bil.	3.4	3.6	3.5	3.8	4.4	4.8	4.8	4.7	4.9	4.9	4.3	0.6
Marketing, storage, & transport.	\$ Bil.	4.2	4.2	4.7	4.5	5.6	6.8	7.2	6.8	7.0	7.1	5.8	1.3
Total Other expenses	\$ Bil.	7.6	7.8	8.2	8.3	10.0	11.6	12.0	11.5	11.9	12.0	10.1	1.9
Share of Cash Expenses	Pct.	6.0	5.8	6.1	6.2	7.1	7.9	7.8	7.1	7.1	7.2	6.8	0.8
Share of Total Expenses	Pct.	5.2	5.1	5.3	5.4	6.2	6.9	6.9	6.3	6.3	6.4	6.0	0.7
Total Energy Related Expenses		28.2	29.8	31.4	31.0	33.2	36.0	38.1	40.1	40.8	40.9	35.0	4.8
Share of Cash Expenses	Pct.	22.1	22.2	23.4	23.2	23.5	24.4	24.8	24.9	24.5	24.6	23.8	1.0
Share of Total Expenses	Pct.	19.2	19.4	20.5	20.3	20.7	21.5	21.9	22.0	21.7	21.8	20.9	1.0

P = preliminary. F = forecast.

1/ Includes commodities placed under CCC loans and profits made on loans redeemed.

2/ Income from custom work, machine hire, recreational activities, forest product sales, and other farm sources

3/ Cash expenses exclude capital consumption, perquisites to hired labor, and farm household expenses from total expenses.

4/ Total gross income includes gross cash income, nonmoney income, and value of inventory change.

Source: Adapted from Tables 29 and 34 Agricultural Outlook USDA-ERS March 1998 for 1989-1993, and ERS website July 1998 update for 1994-1998.

Table A.4: Cash Expenses that Include Energy for U.S. Field and Horticultural Crops, 1996

