THE ROLE OF US AGRICULTURAL AND FOREST ACTIVITIES IN GLOBAL CLIMATE CHANGE MITIGATION

A Dissertation

by

EN ZHU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2007

Major Subject: Agricultural Economics

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Approved by:

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ABSTRACT

The Role of US Agricultural and Forest Activities in

Global Climate Change Mitigation. (August 2007)

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In 2005 the highest global surface temperature ever was recorded. A virtual consensus exists today among scientists that global warming is underway and that human greenhouse gas (GHG) emissions are a significant cause. Possible mitigation of climate change through reduction of net GHG emissions has become a worldwide concern. Under the United Nation's Framework convention on Climate Change, the Kyoto Protocol was formed in 1997 and required ratifying countries to co-operate in stabilizing atmospheric GHG concentrations. The protocol took effect on February 16, 2005.

The mitigation cost for reducing GHG emissions for the US economy has been argued to be high particularly through the energy sector. Agriculture and Forestry (AF) can provide some low cost strategies to help with this mitigation principally through carbon sequestration but must be competitive with mitigation costs in the rest of the economy. A general equilibrium approach is used herein to evaluate the role of AF mitigation in an economy wide setting.

The results show that the AF sectors have significant mitigation potential. Higher carbon prices lead to more sequestration, less emissions, reduced consumer and total

welfare, improved environmental indicators and increased producer welfare. AF mitigation increases as the carbon price increase over time. In the earlier periods, while the carbon price is low, AF emissions and sink are quite small compared to the energy sector. As carbon prices increase over time, the AF sectors mitigate about 25% of the net emissions. This verifies McCarl et al's (2001) argument that the AF sectors "may be very important in a world that requires time and technological investment to develop low-cost greenhouse gas emission offsets."

AF GHG emission mitigation is sensitive to saturation of sequestration sinks. This research finds that ignoring saturation characteristics leads to a severe overestimate of mitigation potential with estimates being inflated by as much as a factor of 6.

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CHAPTER I

INTRODUCTION

Global warming is one of the most serious challenges facing the world today. Warming is already underway. An analysis from Goddard Institute for Space Studies indicates that 2005 is the year with the highest global surface temperature on record. Intergovernmental Panel on Climate Change (IPCC) estimates that the globe has warmed by 0.6°C in the past three decades and 0.8°C in the past century. The IPCC projects that the Earth's average surface temperature will increase by between 2.5° and 10.4°F (1.4°-5.8°C) between 1990 and 2100 if no major efforts are undertaken to reduce the emissions of greenhouse gases (the "business-as-usual" scenario) stating "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system." IPCC argues that warming could have dramatic effects on every aspect of human life.

Warming poses a distributional issue as well since low latitudes where poorer nations reside appear to be more severely affected (Watson, Zinyowera, Moss, and Dokken, 1997; McCarthy et al. 2001). Also health and economic well-being damage of current and future generations is at issue.

This thesis follows the style of *American Journal of Agricultural Economics.*

Possible climate change mitigation through reduction of net greenhouse gas (GHG) emissions has become a worldwide concern. In 1992, the United Nation's Framework convention on Climate Change (UNFCCC) was created with the express objective of stabilizing atmospheric GHG concentrations and was ratified by 176 governments. Under the UNFCCC, the Kyoto Protocol (KP) was formed in 1997 and would require ratifying countries to co-operate in stabilizing atmospheric GHGs. The KP has the stated objective of preventing "dangerous anthropogenic interference with the climate system" and commits to reduce GHG emissions by specific levels by 2008-2010. The KP took effect on Feb. 16, 2005 with 169 nations having signed and ratified it as of April 2007.

Chapter IV of the IPCC report (1996c) addresses the related issues of intertemporal equity (for example, between people living in the present and near term and people living many generations late), discounting and economic efficiency. The long-lived impacts of climate change along with the scale of potential investment and social change needed to arrest changes in the atmosphere raise the intergenerational equity issue. The establishment of intergenerational equity is a goal that in principle very few people would oppose, but the rationale for being concerned about sustainability is still stormily debated. There have been many papers on the philosophical rationale for intergenerational concerns (Pezzey, 1992, 1997; Toman, 1994; Norton and Toman, 1997; Howarth, 1997). The climate problem is global which implies that climate change control is a public good. Moreover, intergeneration transfers are inevitable because global warming will affect primarily people living many generations into the future, which raises complicated ethical questions because they can't participate in current decision-making processes. Intergenerational asymmetry can lead to an externality/public-good problem in which emissions mitigation in the near term may be less than would have been the case if decisions were made with active consideration of the welfare of future generations. Taking into account both intertemporal distributional concerns and cost-effectiveness (not to mention political credibility) remains one of the major challenges in designing and assessing climate policy (Shogren and Tommy 2000, Pezzey and Toman 2002/2003).

