INTEGRATING AGRICULTURAL AND FORESTRY GHG MITIGATION RESPONSE INTO GENEARL ECONOMY FRAMEWORKS: DEVELOPING A FAMILY OF RESPONSE FUNCTIONS

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Abstract

An econometrically estimated family of response functions is developed for characterizing potential responses to greenhouse gas mitigation policies by the agriculture and forestry sectors in the U.S. The response functions are estimated based on results of an agricultural/forestry sector model. They provide estimates of sequestration and emission reductions in forestry and agriculture along with levels of sectoral production, prices, welfare, and environmental attributes given a carbon price, levels of demand for agricultural goods, and the energy price. Six alternative mitigation policies representing types of greenhouse gas offsets allowed are considered. Results indicate that the largest quantity of greenhouse gas offset consistently appears with the mitigation policy that pays for all opportunities. Restricting carbon payments (emission tax or sequestration subsidy) only to aff/deforestation or only to agricultural sequestration substantially reduces potential mitigation. Higher carbon prices lead to more sequestration, less emissions, reduced consumer and total welfare, improved environmental indicators and increased producer welfare.

Keywords: Agricultural and forest sector, greenhouse gas, mitigation strategies, sequestration and emissions reductions.

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1. Introduction

There has been a recent increase in concern over the greenhouse gas (GHG) climate change forcing issue. According to the Intergovernmental Panel on Climate Change (IPCC), buildup in the atmospheric concentrations of GHGs, especially carbon dioxide, will affect global climate causing substantial rises in global temperatures and changes in precipitation patterns (IPCC 2000; IPCC 2001a, b). Potential climatic change impacts include impacts on human health, ecological and environmental systems, and socioeconomic aspects in agriculture, forestry, energy, coastal resources, and water availability (National Assessment Synthesis Team 2000; Watson et al. 1997). Although natural changes may be contributing to the warming, the IPCC argues that greenhouse gas emissions by human-induced activities are responsible for the majority of changes (Houghton et al. 1996; Watson et al. 1997; IPCC 2001a). A broad vulnerability of climate change impacts among regions is expected since geographical locations influence environmental and ecological systems. For example, Watson et al. (1997) found large shifts of vegetation toward higher latitudes and elevations under climate change scenarios. To avoid climate change impacts, a number of societal groups are entertaining the possibility of actions directed at somehow reducing concentrations through mitigation actions as evidenced by a substantial increase in GHG mitigation literature in the last decade.

Examples of economy-wide analysis of greenhouse gas mitigation options can be found in a special issue of the *Energy Journal* (Weyant and Hill 1999) on the costs of the Kyoto Protocol. These models generally include enough detail on the energy system to estimate changes in carbon emissions under various carbon policies. However, these models are usually not able to simulate mitigation opportunities outside the energy system and must rely on marginal abatement cost curves from other sources. This is particularly true for mitigation of non-CO_2 greenhouse gases, carbon sequestration in terrestrial ecosystems, and biofuel offsets. Sands et al. (2002) provide a demonstration of using marginal abatement cost curves for soil sequestration, afforestation, and biofuel offsets with a computable-general-equilibrium (CGE) model of the U.S. economy and energy system. In its most simple form, a marginal abatement cost curve provides a relationship between a carbon price and the corresponding reduction in carbon-equivalent emissions. This paper considers other independent variables that may interact with the carbon price in determining greenhouse gas emissions. This paper also considers the dynamics associated with mitigation options that may saturate, such as soil sequestration and afforestation.

One characteristic across the economy wide GHG offset cost studies is a lack of in depth treatment of agricultural and forestry (AF) sector options[1]. In particular, emission mitigation can be achieved through AF efforts by employing sink strategies, biofuel production or emissions management relative to carbon, methane (CH_4) or nitrous oxide (N_2O) as discussed in McCarl and Schneider (2000). Agricultural and forestry participation is partially covered in recent work by Babiker et al. (2002) where the sink part only deals with the business as usual allocation in the Kyoto negotiations and the non-CO_2 part is treated in a relatively simplistic fashion. Specific agricultural mitigation strategies have also been examined by

McCarl et al. (2000) and Stavins (1999). Sohngen and Mendelsohn (2001) also cover such issues in a forestry context integrating with the Nordhaus (2001) DICE/RICE model but do not deal with agriculture or biofuels in depth.

Inclusion of agricultural and forestry options in an economy wide model is a complex endeavor. A number of the alternative mitigation strategies are directly competitive (for example crop land based strategies like conservation tillage adoption on food crops, afforestation and biofuel production are mutually exclusive on a hectare of land) and are misleading when treated independently. Furthermore, there are important market interactions that cause interactions between strategies. For example, afforestation of a hectare that was producing corn reduces available feed and may stimulate production of feed elsewhere as well as intensification (increased fertilized or irrigation), or reduced livestock herd size, all of which have GHG, economic and environmental implications. In addition, the consequences of mitigation actions are strongly influenced by local climate and physical conditions, thus creating substantial differences in potential across the landscape. For example, in the United States, forestry activities are more effective in areas that were previously forested while agricultural carbon sequestration makes more sense in principal farming areas like the Midwest. Thus, proper inclusion of AF reactions requires a detailed examination of the underlying sectoral interactions, but this is difficult in the highly aggregate schemes employed within most CGE models.