Commodity	Region	Direct Energy		Chemicals		Other Inputs ¹²		Dir., Chem., Oth.		T. Cash Expns. ¹¹	Revenue \$/plt.ac.	Expense /Revenue Percent
		\$/plt.ac.	Percent	\$/plt.ac.	Percent	\$/plt.ac.	Percent	\$/plt.ac.	Percent			
			of total		of total		of total		of total			
Corn	United States	21.14	12.9	82.95	50.7	9.76	6.0	113.85	69.5	163.77	388.73	42.1
	Northeast	13.07	8.9	75.34	51.2	9.03	6.1	97.44	66.2	147.27	252.73	58.3
	Southeast	15.38	8.7	97.86	55.6	4.23	2.4	117.47	66.7	176.07	385.29	45.7
	North Central	13.98	9.2	83.15	54.4	9.1	6.0	106.23	69.5	152.74	370.55	41.2
	Plains States	42.67	22.1	80.53	41.6	12.67	6.6	135.87	70.3	193.4	453.78	42.6
Wheat	United States	9.71	13.9	27.34	39.1	5.35	7.6	42.40	60.6	70.01	146.94	47.6
	North Central	5.77	6.8	46.26	54.5	4.04	4.8	56.07	66.0	84.95	141.90	59.9
	Southeast	6.51	6.9	45.63	48.6	7.35	7.8	59.49	63.3	93.97	219.66	42.8
	Northern Plains	7.12	12.0	23.9	40.4	2.72	4.6	33.74	57.0	59.18	143.56	41.2
	Gen. & So. Plains	10.95	17.5	19.78	31.6	7.79	12.4	38.52	61.5	62.59	105.09	59.6
	Pacific	22.34	17.0	50.74	38.7	7.9	6.0	80.98	61.7	131.25	332.18	39.5
Soybeans	United States	9.45	11.8	35.4	44.3	3.65	4.6	48.50	60.6	80	256.36	31.2
	North Central	8.22	10.5	35.88	45.7	4.04	5.1	48.14	61.3	78.54	265.55	29.6
	Northern Plains	12.51	18.2	23.61	34.3	2.41	3.5	38.53	55.9	68.87	254.69	27.0
	Southeast	10.55	10.7	50.35	50.9	2.38	2.4	63.28	64.0	98.88	214.76	46.0
	Delta	14.06	16.3	30.49	35.3	3.88	4.5	48.43	56.1	86.37	232.47	37.2
Cotton	United States	35.67	11.9	97.51	32.6	71.76	24.0	204.94	68.6	298.78	383.84	77.8
	Southeast	24.76	8.0	138.97	45.1	74.86	24.3	238.59	77.4	308.16	536.61	57.4
	Delta	30.17	8.2	145.47	39.6	88.15	24.0	263.79	71.8	367.16	566.19	64.8
	Southern Plains	39.33	18.4	50.1	23.4	41.12	19.2	130.55	61.0	214.04	189.19	113.1
	Southwest	48.98	8.3	139.38	23.5	168.42	28.4	356.78	60.1	593.2	634.70	93.5
Rice	United States	73.03	19.7	123.96	33.4	75.71	20.4	272.70	73.4	371.61	592.70	62.7
	Ark. Non-Delta	77.04	22.8	116.83	34.6	61.72	18.3	255.59	75.7	337.58	630.01	53.6