Cost-benefit analysis can be applied to the economic evaluation of climate-change policies. The widely accepted standard procedure is to estimate future costs and benefits and to discount them to obtain their net present values. In determination of the discount rate, two approaches are common i.e. the "descriptive approach" and the "prescriptive approach". Lind and Schuler (1998) argue that neither of them establishes a defensible social rate of time preference for use in the cost-benefit analysis. There are still unresolved disagreements about the discounting problem concerning the climate change and mitigation actions and further study is required. Typically, policies to mitigate climate change will cause both intertemporal and intratemporal transfers of resources. Therefore, we need to analyze issues of both intergenerational and intragenerational equity. The definition of "fairness" or "equity" in the context of climate change control is not a straightforward task. There are some proposals regarding what could constitute equity in GHG mitigation like allocation-based equity, outcome-based equity and process-based equity criteria.

Naturally occurring GHGs include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Anthropogenic activities result in additional quantities of these gases, thereby changing their global concentrations. The GHG emissions of the US amount to approximately one fourth of the world's total emissions.

Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting US emission trends. Energy-related activities were the primary sources of US anthropogenic GHG emissions, accounting for 85 percent of total emissions on a carbon equivalent basis in 2005（EPA 2006). Emissions from this source category grew by 17 percent from 1990 to 2001 and were responsible for most of the increase in national emissions during this period. In 2001, industrial processes generated 4.1 percent of total US GHG Emissions.

EPA (2003) indicates that agricultural activities were responsible for about 6.8 percent of total US GHG emissions in 2002. CO_2, CH_4 and N_2O are the primary GHGs emitted by agricultural activities. CH_4 and N_2O emissions from enteric fermentation and manure management represent about 19 percent and 6 percent of total CH_4 and N_2O emissions from anthropogenic activities, respectively. Land use, land-use change, and forestry activities in 2001 resulted in an offset of approximately 14 percent of total US CO_2 emissions. Net CO_2 sequestration from total land use, land-use change and forestry declined by approximately 22 percent between 1990 and 2001.

Emissions are widespread across the non agricultural components of the economy but in the US largely arise from fossil fuel combustion in the form of CO_2. CH_4 emissions result primarily from decomposition of wastes in landfills, natural gas systems, and enteric fermentation associated with domestic livestock. Agricultural soil management and mobile source fossil fuel combustion were the major sources of N_2O emissions. (EPA 2003)

Many options exist for a net GHG emission reduction including energy use reduction or energy production fuel source switching, but some of them can be expensive and at least in the short run highly intrusive on today's energy intensive lifestyle in many developed countries. Agriculture and forestry (AF) may be able to provide low-cost GHG emission reduction strategies that permit continuing energy consumption, buying time for energy sector technological development (McCarl and Schneider 1999). In addition, Watson (2000) argues that there are many options where cost-effective AF sector interventions could reduce net GHG emissions and have a wide range of co-benefits consistent with sustainable development.

Polices aimed at reducing global warming through GHG net emission reduction imply global, multi-period and multi-sectoral economic change which will induce general equilibrium effects throughout the whole economy. Thus a general equilibrium (GE) approach is the appropriate way to evaluate the AF role in an economy wide setting. GE approaches depict adjustments in all sectors, enabling consideration of the interactions between all the markets and backward/forward impacts on other sectors. In this thesis a computable general equilibrium (CGE) approach will be used.

To evaluate the effects of GHG reduction policies, the price of avoided GHG emissions which expresses how much one should be willing to pay to emit an additional ton and the opportunity cost of each mitigation strategy need to be calculated, this includes implicit consideration of the supply function for sequestration components. The supply and appropriate role of agricultural and forest actions involves dynamic considerations. In particular one needs to recognize that saturation will occur. Some changes in land use and management practices can increase the stock of C in the soil up to a new equilibrium state. As the soil C level increases, the rate of soil absorption of C eventually decreases and gains stop. West et al. (2000) reviewing over 267 experiments show this occurs after approximately 10-15 years for tillage changes and 30 years for rotation changes. Furthermore, if the management changes, the soil and forest would become an emissions source, so policy needs to be designed not only to encourage sequestration but also to maintain it over time. These concerns have collectively become known as the permanence issue in the international debate over inclusion of soil C as an allowable sink under the Kyoto Protocol.

Previous studies of response to the imposition of binding GHG emission gas caps have taken two basic directions. First, a family of CGE studies have been done that examine alternatives across sectors but have either fixed the level of sequestration or ignored it (e.g. see Weyant and Hill 1999 or Reilly et al. 2002). Second, sectoral or regional studies have been done on the agricultural and forestry response given market prices for emissions offsets that would have had to arise in the rest of the economy. Very limited work has been done on overall market clearing prices considering alternatives in the general economy and the AF sectors (see Sands et al. 2000 and Sohngen et al.1999).

1.1 Research Objectives

As mentioned above and further reviewed below, previous studies examining carbon sequestration mitigation strategies in the agricultural and forest sectors have generally either represented sequestration possibilities under very limited assumptions or have been done in the AF sectors without direct consideration of rest of the economy GHG emission mitigation alternatives. Further, consideration of the dynamic characteristics of permanence has also been weak. Consequently, previous analyses of the mitigation potential of AF GHG mitigation and carbon sequestration programs are incomplete.

This dissertation will simultaneously consider AF and general economy GHG emission mitigation alternatives in a dynamic framework in an attempt to examine the appropriate role of AF mitigation alternatives. This will be done on a US basis through the use of a multi-period CGE model.