The primary objective of this study is to estimate response functions that characterize agricultural and forestry sector responses to greenhouse gas mitigation policies for potential inclusion into integrated assessment models such as those used in Weyant and Hill (1999). These response functions are estimated based on data from multiple runs of a detailed multimarket and multiregional agricultural and forestry sector model that incorporates the interactions and complexities discussed above. Response functions are estimated for the amounts of sequestration and emission reductions along with levels of sectoral production, prices, welfare, and environmental impact indicators. The independent variables in the estimation are numbers anticipated to be generated from an integrated assessment model and include carbon price, levels of demands for agricultural goods, and the energy price.

Other aspects of the study involve allowable GHG strategies and avoiding the possibility of double counting. Considerable debate has gone on in the international greenhouse gas negotiations regarding what counts and what does not count. Alternative rules involving the extent of activities allowed in terms of traditional forest management, biofuels and agricultural soil sequestration are also considered.

On the double counting side, to develop a marginal abatement curve for all agricultural possibilities, this study includes accounting for fuels used in production and processing, and GHG emissions when manufacturing fertilizer among other items. However, emissions for these activities may be accounted for in other sectors within integrated assessment models. Consequently, this study develops GHG response curves for many individual categories, allowing one to choose the specific categories of effects to include.

2. Agricultural and Forestry Sector Model and Data Generation

In order to generate data over which the response functions can be econometrically estimated, this study uses an Agricultural Sector Model (ASM) which has had forestry and greenhouse gas mitigation possibilities added. ASM is a mathematical-programming-based, price-endogenous model. ASM was initially developed in the 1970s by Baumes (1978) and has been maintained by McCarl and others over the years. In recent years, ASM has been expanded and widely applied in several economic, environmental, and climate change projects with the Environmental Protection Agency, USDA, USDOE, USAID (Chang et al. 1992; McCarl et al. 2000; McCarl and Schneider 1999; and Schneider 2000).

The version of ASM used herein (hereafter called ASMGHG) was developed by McCarl and Schneider (2001) and Schneider (2000) to include forestry and greenhouse gas information for use in the assessment of greenhouse gas emission mitigation strategies in the U.S agriculture and forestry.

In terms of scope, ASMGHG depicts production, consumption and international trade in 63 U.S. regions. It depicts markets for 22 traditional crops, 3 biofuel crops consisting of willow, switchgrass, and hybrid-poplar, 29 animal products, and more than 60 processed agricultural products. ASMGHG simulates the market and trade equilibrium in these markets regionally or nationally in the U.S. and for some commodities in 28 major foreign trading partners.

ASMGHG models (*i*) three tillage technologies consisting of conventional tillage, conservation tillage, and zero tillage; (*ii*) four soil types – the first three types are characterized by land erodibility (high, medium and low erodibility) using an erodibility index which is a function of rainfall, soil erodibility, slope length, slope gradient, and soil loss tolerance, and the other type is characterized by a wetness limitation for cropping defined by USDA Land Capability Classes III to VIII; and (*iii*) three nitrogen fertilization technologies including 0%, 30%, and 15% nitrogen stress without nitrification inhibitors.

ASMGHG contains details on the portfolio of agricultural and forestry greenhouse gas emission related management alternatives. ASMGHG accounts for emissions, sequestration, and offsets of three main greenhouse gases — CO_2, CH_4, and N_2O. The accounting takes place at the national level, adding up emissions, sequestration, and offsets from crop and livestock production, processing, and land use change. All gasses are treated on a carbon equivalent basis so that ASMGHG can consider tradeoffs among the gasses. This is done using the IPCC 100-year global warming potentials. In particular, 1, 21, and 310 are used for carbon dioxide, methane, and nitrous oxide, respectively. In turn, all of these items are multiplied by the proportion of carbon in a unit of CO_2 (12/44) to convert to a carbon equivalent (CE) basis.

The forestry component of ASMGHG incorporates results on forest carbon sequestration, afforestation, reforestation, deforestation and land transfers from the forest and agricultural sector optimization model (FASOM) run under alternative carbon prices. Adams et al. (1996) offer detailed documentation for FASOM. Because results generated by FASOM are dynamic in nature, but results generated by ASMGHG are static, the FASOM results are transformed so that they give the average carbon increment found in the first 30 years of the FASOM run with an objective function coefficient that reflects the welfare gained from forest products less the costs of land in agriculture.

ASMGHG allows land-use change in the agriculture and forest sectors, with land conversion based on profit, but the total amount of U.S. land available remains unchanged. A carbon price will make forest or biofuel lands more profitable than agricultural land and therefore agricultural land will convert to forest or biofuel lands. This study assumes no technological change (e.g. no change in yield), and input prices remain at 1997 levels.