	Miss. River Delta	77.36	24.3	116.44	36.6	46.97	14.8	240.77	75.7	318.2	588.32	54.1
	Gulf Coast	69.03	18.7	120.87	32.7	70.39	19.0	260.29	70.4	369.79	543.08	68.1
	California	65.96	13.1	150.81	30.0	144.81	28.8	361.58	71.8	503.27	744.96	67.6
Sorghum	United States	17.95	21.9	30.27	37.0	5.26	6.4	53.48	65.3	81.85	170.91	47.9
	Central Plains	12.31	16.3	32.72	43.2	4.69	6.2	49.72	65.7	75.72	193.37	39.2
	Southern Plains	25.24	28.1	27.11	30.2	5.99	6.7	58.34	65.0	89.76	141.80	63.3
Oats	United States	7.41	14.2	18.87	36.2	4.33	8.3	30.61	58.7	52.17	128.26	40.7
	Northeast	12.38	15.1	33.26	40.7	4.91	6.0	50.55	61.8	81.77	125.37	65.2
	North Central	4.19	8.2	21.38	42.0	5.75	11.3	31.32	61.6	50.85	119.06	42.7
	Northern Plains	9.78	22.2	12.55	28.5	2.42	5.5	24.75	56.2	44.06	115.37	38.2
Peanuts	United States	40.31	11.6	143.83	41.6	25.73	7.4	209.87	60.6	346.1	635.14	54.5
	VA - NC	40.05	9.8	195.14	47.8	10	2.4	245.19	60.0	408.38	832.06	49.1
	Southeast	29.7	8.2	170.14	47.0	27.13	7.5	226.97	62.6	362.3	680.56	53.2
	Southern Plains	61.09	21.7	64.93	23.1	31.5	11.2	157.52	56.1	280.97	481.58	58.3
Sugar Beets	United States	41.64	9.6	144.8	33.3	42.15	9.7	228.59	52.5	435.18	746.61	58.3
	Great Lakes	22.77	7.7	131.49	44.2	28.35	9.5	182.61	61.4	297.2	439.68	67.6
	Red River Valley	21.87	6.7	112.8	34.7	24.88	7.6	159.55	49.0	325.43	698.52	46.6
	Great Plains	53.53	11.1	167.75	34.8	38.86	8.1	260.14	54.0	481.49	692.29	69.6
	Northwest	95.71	14.0	208.57	30.4	49.18	7.2	353.46	51.6	685.53	1017.37	67.4
	Southwest	65.27	8.1	197.3	24.4	195.95	24.3	458.52	56.8	807.69	1246.62	64.8
Sugarcane	United States	29.80	4.3	135.26	19.6	70.30	10.2	235.36	34.1	690.16	979.40	70.5
	Florida	23.79	3.1	119.15	15.7	104.81	13.8	247.74	32.6	760.95	1040.40	73.1
	Hawaii	93.51	3.7	450.15	17.8	62.57	2.5	606.23	24.0	2526.63	2645.37	95.5
	La/Texas	29.73	7.2	119.48	29.1	31.89	7.8	181.09	44.1	410.67	727.00	56.5
		\$ mil.	percent	\$ mil.	percent	\$ mil.	percent	\$ mil.	percent	\$ mil.	\$ mil.	percent
Horticultural	United States	2386	9.8	2275	9.4	2874	11.8	7535.31	31.0	24308	38497	63.1