Meshing together a detailed dynamic landscape AF sector model with a typically highly aggregate CGE model poses a challenge in this research. Typical CGE models are top-down economic models with 10-15 sectors that simulate energy system response to a GHG emission cap and are run for 5 to 10 years at a time for a 100 or so year period in a dynamic recursive setting. On the other hand, the AF response encountered in a time period depends on the volume of the saturating activities used in previous time periods. This dissertation will develop econometrically estimated dynamically evolving response functions for characterizing potential responses.

1.2 Organization of the Dissertation

In chapter II, the literature concerning Global Climate change, AF carbon sequestrations as well as CGE models will be reviewed. The literature review focuses on methodology and results. The FASOMGHG and an analytical approach looking at the economy as a complete system of interdependent components (SGMGAMS) as well as response functions are developed in chapter III. Chapter IV summarizes the theoretical and empirical results of response functions. Chapter V elaborates the detail empirical results integrating the response functions into the SGMGAMS model. The final chapter contains summaries and conclusions, a discussion of study limitations and possibilities for future research.

CHAPTER II
BACKGROUND

2.1 Introduction

In 1824, the French mathematician Jean-Baptise Joseph Fourier first conceived a mechanism via which the Earth could retain sun's heat. His conclusion, still accepted today, is that the atmosphere with clouds and gases on the top is like a huge glass bell jar, could reradiate part of the sun's radiation back to Earth to warm the planet.

Tyndall set out to study the radiative properties of various gases in 1859. His careful experiments identified different absorptive powers of gases such as water vapor, carbon dioxide, ozone, and hydrocarbons. He said, without water vapor, the Earth's surface would be "held fast in the iron grip of frost." He later speculated on the relationship between fluctuations in water vapor besides carbon dioxide and climate change.

In 1896, after reading Fourier's work, the Swedish physical chemist Svante August Arrhenius set up a first theoretical model that directly related the carbon dioxide in the atmosphere to the surface temperature. His result was that that a doubling of CO_2 would cause a temperature rise of 5 degrees Celsius.

Around 1938 an English engineer, Guy Stewart Callenda evaluated old measurements of atmospheric CO_2 concentrations and concluded that over the past hundred years the concentration of the gas had increased by about 10%. This rise, Callenda asserted, could explain the observed warming.

In the 1950s, a few scientists reexamined Callenda's claim with improved techniques, calculations and a sharp increase of government funding. The new studies in 1961 employed careful measurements showed that the level of the carbon dioxide was in fact rising each year and brought warming.

In the early 1970s, concerns about climate and the greenhouse effect increased with the rise of environmentalism. In 1992, the United Nation's Framework Convention on Climate Change (UNFCCC) was created with the express objective of stabilizing atmospheric GHG concentrations. Under the UNFCCC, the Kyoto Protocol (KP) was formed in 1997. Public's attention finally was drawn on the Earth's warming in the summer of 1988, the hottest on record till then. The Intergovernmental Panel on Climate Change (IPCC) in its 2001 assessment stated that, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." Scientists have subsequently found significant evidence in ice cores and through simulation models leading to a virtually consensus conclusion today that the climate is changed including a global warming and this is likely to continue in the future.

2.2 Greenhouse Gas

Naturally occurring greenhouse gases include water vapor, CO_2, methane (CH_4.), nitrous oxide (N_2O), and ozone (O_3.). Total GHG emissions increased by 16 percent since 1990 (1.3 percent per year since 2000). CO_2 emissions, the dominant GHG gas, arise mostly from fossil fuel combustion, which accounts for approximately 80 percent of GWP weighted emissions in 2004. Other sources of emissions include forest clearing, other biomass burning and some non-energy production processes (e.g., cement production) (EPA 2006). The IPCC stated that "the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2" (IPCC 2001).

The effect of Methane (CH_4) on global warming is estimated by the IPCC as being about 20 times more than CO_2. Atmospheric concentrations of methane increased by 143 percent since pre-industrial times and slightly more than half of the current CH4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use, and waste disposal (IPCC 2001).

The ability of nitrous oxide (N_2O) at trapping heat in the atmosphere is approximately 300 times bigger than CO_2 (IPCC). The global atmospheric concentration of N_2O has risen by approximately 18 percent since 1750 (IPCC 2001). The main sources producing N_2O in the US are agricultural soil management, fuel combustion in motor vehicles, manure management, nitric acid production, human sewage, and stationary fuel combustion. Agricultural soil management is the largest US N_2O emissions source, which is about 68 percent (261.5 Tg CO_2 Eq.) of 2004 emissions (EPA 2006).

Some other synthetic greenhouse gases like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are accounted for in national greenhouse gas inventories by the UNFCCC.

Table 2.1 shows data on the concentration of GHGs indicating that

- CO_2 concentration has grown from 280 ppm in 1750 to 376.7 ppm in 2004 (34.5

percent).

- CH4 has increased from 0.722 ppm in 1750 to about 1.756 ppm in 2004 (a 143% increase).
- N_2O has increased from 0.270 ppm to 0.319 ppm (18 percent).