ASMGHG provides extensive output regarding the level of AF sector GHG emissions, sequestration, and offsets; the social welfare for the U.S. consumer and producer and the rest of the world (ROW); agricultural and forestry GHG mitigation practice usage; agricultural prices and agricultural production; factor input usage; and environmental indicators on water pollution for nitrogen, phosphorous, and potassium, and soil erosion. These outputs are used as data in the response function estimation procedure.

ASMGHG is calibrated to ensure that the baseline results on the crops and livestock prices and production are consistent with the base year, in this case 1997. Supply and demand information is mainly drawn from USDA Agricultural Statistics (2000). The base results exhibit close replication of the year 1997 with all primary crop prices and production within ±10% and most within 1-2%. Information regarding crop management technologies and GHG emissions, sequestration, and offsets coefficients is obtained from the erosion productivity impact calculator (EPIC) model (Williams et al. 1989) and the U.S. EPA (U.S. EPA 1999; 2001) as well as the IPCC. Schneider (2000) offers considerably detailed calculations on how these GHG coefficients are developed and applied to ASMGHG. Additional details on ASMGHG are available at http://agecon.tamu.edu/faculty/mccarl/asm.html.

3. Mitigation Strategies

There are a number of questions regarding what will and will not count toward allowed GHG mitigation in the agricultural and forestry sectors (e.g., in the KP only afforestation and deforestation seem to count among a number of possible actions in the forest sector). To investigate these issues, this study looks at three specific alternatives with and without certain items counting with respect to forest and agricultural alternatives. These alternatives are further varied in thirteen combinations as identified in Table I.

The forest alternative involves two specific scenarios. The first scenario considers only forest carbon from afforestation with charges for deforestation but no consideration of management or reforestation of continuing forests. The second scenario considers all forest carbon with carbon payments applying to any change in forest carbon above and beyond 1990 levels on existing, reforested or afforested lands with charges for deforestation.

The agricultural alternatives are depicted by four scenarios. The first scenario allows carbon payments for any and all of the possible agricultural emissions and sink accounts modeled in ASMGHG as discussed in McCarl and Schneider (2001). In the second scenario, biofuel payments are excluded but all other agricultural items are allowed. In the third scenario, all methane and nitrous oxide contributions are excluded with payments only to CO_2 and carbon offsets. The last scenario considers everything except for carbon from sequestration such as soil carbon, tree carbon, and pasture generated carbon.

This study also considers issues on permanence and discounting where all emissions and sequestration are treated on an equal footing and sink emissions are discounted for permanence concerns – agricultural credits are given a discount factor of 0.5 while forestry credits are given a discount factor of 0.75 based on Antle and McCarl (2001).

4. Response Function Estimation

ASMGHG is a large and complex model containing close to 50,000 variables and 5,000 constraints. As such it is not suitable for direct incorporation into a general economy wide computable general equilibrium model. Alternatively, this study simulates the model under a number of alternative possible signals from a CGE model to generate data on responses, and encapsulate that data into a set of econometrically estimated response functions that could be incorporated into a CGE model. This entailed making three main decisions on: (*i*) definition of the items that will convey information from a CGE model – economic signals and the levels over which to vary these economic signals, (*ii*) definition of the items for which response functions are to be estimated, and (*iii*) selection of a functional form.

4.1. ECONOMIC SIGNALS – INDEPENDENT VARIABLES

Signals from the rest of the economy that will constitute independent variables in the estimated functions are carbon price, fuel prices for ethanol and energy, and the level of agricultural demand domestically and internationally. Among these signals, the carbon prices are of a particular interest. Intuitively, carbon prices would have a negative relationship with GHG emissions and a positive relationship with GHG sequestration.

A wide range of settings for the signals passed from the general economy is necessary to insure a good fit of the response functions. Results were generated using ASMGHG under 405 combinations of the independent variables including fifteen alternative carbon prices ($0, $5, $10, $20, $30, $40, $50, $60, $70, $80, $90, $100, $200, $300, and $400 per ton of CE); three levels of fuel prices for ethanol and energy (at 80%, 100%, and 120% of base levels), three levels of demand for agricultural products (at 90%, 100%, and 110% of 1997 demand levels), and three levels of demand for exports (at 90%, 100%, and 110% of 1997 demand levels). For example, at $10 per ton of CE, twenty-seven scenarios can be simulated with a combination of three levels of fuel prices, demand for agricultural products, and demand for exports (e.g. 100% x 100% x 100%, 100% x 100% x 110%, 100% x 100% x 90%, … , 120% x 100% x 100%, and 120% x 90% x 90%). In addition, another 100 scenarios were randomly drawn from the ranges above for each of the four items to build degrees of freedom for parameters applied to each of the four varied factors.

4.2. RESPONSE FUNCTIONS ESTIMATED

The response functions estimated can be characterized into three classes.