¹¹ Total cash expenses for commodities include cash expenses as reported in ERS Cost of Production tables.

¹² Other expenses that embody energy include custom costs for all commodities, cotton ginning, rice and peanut drying, and marketing, storage, and transport costs for horticultural products.

¹³ Expenses including energy as a proportion of cash expenses.

¹⁴ Revenue per acre is yield times price. Revenue for horticultural farms is gross cash income, of which \$38540.9 mil. (95 percent) is generated by vegetable, fruit, greenhouse, and nursery sales.

Sources: USDA-ERS webpage, <http://www.econ.ag.gov/briefing/fbe/car/car.htm>, and USDA-ERS-RED-FSP.

Table A.5: Cash Expenses that Include Energy for U.S. Livestock Enterprises (1996) and Broiler Farms (1995)

Enterprise	Region	Fuel, Lub., & Elec.		Marketing & Hauling		Custom Serv. & Sup.		Energy ¹² Share of Total	Animal Feed		Total Cash Expenses	Revenue
		Expense	Share of Total	Expense	Share of Total	Expense	Share of Total		Expense	Share of Total		
		\$ per cwt. milk	percent	\$ per cwt. milk	percent	\$ per cwt. milk	percent	percent	\$ per cwt. milk	percent	\$ per cwt. milk	\$ per cwt. milk
Dairy	United States	0.53	4.6	0.80	7.0	0.42	3.7	15.2	7.53	65.5	11.49	14.78
	Northeast	0.7	5.6	1.13	9.0	0.54	4.3	18.9	7.46	59.6	12.51	15.19
	Southeast	0.34	2.6	1.49	11.2	0.65	4.9	18.7	8.12	61.2	13.27	17.41
	Upper Midwest	0.62	5.5	0.50	4.5	0.34	3.0	13.0	7.17	64.1	11.19	14.74
	Corn Belt	0.58	4.7	0.74	5.9	0.38	3.0	13.6	8.35	67.0	12.47	14.88
	Southern Plains	0.49	4.0	0.85	6.9	0.31	2.5	13.4	9.09	74.1	12.27	15.10
	Pacific	0.28	2.8	0.83	8.2	0.40	4.0	15.0	7.25	71.9	10.08	13.89
		\$ per bred cow	percent	\$ per bred cow	percent	\$ per bred cow	percent	percent	\$ per bred cow	percent	\$ per bred cow	\$ per bred cow
Cow-calf	United States	23	6.7	8.34	2.4	0.00	0.0	9.2	212.17	62.2	341.28	287.42
	North Central	28.2	10.0	5.28	1.9	0.00	0.0	11.9	157.99	56.1	281.41	281.43
	South	22.76	8.2	10.97	4.0	0.00	0.0	12.2	140.66	50.9	276.23	216.17
	Great Plains	24.95	6.8	7.45	2.0	0.00	0.0	8.9	232.23	63.6	365.30	319.70
	West	17.54	4.5	8.93	2.3	0.00	0.0	6.9	266.69	69.1	386.12	298.98
		\$ per cwt. gain	percent	\$ per cwt. gain	percent	\$ per cwt. gain	percent	percent	\$ per cwt. gain	percent	\$ per cwt. gain	\$ per cwt. gain
Hogs	United States	1.83	3.8	0.59	1.2	0.51	1.1	6.1	35.48	74.1	47.86	60.16
	North	1.84	3.8	0.56	1.2	0.47	1.0	6.0	35.62	74.3	47.97	59.58
	South	1.78	3.7	0.70	1.5	0.64	1.3	6.6	34.98	73.6	47.50	62.12
		\$ per farm ¹⁴	percent	\$ per farm ¹⁵	percent	\$ per farm	percent	percent	\$ per farm ¹⁶	percent	\$ per farm	\$ per farm
Broiler Farms ¹³	Appalachia	9871	22.3	na	na	1450	3.3	25.6	na	na	44225	78543
	Southeast	17731	28.1	na	na	3213	5.1	33.2	na	na	63055	93076
	Delta	11024	26.0	na	na	2694	6.4	32.4	na	na	42325	77041
	Other regions	8515	13.5	na	na	917	1.5	15.0	na	na	63027	95165
	United States, with gross cash income ≥ \$50,000	12529	23.4	na	na	2713	5.1	28.5	na	na	53446	84048