From 1990 to 2004, total emissions of CO_2 increased by 20 percent, while methane decreased by 10 percent (61.3 Tg CO_2 Eq.) and N_2O decreased 8.2 Tg CO_2 Eq. (2 percent), aggregate weighted emissions of HFCs, PFCs, and SF6 rose by 52.2 Tg CO_2 Eq. (58 percent).

Table 2.1. Global Atmospheric Concentration (ppm unless otherwise specified), Rate of Concentration Change (ppb/year), and Atmospheric Lifetime (years) of Selected Greenhouse Gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6 [a]	CF_4 [a]
Pre-industrial atmospheric concentration	280	0.722	0.270	0	40
Atmospheric concentration[b]	376.7	1.756	0.319	5.4	80
Rate of concentration change[c] Atmospheric lifetime	1.6 50-200[d]	0.005 12[e]	0.0007 114[e]	0.23 3, 200	1.0 >50, 000

Source: Current atmospheric concentrations and rate of concentration changes for all gases but CF_4 are from Hofmann (2004), data for CF_4 are from IPCC (2001). Pre-industrial atmospheric concentration and atmospheric lifetime taken from IPCC (2001).

[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.

[b] Concentration for CF_4 was measured in 2000. Concentrations for all other gases were measured in 2004.

[c] Rate is calculated over the period 1990 to 2004 for CO_2, CH_4, and N_2O; 1996 to 2004 for SF_6; and 1990 to 1999 for CF_4.

[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

[e] This lifetime has been defined as an “adjustment time” that takes into account the indirect effect of the gas on its own residence time.

The Global Warming Potential (GWP) is a measure indicative of the relative impact of alternative greenhouse gasses (see Table 2.2). It is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). The reference gas used is CO_2 so the GWP for CO_2 is 1, it is 21 for CH4 and 310 for N_2O.

Table 2.3 lists the top fifteen CO_2 emitting countries for the year 2002. The US is the biggest CO_2 emitting country contributing 24.3% of global emissions. China, India, and Mexico are countries not directly covered under the Kyoto Protocol (KP) and these three countries account for around 18.76% of global CO_2 emissions.

Table 2.4 demonstrates the CO_2 emission trends in KP Annex B and non-Annex B countries. The aggregated GHG Emissions of the 39 Annex B countries are responsible for more than half of the global emissions, but the magnitude, in general, exhibits in a decreasing trend. On the other hand, along with the economic growth in developing countries, the aggregate CO_2 emissions in non-Annex B countries increased over 30% from 1990 to 1998. With the emission increment in non-Annex B countries and emission decrease in Annex B countries, the aggregate CO_2 emission contribution from Annex B countries dropped from 64% in 1990 to 57% in 1998.

Table 2.2. Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years)

Gas	Atmospheric Lifetime	GWP[a]
CO_2	50-200	1
CH_4[b]	12±3	21
N_2O	120	310
HFC-23	264	11, 700
HFC-32	5.6	650
HFC-125	32.6	2, 800
HFC-134a	14.6	1, 300
HFC-143a	48.3	3, 800
HFC-152a	1.5	140
HFC-227ea	36.5	2, 900
HFC-236fa	209	6, 300
HFC-4310mee	17.1	1, 300
CF_4	50, 000	6, 500
C_2F_6	10, 000	9, 200
C_4F_{10}	2, 600	7, 000
C_6F_{14}	3, 200	7, 400
SF_6	3, 200	23, 900

Source: (IPCC 1996)

[a] 100-year time horizon

[b] The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Table 2.3 World's Top Fifteen CO_2 Emitting Countries in 2002

Country	CO_2 emissions (1000 metric tons)	Percentage
World Total	24,126,416	100.0%
United States	5,872,278	24.3%
China	3,550,371	14.7%
Russian Federation	1,432,913	5.9%
India	1,220,926	5.1%
Japan	1,203,535	5.0%
Germany	804,721	3.3%
United Kingdom	544,813	2.3%
Canada	517,157	2.1%
Korea, Republic of	446,190	1.8%
Italy	433,018	1.8%
Mexico	383,671	1.6%
France	378, 267	1.6%
Iran (Islamic Republic of)	360,223	1.5%
Australia	356,342	1.5%
South Africa	345,382	1.4%

Source: United Nations Statistics Division. (accessed Nov. 2006).

Table 2.4. Kyoto-Related Fossil-Fuel CO_2 Emissions Totals in Million Metric Tons of Carbon

Year	Annex B Countries	Non-Annex B Countries	Global	Annex B Contribution
	-------------- millions of metric tons of carbon --------------			
1990	3871	2144	6015	64%
1991	3783	2318	6101	62%
1992	3680	2281	5961	62%
1993	3617	2340	5957	61%
1994	3593	2490	6083	59%
1995	3629	2611	6240	58%
1996	3673	2702	6375	58%
1997	3740	2765	6505	57%
1998	3740	2751	6491	58%
1999	3694	2626	6320	58%
2000	3779	2691	6470	58%
2001	3834	2811	6645	58%
2002	3790	2986	6776	56%

Source: Gregg Marland and Tom Boden (CDIAC, Oak Ridge National Laboratory).