4.2.1. Quantity of GHG emissions, offsets and sequestration.

GHG coverage includes CO_2, CH_4, and N_2O. Separate emissions, offsets and sink functions by gas are reported since these items are expected to move in different directions with respect to a carbon price. CO_2 emissions functions are estimated for the use of fuel, more intense tillage, fertilizer manufacture, pesticide manufacture, irrigation pumping, and ethanol production. CH_4 emissions functions are estimated for enteric fermentation, manure, rice, biomass power plant production, and corn ethanol processing. N_2O emissions functions are estimated for fertilizer use, manure, residue burning, biomass production and use, and corn ethanol processing. CO_2 sinks functions are estimated for forests, grassland expansion and tillage change. A CO_2 offset function is also estimated for biofuel production involving both ethanol and power plant use of woody crops or switchgrass.

4.2.2. Economic performance.

The economic performance functions involve (*i*) agricultural market characteristics including levels of production, exports, imports and prices, (*ii*) land use, allocation and valuation, and (*iii*) welfare implications of GHG mitigation policies. Since the agricultural production and prices are heterogeneous such that quantities and prices are in different measures, Fisher index numbers are developed and used in the estimation. Thus, the functions tell how indices of agricultural production, exports, imports and prices are affected by carbon prices, demand levels and energy price. The base Fisher index number equals 100 and represents 1997 market conditions without carbon prices.

A number of AF GHG mitigation strategies involve changes in tillage practices or conversion from traditional cropped land to biofuel lands, pasture/grassland, and forest land. Functions for cropped land, biofuel land, pasture/grass land, and forest land along with land rental rates and area under tillage practices are estimated. Alterations in carbon prices and demand levels alter welfare distributions. Functions include U.S. consumers' surplus, U.S. producers' surplus and foreign welfare.

4.2.3. Environmental indicators.

GHG mitigation policies and changes in economic signals influence the level of environmental externalities and co-benefits. For example, economic and population growth will demand more agricultural food consumption; consequently, agricultural production increases. This expansion leads to more management intensification (more fertilizer or pesticide) causing more GHG emissions (negative externality). On the other hand, carbon taxes on fertilizer usage not only reduce GHG emissions, but also increase other environmental indicators such as water or air quality improvement (co-benefits). We estimate functions forecasting usage of irrigated cropland, irrigation water, nitrogen, phosphorus, potassium, pesticides, and fossil fuels along with levels of water and wind erosion. Definitions of the dependent and independent variables along with their corresponding values at the 1997 base year are presented in Table II.

4.3. FUNCTIONAL FORM

The general estimation approach involves 2 parts — a base functional form choice and accompanying model specification and a set of procedures for incorporation of policy dummy variables depicting allowable GHG offsets.

4.3.1. *Base Model Specification*

These response functions are conceptually specified as:

$$\mathbf{Y} = f(\mathbf{x}, \varepsilon),$$

where **Y** is a vector of dependent variables (as listed in Table II), **x** is a vector of independent variables (carbon price and indices of relative domestic demand, export demand and energy price levels), and **ε** is a vector of error terms for each item in the **Y** vector. All functions are estimated with a multiplicative functional form,

$$\mathbf{Y_k} = \mathbf{A_k} \prod_i \mathbf{x_i}^{\beta_{ki}} \varepsilon_k$$

where A_k is the intercept term associated with the *k*th response function and β_{ik} is a vector of estimated parameters associated the vector **x** of signals. The base functions with all of the independent variables held at the base level (0 for carbon price and 100 for the others) depict the ASMGHG output under a zero carbon price with 100% of the 1997 domestic demand, export demand and energy price levels. Because of the log-functional form, in the estimation a carbon payment of $1 is used for a zero carbon price cases.

4.3.2. *Restricting Payments to Mitigation Strategies*

Inclusion or exclusion of mitigation options will shift the potential contribution for agriculture and forestry to mitigate GHG emissions. For example, if afforestation is the only forest strategy allowed, then the potential falls relative to a case where both existing and new forested lands could be used and the ultimate peak level of mitigation is much less. Thus, the second estimation concern involves the choice of a functional form that will adequately reflect the allowed mitigation strategies. This study uses a case-by-case estimation of the response function according to the mitigation policy. The thirteen mitigation policies identified in Table I can, in fact, be framed by six categories of mitigation policies. An adaptation of these mitigation policies can be shown as:

$$\mathbf{Y_{km}} = \mathbf{A_{km}} \prod_i \mathbf{x_i}^{\beta_{kim}} \varepsilon_{km}$$

where **Y**, **A**, **x**, **β**, and **ε** are previously defined but now each of the functions is separately estimated under each mitigation policy *m* listed at the bottom part of Table I. This yields 228 regressions to be estimated covering 38 dependent variables shown in Table I, each estimated under six different mitigation policies (Table I).

5. Results

Initial experimentation found the ASMGHG data generation task would have taken months of computer time. Consequently, an aggregated version of ASMGHG is used. In that version the 63 U.S. regions depicted within ASMGHG were aggregated into the 10 farm production regions typically used by USDA[2]. The results represent sectoral response under 1997 conditions and give a regional depiction of the economy under a zero carbon price with 1997 demand and fuel prices and no GHG mitigation.