¹¹ Total cash expenses for enterprises include cash expenses as reported in ERS Cost of Production tables for 1996.

¹² Energy-related expenses as a proportion of cash expenses.

¹³ Broiler farm revenues are 1995 gross cash income, including other livestock and crop-related income.

Broilers comprise 74 percent of Appalachia gross cash income, 76 percent of Southeast, 89 percent of Delta, and 77 percent of U.S. farms with income over \$50,000.

¹⁴ Broiler farm fuel, lub. and electricity includes telephone expenses.

¹⁵ Marketing and hauling is included as "Other variable expenses", defined as "Supply, transportation, storage, and general business expenses, and registration fees."

For the U.S. farms, "Other variable cost" is \$2483 about 20 percent of fuel, lube, and electricity.

¹⁶ Sufficient detail not available for feed cost presentation.

Sources: USDA-ERS webpage, <http://www.econ.ag.gov/briefing/fbe/car/car.htm>, and

Perry, Janet, David Banker, Robert Green, "Organization, Management, and Performance of Broiler Farms". USDA, ERS, cleared manuscript, July 13, 1998.

Table A.5: Cash Expenses that Include Energy for U.S. Livestock Enterprises (1996) and Broiler Farms (1995)

Enterprise	Region	Fuel, Lub., & Elec.		Marketing & Hauling		Custom Serv. & Sup.		Energy ^{\2}	Animal Feed		Total Cash Expenses	Revenue
		Expense	Share of Total	Expense	Share of Total	Expense	Share of Total		Expense	Share of Total		
		\$ per cwt. milk	percent	\$ per cwt. milk	percent	\$ per cwt. milk	percent	percent	\$ per cwt. milk	percent	\$ per cwt. milk	\$ per cwt. milk
Dairy	United States	0.53	4.6	0.80	7.0	0.42	3.7	15.2	7.53	65.5	11.49	14.78
	Northeast	0.7	5.6	1.13	9.0	0.54	4.3	18.9	7.46	59.6	12.51	15.19
	Southeast	0.34	2.6	1.49	11.2	0.65	4.9	18.7	8.12	61.2	13.27	17.41
	Upper Midwest	0.62	5.5	0.50	4.5	0.34	3.0	13.0	7.17	64.1	11.19	14.74
	Corn Belt	0.58	4.7	0.74	5.9	0.38	3.0	13.6	8.35	67.0	12.47	14.88
	Southern Plains	0.49	4.0	0.85	6.9	0.31	2.5	13.4	9.09	74.1	12.27	15.10
	Pacific	0.28	2.8	0.83	8.2	0.40	4.0	15.0	7.25	71.9	10.08	13.89
		\$ per bred cow	percent	\$ per bred cow	percent	\$ per bred cow	percent	percent	\$ per bred cow	percent	\$ per bred cow	\$ per bred cow
Cow-calf	United States	23	6.7	8.34	2.4	0.00	0.0	9.2	212.17	62.2	341.28	287.42
	North Central	28.2	10.0	5.28	1.9	0.00	0.0	11.9	157.99	56.1	281.41	281.43
	South	22.76	8.2	10.97	4.0	0.00	0.0	12.2	140.66	50.9	276.23	216.17
	Great Plains	24.95	6.8	7.45	2.0	0.00	0.0	8.9	232.23	63.6	365.30	319.70
	West	17.54	4.5	8.93	2.3	0.00	0.0	6.9	266.69	69.1	386.12	298.98
		\$ per cwt. gain	percent	\$ per cwt. gain	percent	\$ per cwt. gain	percent	percent	\$ per cwt. gain	percent	\$ per cwt. gain	\$ per cwt. gain
Hogs	United States	1.83	3.8	0.59	1.2	0.51	1.1	6.1	35.48	74.1	47.86	60.16
	North	1.84	3.8	0.56	1.2	0.47	1.0	6.0	35.62	74.3	47.97	59.58
	South	1.78	3.7	0.70	1.5	0.64	1.3	6.6	34.98	73.6	47.50	62.12
		\$ per farm ^{\4}	percent	\$ per farm ^{\5}	percent	\$ per farm	percent	percent	\$ per farm ^{\6}	percent	\$ per farm	\$ per farm
Broiler Farms ^{\3}	Appalachia	9871	22.3	na	na	1450	3.3	25.6	na	na	44225	78543
	Southeast	17731	28.1	na	na	3213	5.1	33.2	na	na	63055	93076
	Delta	11024	26.0	na	na	2694	6.4	32.4	na	na	42325	77041
	Other regions	8515	13.5	na	na	917	1.5	15.0	na	na	63027	95165
	United States, with gross cash income $\geq$ \$50,000	12529	23.4	na	na	2713	5.1	28.5	na	na	53446	84048

^{\1} Total cash expenses for enterprises include cash expenses as reported in ERS Cost of Production tables for 1996.

^{\2} Energy-related expenses as a proportion of cash expenses.

^{\3} Broiler farm revenues are 1995 gross cash income, including other livestock and crop-related income.

Broilers comprise 74 percent of Appalachia gross cash income, 76 percent of Southeast, 89 percent of Delta, and 77 percent of U.S. farms with income over \$50,000.

^{\4} Broiler farm fuel, lub. and electricity includes telephone expenses.

^{\5} Marketing and hauling is included as "Other variable expenses", defined as "Supply, transportation, storage, and general business expenses, and registration fees."

For the U.S. farms, "Other variable cost" is \$2483 about 20 percent of fuel, lube. and electricity.

^{\6} Sufficient detail not available for feed cost presentation.

Sources: USDA-ERS webpage, <http://www.econ.ag.gov/briefing/fbe/car/car.htm>, and

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Appendix I. Energy Use in Agriculture

Agricultural energy uses comprise on-farm direct uses of fuels and electricity to operate vehicles, machinery, irrigation, and drying systems; indirect uses of energy in manufactured fertilizers and pesticides; and uses of energy in hired or purchased services. Energy is included in smaller proportion in other expenses including commodity transportation, hired custom and machine work, and purchased feed. Agricultural fossil fuel use peaked in 1978, declining in response to the oil price shocks of the 1970s and early 1980s (TableA.1). By 1993, fossil energy use declined by 25 percent, but electricity use increased by about 17 percent (ERS, 1997).