Figure 2.1 shows the US emission distribution by economic sector for 1990 and 2004. Emissions from electricity generation account for the largest portion of US greenhouse gas emissions (33 percent in 2004). Transportation activities, in aggregate, accounted for the second largest portion (28 percent). Emissions from industry accounted for 19 percent of US greenhouse gas emissions. The remaining 20 percent of US greenhouse gas emissions were contributed by the residential, agriculture, and commercial sectors, plus emissions from US territories. Activities related to agriculture accounted for roughly 7 percent of US emissions; unlike other economic sectors, agricultural sector emissions were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation, rather than CO_2 from fossil fuel combustion.

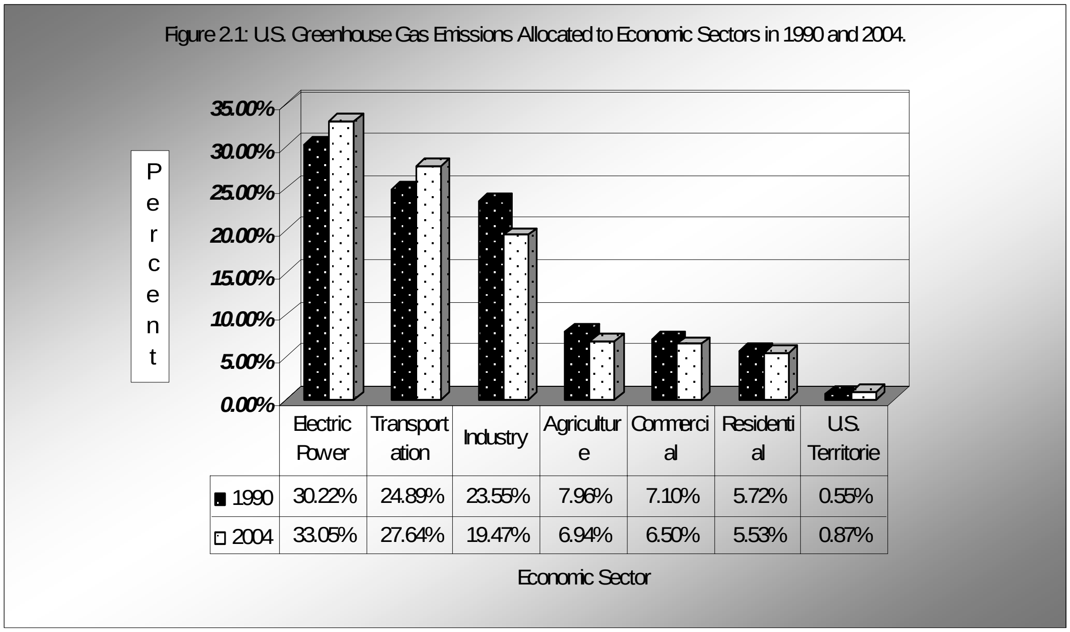

Figure 2.1. U.S. greenhouse gas emissions allocated to economic sectors in 1990 and 2004 (Source: EPA (2006))

2.3 The Potential Impacts of Climate Change and the Kyoto Protocol

In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), recognizing the growing problem of global climate change, established the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established to understand the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC Third Assessment Report (2001) stated that projected climate change will have beneficial and adverse effects on both environmental and socio-economic systems, but the larger the changes and rate of change in climate, the more adverse effects predominate. The IPCC 4th Assessment Report (2007) states that Warming of the climate system is unequivocal and most of the observed global warming since mid-20th century is very likely due observed increase in anthropogenic GHG concentrations.

The IPCC argues that the adverse impacts will include threats to human health, particularly in lower income populations, species extinction, agricultural yield loss in some regions accompanied by hunger, water shortages, sea-level rise and storm surge damage, increased climate variability and extreme event frequency, increased disturbance factors, such as hurricanes, forest fires, drought, pests, and disease.

Although it is uncertain for the response of health outcomes to climate change, currently available information suggests climate change can affect human health positively like reduced cold stress, or negatively such as increased and prolonged heat stress, loss of life in floods and hurricanes. The health effects include expansions in the ranges of vector- and rodent borne diseases, water-borne diseases, adverse effects on water quality, expanded air pollution, and altered food availability and quality.

Significant disruptions of ecosystems from disturbances such as fire, drought, pest infestation, invasion of species, storms, and coral bleaching are expected (IPCC 2001).

In most tropical and subtropical regions, projected warming decreases agricultural yields, increases food prices globally, and may expand the risk of hunger. Climate change may alter water availability and exacerbate water shortages in many water-scarce areas of the world; also warming can degrade fresh water quality.

The IPCC estimates that sea level will rise 9 to 88 cm by the year 2100. Sea-level rise and storm surges will adversely affect populations that inhabit coastal areas. Tens of millions of people will face risk of displacement.

Climate change will have more severe adverse impact on developing countries and poor people. Moreover, poverty and other factors also are less capable to adapt to climate change in most developing countries.

In May 1992, 165 countries joined and signed an international treaty -- the United Nations Framework Convention on Climate Change (UNFCCC) at the 'Earth Summit' in Rio de Janeiro. The UNFCCC took effect on 21 March 1994. 189 countries have ratified it to date.