5.1. BASIC GHG ABATEMENT CURVES

The basic form of the ASMGHG results is found in the graphs of the mitigation abatement curves in Figures 1 and 2 where the results for CO_2, CH_4, and N_2O emissions, sequestration, and total offsets are portrayed. In these Figures, the curves give the amount of GHG abatement encountered at alternative per ton CE prices ranging from \$0 to \$400 per ton CE but with the other independent variables held at their base levels. Figure 1 portrays emission offsets through alterations in fossil fuel, fertilizer use, afforestation, livestock manure management, etc. Figure 2 shows the total emission reduction disaggregated by major agricultural GHG components under all forestry allowed mitigation and CE prices. These results are similar to McCarl and Schneider's results (2000). For the most part, the chosen Cobb-Douglas functional forms fit the data well, particularly for the all offsets and sequestration levels curve. However, the multiplicative functional form is not satisfactory for some items such as agricultural soil carbon sequestration and tillage use patterns, which rise and then fall as more cropland is diverted to biofuels or trees as indicated by the shapes in Figure 2. In these cases, quadratic and polynomial functional forms were used as discussed in the next section.

5.2. RESPONSE FUNCTION RESULTS

A total of 228 response functions were econometrically estimated using ordinary least squares linear regression. The full set of econometric results entailing more than 1000 numbers and corresponding spreadsheet forms are available from a website at http://ageco.tamu.edu/faculty/mccarl/1016.xls. In this paper, we will only make general statements about the overall results and then will discuss the major effects of policy changes on the forecast result.

In general, the regressions had good structural fits according to the goodness-of-fit statistic (R^2) with the exception of those for land values and use of tillage methods. The few poor fits are likely caused by functional form choice[3]. Fortunately, the functions critical for inclusion into a CGE economy wide framework worked well (emissions, sequestration, total production and commodity price).

Turning to the most inclusive *AllCarb* scenario (Table III), a rise in the carbon price leads to expected decreases in emissions and increases in sequestration. Agricultural production is negatively affected, as are exports, while agricultural prices and imports are positively affected. Crop and pasture land use falls with higher carbon prices while biofuel and tree hectare rises, as do land values. Conventional tillage tends to fall with no-tillage and conservation tillage rising. Welfare is increased for producers but decreased for consumers and overseas interests. Finally, all of the environmental accounts show improvement with reductions in total cropped land, irrigated land and chemical use.

Responses to demand shifts depend in part on their sources. Shifts in domestic demand have larger effects as the majority of the consumption is domestic and a demand shift of the index (from a base of 100) depicts a larger underlying quantity shift. Export results also reflect the grain dominated export mix and thus act differently from the domestic mix which contains a broader variety of products. Domestic demand increases tend to increase GHG emissions and decrease sinks. Cropped land use goes up as does production and prices with exports falling. All the environmental indices rise indicating a larger impact.

Export increases tend to increase nitrous oxide emissions again reflecting land competition and increased grain demand. The livestock related methane account goes down reflecting feed competition and a smaller herd. Production and prices rise as does producer welfare. Consumer welfare falls. The environmental impact indices all rise.

Increased fuel prices cause increased levels of agricultural prices and producer welfare. CO_2 emissions increase and sinks increase, with the magnitude of the effect on sinks larger than that on emissions. One possible explanation for the positive estimated fuel price effect on CO_2 emissions is as the fuel price increases the biofuel price also increases which leads to an expansion in agricultural production which, in turn, increases the CO_2 emissions.

5.3. EFFECTS OF DIFFERENT POLICIES

The effects of policy choices on the potential for GHG reductions can be examined using these functions. Figure 3 shows how policy alteration affects net GHG mitigation. The expected results are obtained. The largest quantity of GHG offset consistently appears with the *AllCarb* scenario where everything is allowed. Referencing activity at a $100 per ton CE price, the results show (*i*) elimination of biofuels leads to about a 25% reduction in mitigation potential, (*ii*) restriction of forestry attention to afforestation and deforestation reduces potential mitigation by about 10%, (*iii*) a sequestration only strategy which also eliminates forestry sequestration can reduce potential mitigation by more than one-half, and (*iv*) not a lot is lost with elimination of the non-CO_2 strategies (about 3%).

6. Conclusions

Typically, the national and international scale in integrated assessment models for the analysis of greenhouse gas mitigation options involves top-down economic models with limited detail, if any, on agriculture and forestry offsets (Weyant and Hill 1999). The agricultural and forestry sectors are important because of emissions of methane and nitrous oxide, opportunities for sequestering carbon in agricultural soils, the carbon stored in forests, and the link to the energy system through biomass-based fuels. A complete analysis of greenhouse gas mitigation options including sequestration requires an improved representation of agriculture and forestry within the models used. Analysis of agricultural and forestry sector greenhouse gas mitigation options is usually carried out in a detailed bottom-up sectoral model. Linking response functions from the latter into the former allows one to combine the top-down economic and energy structure of an economy-wide computable-general-equilibrium model with a detailed sectoral appraisal.