Major factors in agricultural use of refined petroleum products and electricity use are planted acreage and irrigated acreage (ERS, 1997; and Uri and Gill;). Irrigated land in farms increased from 46.4 to 53.3 million acres between 1987 and 1996 (TableA.2). Planted acres in 1990-96 averaged 337 million acres with a low of 330 million acres in 1993 and a high of 346 million acres in 1996. More energy efficient diesel machinery and reduced tillage systems have allowed diesel use to be maintained at about 1978 levels while reducing gasoline use by over half. Estimated electricity use increases are consistent with increased irrigated acres. Uses of nitrogen fertilizer, the most energy intensive nutrient, increased by about 10 percent, phosphorous declined by a similar amount. Potash and pesticide use levels show little change until 1994, with pesticides increasing by 14 percent in one year.

U.S. Farm Sector Income and Energy Expenses

U.S. agriculture commodity cash receipts are about \$203 billion (1996 through the 1998¹⁶),

¹⁶Values for 1998 are USDA-ERS forecasts.

about 53 percent from crops and 47 from livestock (Table A.3). The crop proportion is slightly higher than the 51 percent share from 1989 through 1998. Energy related expenses are about \$40-41 billion per year (1996 through 1998). The energy-related share of the U.S. farm sector cash expenses averaged about 24 percent from 1989 through 1998, showing a slight increase since 1994. This increase is consistent with the increases in planted and irrigated crop land.

Manufactured inputs include fuels, oils, and fertilizers and other agricultural chemicals. Annual manufactured input expenses are around \$29 billion (1996 through 1998). Manufactured inputs accounted for about 17 percent of U.S. farm cash expenses from 1989 through 1998, and with a slight increase since 1994. This increase is driven by rising expenditures for fertilizer and pesticides. The direct energy share of cash expenses has declined slightly since 1994 to about 5.5 percent. Expenditures for other energy intensive inputs have averaged about \$12 billion per year since 1994. This category includes "machine hire and custom operations" and "marketing, storage, and transportation."

Adjustments can be expected in input usage with long-run shifts in relative prices and changes in technology. Machine hire and custom work can substitute for farm owned and operated machinery and its attendant direct energy expenditures. Past and future shifts in custom expenditures could be associated with greater efficiency in the use of machinery, labor, and energy. The shift to reduced tillage has reduced direct energy expenditures and increased pesticide expenditures. The extent of irrigated acres and quantity of irrigation water applied is related to costs of pumping and the returns to irrigation, and over time efficiency gains have occurred with irrigation (ERS, 1997).

Crop Enterprises

Expenditures for direct energy, chemicals, and on other energy intensive inputs range between about 30 and 75 percent of total crop cash expenses (TableA.4). As a share of total cash expenditures, this sum is quite stable across each crop's reporting regions. Of three input groups, chemical expenditures show the least variation in expenditure shares, followed by direct energy. Corn and wheat are cases in point, with significant variation in direct energy and chemical expenditures, but with little variation in the energy-intensive share of total expenditures.

Irrigation accounts for higher magnitude expenses and revenues for Plains States corn and Pacific wheat, but the energy share of total cash expenses is similar to other regions. Revenues can be affected by both yields and regional price variation. The regional variation in direct energy and chemical expenditures and shares of total cash expenses reflect the differences in production techniques and possibilities across the country. Further, the data presented are regional averages--considerable variation would be expected within regions, driven by land quality, farm type, land tenure and other factors. The regional stability of the share of direct, chemical, and other energy including expenses of total cash expenses for each crop, is hypothesized to reflect competitive profit maximizing relationships among commodity and input prices and land productivity.

The complexity and the difficulty in using cost of production budgets and returns alone to predict the effects of energy price increases on regional crop production is illustrated by corn, wheat, and soybean production in the Southeast. The high Southeastern expenditures on fertilizer and pesticides are offset by yields or prices, to generate average or higher ratios of expenses to revenues for wheat and corn. While the ratio is higher than average for soybeans (at

least for 1996), Southeast soybeans are often double cropped with wheat in rotation with corn. Further, the livestock industry in the Southeast and the eastern ports contribute to higher grain prices than in the Midwest markets. Thus it is not at all clear from budgets alone what the effects of higher energy costs will be on regional production patterns.