Under the UNFCCC, the Kyoto Protocol (KP) was formed in 1997 that would require ratifying countries to co-operate in stabilizing atmospheric GHGs with the objective of preventing "dangerous anthropogenic interference with the climate system" and commit to reduce GHG emissions by at least 5.2 per cent compared to 1990 emissions levels by 2008-2010 (Table 2.5). Table 2.5 shows reduction commitments of the KP and emissions development from 15 major parties. The KP incorporates flexible mechanisms, such as emission trading[1], joint implementation among developed countries[2], and the clean development mechanism.

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[1] The KP allows countries with emission targets (Annex B countries) to trade their GHG emission shares. Using this mechanism, Annex B countries can achieve emission reduction at the lowest cost.

[2] Annex B countries may obtain emission reduction credit through project-base emission reductions in other Annex B countries.

From 1990 to 2004, net emissions of GHGs in the US increased by 21.1% (Table 2.6), and thus a nearly 30% reduction would have been needed to meet the KP reduction commitment which is 7% below the 1990 emission levels by 2008-2012. In summer 2001, the Bush Administration announced that it would not participate in the implementation of the KP (White House, 2001) on three grounds as summarized by EPA: (1) The KP is fundamentally flawed; (2) Ineffective in addressing climate change because it excludes developing countries; and (3) The KP risks significantly harming the US and global economies.

After withdrawing from the KP, the Bush administration posed a plan for reducing GHG emissions intensity, which lowers emissions to tie with economic output. The Bush plan sets a goal to reduce the GHGE intensity by 18% by 2012 which will allow real GHG emissions to increase by 12%. (Pew center 2006).

Kyoto Protocol finally took effect on Feb. 16, 2005 with a total of 161 ratified Parties. As of Dec. 2006 169 countries and other governmental entities have ratified. Many countries have already made significant progress for achieving their Kyoto commitments according to 2006 reports to the UNFCCC.

2.4 Previous Studies

Since the rise of environmentalism in the 1970s, the first environmental models were created and developed to examine GHG emissions and their implications. These models are mainly technical-climate models rather than economic models.

Table 2.5. Reduction Commitments of the Kyoto Protocol and Emissions Development

Party	Reduction Commitments	Emissions 1990 in Mt	Emissions 2000 in Mt	Emissions 2002 in Mt	Change 1990-2002
EU	-8 %	4 233	4 093	4 122	-2.6 %
Liechtenstein, Monaco, Switzerland	-8 %	53	53	53	-1.6 %
Bulgaria, Czech Republic, Estonia, Latvia, Lithunia, Romania, Slovakia, Slovenia	-8 %	812	459	463	-43.0 %
USA	-7 %	6 129	7 038	6 935	+13.1 %
Japan	-6 %	1 187	1 337	1 331	+12.1 %
Canada	-6 %	609	725	731	+20.1 %
Poland, Hungary	-6 %	677	464	461	-32.0 %
Croatia	-5 %	32	26	28	-11.5 %
New Zealand	0 %	62	70	75	+21.6 %
Russian Federation	0 %	3 050	1 876	1 876	-38.5 %
Ukraine	0 %	919	455	484	-47.4 %
Belarus	0 %	127	68	70	-44.4 %
Norway	+1 %	52	56	55	+6.2 %
Australia	+8 %	431	513	526	+22.2%
Iceland	+10 %	3	3	3	-4.2 %
Total	-5.2 %	18 376	17 237	17 212	-6.3 %

Source: UNFCCC, these values refer to carbon dioxide equivalents excluding land-use change and forestry

Table 2.6. US Greenhouse Gas Emissions and Sinks (Tg CO_2 Equivalents)

Emissions	1990	2004	Absolute Change	% of Change
Fossil Fuel Combustion	4696.6	5656.6	960.0	20.4
Land Use Change and Forestry	-910.4	-780.1	130.3	-14.3
CO_2	5005.3	5988.0	982.7	19.6
CH_4	618.1	556.7	-61.3	-9.9
N_2O	394.9	386.7	-8.2	-2.1
HFCs, PFCs, and SF6	90.8	143	52.2	57.5
Total Emissions	6109	7074.4	965.4	15.8
Net Emissions	5198.6	6294.3	1095.7	21.1

Source: EPA (2006). [1] The numbers in this row refer to the net emission when land use change and forestry is included.

Economics began to be a part of GHGs and environmental modeling in general at the end of the 1970s. Climate modeling boomed after the Toronto climate Conference in 1988.

In the late 1980s and the early 1990s, the applied general equilibrium models were popular with the improvements in computer technology and solution methods. As a result, the bottoms-up and top-down models have been used to estimate the cost of GHG mitigation.

Recently, so-called integrated assessment models (IAMs) have been used to amalgamate the knowledge from multidisciplinary fields and seeks to inform policy and decision-making. The RICE model proposed by Nordhaus and Yang (1996) is one of popular IAMs.

Climate change research has taken several directions. Some study the observed nature of climate change such as reviewing evidence of past climate change, signs of human-caused climate change; some examine the impacts, vulnerability, and adaptation of climate change on the environmental, social, and economic aspect; some project the future climate change and some focus on the mitigation analysis. We focus mainly on impact and mitigation studies here.