This study estimates a family of response functions summarizing agricultural and forestry response from a detailed sectoral model for inclusion into economy wide integrated assessment studies. The response functions depict the effects of carbon prices, energy prices, domestic agricultural demand, and foreign agricultural demand on GHG emission reductions and sequestration, agricultural production and prices, mitigation practices employed, sectoral welfare, and environmental indicators.

The functions indicate the extent to which agricultural and forestry sinks will increase and emissions decrease as a carbon price rises. Rules on the inclusion of biofuels and forests are critical factors determining the emissions and sequestration response to a mitigation policy. The analysis also indicates that AF production and consumer welfare are negatively correlated with mitigation efforts while environmental indicators and producer welfare are positively correlated.

At present, we are beginning an integrated assessment study incorporating these response functions into the Second Generation Model, an international computable-general-equilibrium model of energy and economy (Edmonds et al. 1993). Preliminary results show interesting roles for agricultural and forestry sinks (Sands et al. 2003). We are extending this approach to include dynamics, transactions costs, and discounting for permanence.

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Notes

1. The range of potential options is discussed in McCarl and Schneider (1999; 2000)

2. This study recognizes the errors or differences in results introduced by aggregation; however, we believe that these errors are probably minor. Onal and McCarl (1991) and McCarl (1982) offer detailed discussion on aggregation in mathematical programming.

3. The work by McCarl and Schneider (2000) shows that tillage use first rises and then falls as more land is diverted out of the sector to biofuels and forestry and a multiplicative functional form cannot replicate such behavior.

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TABLE I Mitigation policy definitions, acronyms, and descriptions used in the analysis

Mitigation policy Acronym	Description
AffDef	Restricting forest carbon to aff/deforestation only (with zero meaning all forest carbon counts)
AllCarb	Allowing for existing carbon
NoBiof	Prohibiting carbon payments to biofuels
OnlyCO2	Restricting carbon payments to CO_2 gas only ignoring nitrous oxide and methane
Sequest	Restricting carbon payments in agriculture to sequestration only

TABLE II Dependent and independent variable definitions, units, base levels, and average values

Variable	Definition	Unit	Base	Average
Dependent				
Total GHG Emissions in agriculture and forestry				
CO_2	CO_2 emissions	MMTCE	51.94	32.18
CH_4	CH_4 emissions	MMTCE	59.76	54.02
N_2O	N_2O emissions	MMTCE	38.71	35.86
GHG Sequestration in agriculture and forestry Sinks:				
CO_2	CO_2 sequestration	MMTCE	22.09	141.68
CH_4	CH_4 sequestration	MMTCE	0.001	1.64
Agricultural Market conditions:				
Agricultural Price Index	Fisher index of prices of U.S. Agricultural goods including crop and livestock commodities	Fisher index	100	116.7
Agricultural Production Index	Fisher index of production of U.S. Agricultural goods including crop and livestock commodities	Fisher index	100	92.7
Agricultural Exports Index	Fisher index of exports for U.S. Agricultural goods including crop and livestock commodities	Fisher index	100	84.9
Agricultural Imports Index	Fisher index of imports for U.S. Agricultural goods including crop and livestock commodities	Fisher index	100	102.9

Agricultural and Forestry Land related data:

Crop land	Area of crop land farmed	10^6 hectares	133.64	95.39
Crop land rent	National average crop land rental rate	\$/hectare	105.29	260.01
Pasture land	Area of pasture land used	10^6 hectares	176.28	164.99
Pasture land rent	National average pasture land rental rate	\$/hectare	47.25	52.85
Afforested land	Area afforested	10^6 hectares	0	29.46
Biofuel land	Area devoted to biofuel crops for power plants	10^6 hectares	0	8.78
Conventional tillage	Crop Area treated with conventional tillage	10^6 hectares	69.57	30.82
Conservation tillage	Crop Area treated with conservation tillage	10^6 hectares	3.31	3.31
No-tillage	Crop Area treated with no-till practices	10^6 hectares	25.86	70.28

Welfare:

Producer Welfare	U.S. producer welfare	Million \$	24.67	62.97
Consumer Welfare	U.S. consumer welfare	Million \$	1183.0	1167.0
Rest of the World	Rest of the world welfare	Million \$	250.75	249.59

Environmental Indicators:

Irrigated land	Total area of irrigated land	10^6 hectares	17.32	14.25
Irrigation water use	Total irrigation water use	10^6 hectare-m	8.61	7.41
Nitrogen fertilizer	Total nitrogen fertilizer use	10^6 tons	13.45	13.10
Phosphorus fertilizer	Total phosphorus fertilizer use	10^6 tons	3.49	3.35
Potassium fertilizer	Total potassium fertilizer use	10^6 tons	5.14	5.00
Pesticide	Total pesticide expenditures	10^6 dollars	8871.8	9297.1