Livestock Enterprises

Energy related expenses as a share of total cash expenses range between about 6 and 33 percent for livestock and poultry (Tables A.5). Energy related expenses include expenditures on fuel, lubrication, and electricity; marketing and hauling; and custom services and supplies. Feed expenditures, broken out separately in ERS cost of production tables, range from 50 to 75 percent of total cash expenses. Broiler farms stand out with energy expenses ranging from 28 to 33 percent of total cash expenses, attributed to heating and cooling requirements for broiler houses. The energy share of hog expenses is 6 percent, but the animal feed expenses are 73 percent of cash expenses. Hog feed is primarily composed of feed grains and soybeans, among the highest in energy expenses.

Dairy, with cooling and milking equipment power requirements, follows with energy shares averaging about 15 percent of total cash expenses. Northeast and Southeast energy shares stand out at 19 percent, resulting from higher marketing and hauling expenses. Feed expenses as a percent total cash expenses increase with reliance on feeding grains and concentrates as opposed to forage, with the upper Midwest and Pacific regions below average. The Pacific region stands out as well with lower direct energy expenditures, consistent with its lower feed expenditures.

Cow-calf regional feed expenditure differences are mainly due to harvested forage and pasture expenses, which in turn are related to direct energy, chemical and irrigation expenses.

Somewhat offsetting the South's lower feed expenditures is a higher marketing and hauling expenditure. Similarly, lower direct energy expenses in the West are more than offset by higher feed expenses. Noting the losses per bred cow in 1996 and the cyclical nature of the cattle industry, the beef industry faces longer term competitive problems with respect to pork and broilers as background for any potential energy increases (ERS, 1998).

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Appendix 2. USMP Regional Agricultural Model

The U.S. Regional Agricultural Sector Model (USMP) is designed for general purpose economic, environmental, and policy analysis of the U.S. agriculture sector¹⁷. USMP is linked with regularly-updated USDA production practices surveys, the USDA multi-year baseline (USDA, 1997), and geographic information system (GIS) databases such as the National Resources Inventory (NRI). USMP predicts how changes in farm, resource, environmental, or trade policy, commodity demand or technology will affect regional supply of crops and livestock, commodity prices and demand, use of production inputs, farm income, government expenditures, participation in farm programs, and environmental indicators (such as erosion, nutrient and pesticide loadings, greenhouse gases and others). An agriculture sector spatial equilibrium model (as described in McCarl and Spreen), USMP incorporates agricultural commodity supply, use, and policy measures (House), as well as natural resource and environmental impacts derived through biophysical models (Faeth).

Baseline validation; demand and supply response

USMP does not make dated forecasts or projections. Instead, acreage, supply/use, prices, production practices, environmental loadings and so forth are validated exactly to any USDA baseline year or recent historical year (e.g. between 1988 and 2005) and corresponding

¹⁷ USMP is designed and maintained by Robert House, Mark Peters, and Howard McDowell of the USDA/Economic Research Service/Resource Economics Division. USMP is modeled in the General Algebraic Modeling Language (GAMS) as a nonlinear programming problem with solutions obtained using the MINOS nonlinear optimizer solver. USMP consists of some 2000 equations (of which 550 are nonlinear) and 5400 variables (900 nonlinear). Links with geographic information system (GIS) databases on the input data and output results sides of USMP further disaggregate the economic and environmental impact analyses supported by USMP.