2.4.1 Impact Studies

Global warming could have dramatic effects on every aspect of human life and is already underway. The economic and distributional effects plus social implications of global climate change have become the focus of intense studies. Kokoski and Smith (1987) show that there is evidence of a potentially large and mixed price effect of CO2 induced climate change. Adams et al. (1988, 1990) discovered net welfare reductions for US agriculture using the GISS and GFDL climate models and find that the impact on the US economy strongly depends on which climate model is used. They utilize a crop simulation approach to predict the impact of climate change on crop yields. Nordhaus (1991) first brought in the concept of a greenhouse damage function which describes the costs that accrue to society from climate change and concluded that only a limited amount of greenhouse abatement would be warranted. Mendelsohn et al. (1994, 1996) pioneered the agricultural Ricardian approach to predict how farmland profitability changes as a consequence of changes of local climate with other factors controlled and concluded that global warming could have positive impact to the US agriculture if production adaptations are considered and no CO2 effect. Yohe et al. (1996) detected a continuous decrease in estimated damage costs from sea level rises. Aber et al. (2001)

suggested that climate change is generally expected to boost forest productivity by a slight to moderate (5%–30%) level and more than 20% at the national scale. Irland et al. (2001) got the similar conclusion assuming there are no major shifts in timber demand, they projected that the climate change will increase forest timber volume and market welfare by 0.2%. Mendelsohn (2003) argued that global warming may not be unilaterally harmful and it will become harmful as warming becomes more severe. He predicted that "the emissions over the next few decades are expected to cause only small harm along the low latitudes and likely benefits in the higher latitudes" (Mendelsohn et al. 2000; Mendelsohn 2003).

2.4.2 Mitigation Analysis

In the next ten years, the Kyoto target to reduce GHG emissions will have a profound effect on Annex 1 countries. Mitigation which is the most cost-effective and feasible will be the key to decreasing adverse socioeconomic impacts.

Many options exist for net GHG emissions reduction including energy use reduction or energy production fuel source switching, but some of them can be expensive and at least in the short run highly intrusive on today's energy intensive lifestyle in many developed countries. Agriculture and forestry may be able to provide low-cost GHG emission reduction strategies that permit continuing energy consumption, buying time for energy sector technological development (McCarl and Schneider 1999). In addition, Watson (2000) argues that there are many options where cost-effective AF sector interventions could reduce net GHG emissions and have a wide range of co-benefits consistent with sustainable development.

The European Union (EU) has a Kyoto target to reduce their emissions by 8% below 1990 levels. Currently, emissions are already below the 1990 levels and are expected to go beyond its target and reduce emissions by 9.3% by 2010.

The Kyoto Protocol would require the US to cut its emissions by 7% below its 1990 emissions. At the end of 2004, US emissions were 27% above the Kyoto target. Energy Information Administration models forecast US CO2 emissions to be 38% above the Kyoto target in 2008 and 47% above the Kyoto target in 2002. The US has not ratified the Kyoto Protocol mainly because of the cost of mitigation and the debate over the costs of GHG emission reduction has become more complex over the last two decades.

2.4.2.1 Cost of GHG Abatement

Hazilla and Kopp (1990) pointed out that the welfare change in a given mitigation project should be included in a social cost assessment. Bernstein et al. (1999) analyzes economic impacts on the world of the Kyoto agreement using a dynamic general equilibrium model (MS-MRT model). Their model create a uniform permit price of about US$89 per metric ton in 2010 if global emission trade among Annex 1 countries is allowed and about US$30 per metric ton in 2010 in the global trade scenario. Peters et al. (2001) summarize selected carbon charges from 12 studies that employ multi-region, multisector general equilibrium models to look at the macroeconomic impacts of using such charges to reduce US GHG emissions to meet the Kyoto target. “All the studies estimate a national carbon price from $48 per mt (Bollen et al.1999) to $407 per mt (Cooper et al. 1999) and have a mean of $199 per mt" assuming no global emission trading.

2.4.2.2 Carbon Leakage and Effects

Carbon leakage refers to the increase in GHG emissions in some countries which are stimulated by an emission reduction in other countries with climate policy. IPCC defines leakage as "... the indirect impact that a targeted land use, land-use change and forestry activity in a certain place at a certain time has on carbon storage at another place or time" (IPCC 2000). IPCC (2001) estimates "carbon leakage" can occur in the order of 5%-20% through a possible relocation of carbon-intensive industries, there are at least three reasons: (1) Reduced Annex B competitiveness in the international marketplace; (2) Lower producer prices of fossil fuels in the international market; (3) Changes in income due to better terms of trade.

Several studies have estimated carbon leakage rates, they ranged from close to zero (Martin et al.(1992) using the GREEN model) or negligible (Barker, 1999) to substantial (Pezzey (1992), Felder and Rutherford, 1993). Babiker (2005) even finds a leakage rate of 130% for one of his scenarios. CGE models have also been widely used to study the problem of carbon leakage. These models generally report leakage rates ranging from 5% to 20% (Burniaux and Oliveira Martins 2000). Babiker (2001) pointed out that KP may cause some energy intensive industries to move to developing countries and estimated the leakage rate due to non-global mitigation implementation.