Fossil fuel	Fossil fuel expenditures	10^6 dollars	2445.0	2096.3
Erosion	Water and wind erosion	10^6 tons	1337.3	403.64
	Independent Variables			
Carbon Price	Carbon price representing a tax on emissions and a subsidy on sequestration	$/ton of CE	1	1 to 400
Fuel Price	Fuel price in percent relative to 1997 base price	%	100.0	-
Agriculture Demand	Quantity of domestic agricultural demand in percent relative to the 1997 base demand. This represents a demand curve shifter i.e. demand is higher by 10%, in turn ASMGHG determines the exact demand and price level some where on the shifted demand curve.	%	100.0	-
Exports	Quantity of excess demand (rest of the world demand) in percent relative to the 1997 base demand	%	100.0	-

TALBE III. Estimated regression parameters for the *AllCarb* mitigation scenario

Dependent Variables	Intercept	Carbon Price	Agriculture Demand	Exports	Fuel Price	R^2
GHG Accounts:						
Total CO_2 emissions[a]	19.6450	-0.1725	0.1844	-0.0322*	0.0904	0.879
CO_2 from fert. irrig. and fuel use[b]	0.6034	-0.0757	0.3951	0.2459	0.2360	0.901
Total CH_4 emissions	85.3070	-0.0742	0.0303*	-0.0252*	-0.0428	0.785
Total N_2Oemissions	9.9328	-0.0653	0.1477	0.0886	0.0975	0.763
Total CO_2 sinks[c]	10.3359	0.3778	-0.0112*	0.0204*	0.1634	0.8959
CO_2 offset from biofuel	0.000001	3.457	-0.985	-1.243	2.850	0.733
Soil carbon sequestration	18.2158	0.1590[d]	0.0777	0.1331	0.0581	0.904
Forest carbon sequestration	24.8063	1.1713	-0.6206	-0.1814*	-0.2063*	0.8265
Agricultural Prices and Production:						
Price	12.9690	0.1309	0.1208	0.1365	0.1086	0.685
Production	72.1472	-0.0642	0.0810	0.0106*	0.0147*	0.732
Exports	2.4464	-0.1826	-0.2640	1.2012	-0.0194*	0.589
Imports	18.2478	0.0197	0.3122	0.0129*	0.0324	0.603
Welfare:						
U.S. Producer Welfare	0.0228	0.5828	0.3046	0.5198	0.3350	0.713
U.S. Consumer Welfare	856.9744	-0.0146	0.0998	-0.0108	-0.0097	0.693
Rest of the World Welfare	13.8110	-0.0049	-0.0063	0.6313	0.0080	0.992
Agricultural and Forestry Practices:						
Cropped land	72.894	-0.062	0.159	0.145	0.037	0.560
Cropped land rent	0.0047	0.5149	0.4991	0.7097	0.4689	0.738
Pasture land	1183.0475	-0.0459	-0.0552	-0.0917	-0.0460	0.812
Pasture land rent	0.3130	0.0098*	0.1811*	0.3134	0.4079	0.123
Forest land	0.0017	2.1517	0.1785	0.0508	-0.1275	0.816
Biofuel crop land	0.0832	1.2779	-0.7345	-0.3433	1.0101	0.864

Conventional tillage	42.4698	-0.0866	-0.0752*	-0.0410*	0.1512	0.116
Conservation tillage	0.9750	0.0875	0.5551	-0.1357*	-0.0378*	0.147
No-tillage	27.6201	0.0036*	0.1426	0.1927	0.0655	0.013
Environmental Indicators:						
Irrigated land	0.0460	-0.0535	0.6301	0.3243	0.5287	0.395
Irrigated water use	0.2387	-0.0542	0.5549	0.3276	0.3613	0.591
Nitrogen fertilizer	820.0268	-0.0487	0.2701	0.1750	0.1981	0.638
Phosphorus fertilizer	448.8914	-0.0638	0.2368	0.1412	0.1125	0.603
Potassium fertilizer	583.1322	-0.1040	0.2142	0.1359	0.2027	0.477
Pesticide	1296.0572	-0.0406	0.2523	0.1555	0.0554	0.421
Fossil fuel	474.0567	-0.0860	0.1946	0.1497	0.0492	0.735
Erosion	631.3700	-0.3158	0.1598	-0.0052*	-0.0247*	0.954

Notes: All of estimated regression parameters, except for the intercept terms, could be interpreted as elasticities because of the multiplicative Cobb-Douglas functional form. These elasticities measure the responsiveness of dependent variables to changes in independent variables. For example, Table III indicates that carbon price elasticity for the total CO_2 sinks is 0.3778. Hence, a one percent increase (decrease) in a carbon price will increase (decrease) the quantity of CO_2 sinks by 0.3778 percent. On the other hand, the carbon price elasticity for the total CO_2 emissions is -0.1725. Hence, a one percent increase (decrease) in a carbon price will decrease (increase) the quantity of CO_2 emissions by 0.1725 percent.

[*] An asterisk marks estimates insignificant from zero at a 0.10 significance level using a one-tailed test.