geographic information. For example, for scenario analysis with a 2001 base year, USMP's base U.S. corn acreage planted equals the USDA baseline's 2001 projection (80.5 million acres), and corn acreage in each model region/practice strata is determined by share information from NRI and USDA Cropping Practices Survey (CPS) regional data. From there, comparative static adjustments to the scenario "shock" (e.g. a policy change) explain how the sector changes (through both aggregate indicators such as U.S. farm income and detailed indicators such as acreage in corn-bean rotation using mulch tillage in the central Corn Belt) between the base period and several years later when the change has worked itself out and the sector returns to equilibrium. USMP acreage planted/commodity supply response uses a positive mathematical programming (PMP) formulation (Howitt) with U.S. aggregate commodity supply response calibrated to supply response elasticities from the FAPSIM econometric simulation model (Green and Price). Responses in individual region, tillage practice, rotation and other strata follow nested adjustment functions which are part of the PMP calibration, and sum up to aggregate response. No bounds or flexibility constraints are used.

Commodity coverage

USMP models production of 10 crops: corn, sorghum, oats, barley, wheat, rice, cotton, soybeans, hay and silage. Some 16 primary livestock production enterprises are included, the principal being dairy, swine, beef cattle, and poultry. Several dozen processed and retail products are included in the model structure, the principal being dairy products, pork, fed and nonfed beef, poultry, soy meal and oil, livestock feeds, and corn milling products. Additionally, the model incorporates domestic use, imports, exports, and inventory/stock product markets. USMP

includes government conservation, acreage, price, and income programs. Production, consumption (demand), trade, and price levels for crop and livestock commodities and most processed or retail products are endogenously determined within the model structure with domestic consumption, commercial stock, export and other demand elasticities from the FAPSIM model.

Integrated economic and resource/environmental analysis

USMP's crop production enterprises include both economic items (e.g. yield, nitrogen cost, etc.) and environmental indicator coefficients corresponding to the specific rotation and tillage practices (e.g. soil erosion, nitrogen leaching, etc.). Economic coefficients in the enterprise budgets were developed from USDA data including the National Resources Inventory, Cropping Practices Survey, and Farm Costs and Returns Survey, and calculations (of e.g. machinery costs) standard to crop budget generators. Most environmental measures were estimated using the USDA Erosion/Productivity Impact Calculator (EPIC) model. For each "baseline" solution or alternative scenario, the model tallies associated levels of selected agricultural environmental indicators and acreage under various rotation/tillage practices. Impacts are determined within USMP for the national level, 10 farm production regions, and 45 land resource regions. Environmental impacts, using Geographic Information System databases such as the National Resources Inventory, are further disaggregated depending on the analysis.

USMP has been applied to project the effects on U.S. national and regional agriculture of changes in export levels and variability (Miller *et al.*), trade agreements (Burfisher *et al.*), imports (Spinelli *et al.*), input taxes (Peters *et al.*), irrigation policy (Horner *et al.*), ethanol

production (House *et al.*), wetlands policy (Heimlich *et al.* 1997a), and various other policy and program scenarios.

Crop System Biophysical Calibration

Crop system calibration is performed to ensure that the EPIC simulations of each crop system in the model correctly represent yield and other characteristics. Representative soil type and weather conditions are inputs to the biophysical model, as are the crop(s) grown, multi-year rotation of crops, and cultural practices of production. A representative soil was selected for each region from the National Resources Inventory (NRI) and Soils5 databases using a multidimensional similarity measure to regional average Universal Soil Loss Equation variables capturing slope, hydrological, and erodability characteristics. Representative weather conditions are specified as distributional information on temperature, rainfall, and other variables (NOAA). County yield data for the 10 crops are aggregated into the 45 regions to estimate average crop yields (NASS).

Each crop system is specified as a sequence of crops with dated field operations including cultivation, planting, harvesting, and application of specific fertilizer formulas and pesticides. Biological parameters in the biophysical are validated in each production region to ensure calibration of the model's simulated yield to regional yield statistics and to ensure the yield-nitrogen response is consistent with observed nitrogen application rates and rational use of nitrogen. The 60-year average results of the calibrated EPIC simulations are entered as environmental coefficients for the crop system in the USMP system budget.