[a] Total CO_2 emissions from use of fuel, more intense tillage, fertilizer manufacture, pesticide manufacture, irrigation pumping, more intense tillage and grassland development.

[b] CO_2 emissions from the use of fuel, fertilizer manufacture, pesticide manufacture, and irrigation pumping that maybe accounted elsewhere in and integrated assessment model.

[c] Total CO_2 sinks adds up CO_2 in forests and CO_2 in agricultural soil.

[d] A polynomial was used for agricultural soil carbon sequestration (ASC). The estimated function is

$$\text{ASC} = 18.2158 + 0.7096*\text{Carbon Price} - 0.007*(\text{Carbon Price})^2 + 2.35\text{E-}05*(\text{Carbon Price})^3$$
$$- 2.59\text{E-}08*(\text{Carbon Price})^4 + 0.0777*\text{Agricultural Demand} + 0.1331*\text{Exports}$$
$$+ 0.0581*\text{Fuel Price}.$$

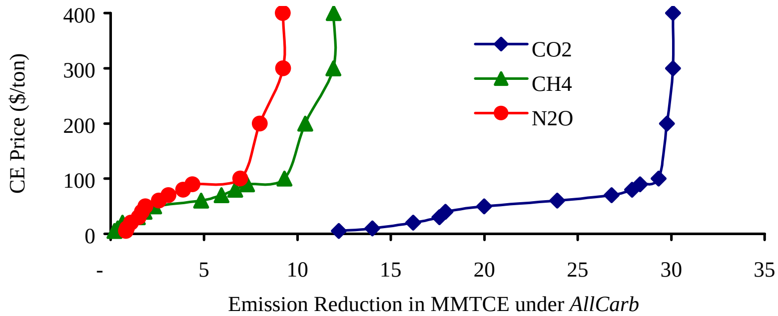

Figure 1. Greenhouse gas emission reductions in million metric tons of carbon equivalent (MMTCE) as a function of the carbon price. The carbon emission reductions in this figure do not consider sequestration or biofuel offsets.

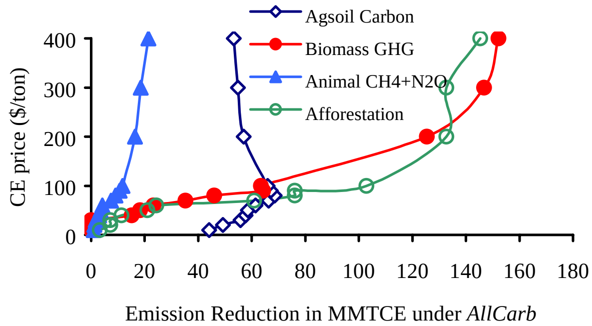

Figure 2. The portfolio of agricultural greenhouse gas mitigation options employed under the *AllCarb* mitigation strategy.

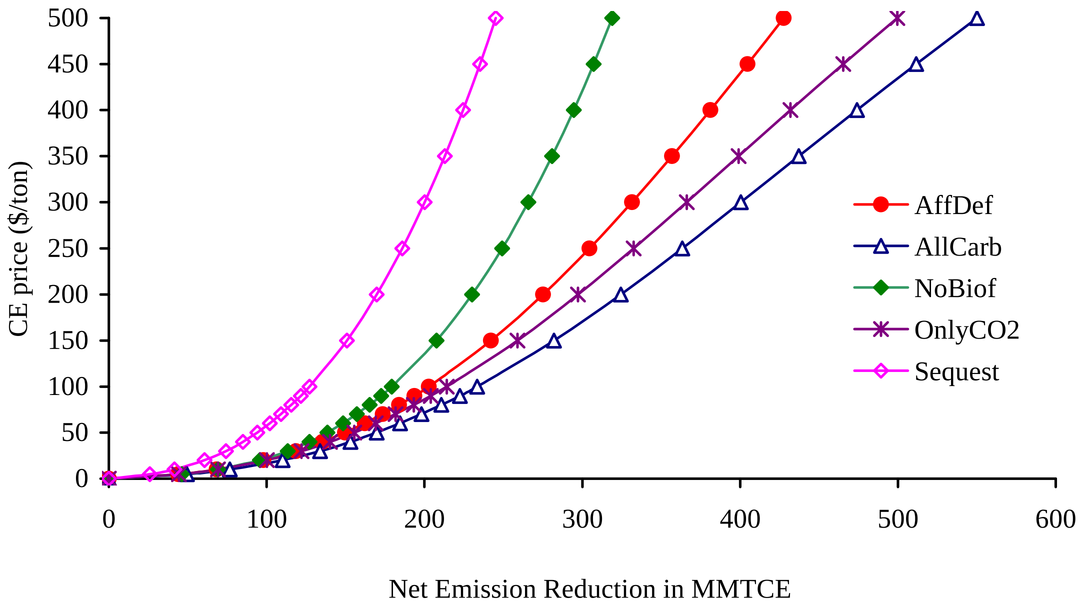

Figure 3. Comparison of net greenhouse gas emissions reductions across mitigation strategies using a log-linear functional form.