Leakage can occur in all sectors of the economy with GHG mitigation including agriculture and forestry, Wu (2000) examined the United States Conservation Reserve Program which rural landowners are paid to convert environmentally sensitive farmlands to forest or grassland and found that there was 20% leakage. Wu et al.(2001) further examined this problem and argued that cost benefit analysis of individual projects maybe misleading and need more comprehensive treatment.

McCarl et al. (2001) illustrated the leakage effects through AF operations due to N2O and CH4 mitigation strategies. Adoption of these strategies decrease overall agricultural production but increase their prices and then diminish US exports and drive up international production, as a result leakage happen. Alig et al.(1997) found a leakage rate for carbon-sequestration projects is more than 100% following a 4.9 Mha afforestation program in the US. Sedjo and Sohngen (2000) used a global timber market model to show that potential leakage from 50 Mha of new carbon plantations could be considerable and suggest that these plantations would decrease sequestration outside the new forests by 50%. Golombek and Hoel (2004) showed how the design of an international climate agreement might affect the incentives for technology; the paper effectively built a mechanism to counteract the free-riding incentives and thus reverse the leakage.

CHAPTER III

MODELING APPROACHES USED

In this thesis three analytical approaches are employed: Computable general equilibrium economy wide modeling of GHG mitigation, agricultural and forestry sector modeling and response functions to link them. All three are reviewed below

3.1 CGE Modeling of GHG Emission Mitigation

A CGE model is a system of equations that describes a market equilibrium and is solved to simulate changes in market equilibrium due to external forces. It includes equations describing consumers' and producers' supply and demand behavior derived explicitly from conditions for profit or utility maximization and market-clearing conditions in product and input market (Conrad). Applied CGE models are based on microeconomic, neoclassical theory, but also incorporate structural adjustments intended to capture non-neoclassical behavior, macroeconomic imbalance, and institutional changes. The CGE literature dates back to the late 1930s. Many economists and mathematicians (Ginsburgh and Waelbroeck; Taylor) have contributed to its development and applications since Johansen's (1960) pioneering work on applied CGE modeling. The CGE modeling approach has been further developed and applied to a wide range of economic studies (Devarajan et al; Dixon et al.; Scarf; Shoven and Whalley). Some recent developments include the incorporation of money, assets, and financial markets along with dynamic modeling.

With the improvements in theory and modeling capacity, the CGE modeling approach has become a powerful methodological tool for policy analysis, particularly when multi-sectoral linkages are important. They also make it possible to measure welfare gain or loss associated with a policy change (Gan et al.2003). Given their unique advantages, CGE models are typically suitable for analyzing trade and environmental policies (Adkins and Garbaccio). Because CGE models can provide a framework that allows altering market structure and rationalizing industries, they have also been used to analyze technical standards and regulations (Gasiorek et al and Harrison et al) along with CO2 emission rights trading associated with global warming (Ellerman and Decaux). Because CGE frameworks have the capacity to model all relevant components of an economy and their interrelationships, they are considered to be fruitful for the modeling of climate change impacts and mitigation.

Existing global warming studies mainly use multi-regional models to study energy-economy-environment interactions. These include studies by and with the Nordhaus DICE model (Nordhaus, 1992), the Global 2100 model of Manne and Richels (1990, 1992), the MERGE model of Manne et al.(1995), the OECD model GREEN of Bumiaux et al.(1992a, b), and the EU model GEM-E3 (Capros et al.1996). The GEM-E3 model (Capros et al. 1996; Conrad and Schmidt 1998a, 1998b) is based on a disaggregated representation (11 industries) of 14 EU member state economies linked by trade flow matrices for 11 goods. The model addresses problems of global warming and acidification. Emissions of CO2, SO2 and NOx are differentiated by country, sector of origin, type of fuel, and by goods (producers and consumers' durable goods, and non-durable goods). A variety of policy instruments are used to affect transboundary air pollution, deposition, additive (end-of-pipe) and integrated (substitution) abatement. Recent CGE models address the importance of international trade and financial flows in evaluating greenhouse gas (GHG) control costs. In principle, CGE models could be used to study optimal GHG policies under the possibility of an irreversible global catastrophe (Conrad 1998). Also Pohjola (1996) evaluated the efficient use of forests as an intertemporal allocation problem.

Existing CGE models provide potential data sources for our CGE model and helpful ideas for modeling the AF sectors. However, literature on the response function of AF in climate change and their effects when incorporating uncertainty is relatively limited. Not many CGE models are econometrically estimated (Conrad 1998). Existing studies are limited to firm-level cost responses to these new changes. Simulation experiments are required to check the robustness of the results given the limited quality of the deterministic calibration. Fortunately, existing studies have generated information and data needed for assessing their impacts from an intersectoral, international, and intertemporal perspective. The literature on CGE provides valuable theoretical and empirical references for this proposed integrative modeling analysis and indicated the feasibility of quantifying the impacts of global climate change,

Because soil C stocks change over a long periods of time, it is relatively difficult to measure such changes directly in the soil, although such methods do exist and have been applied at long-term study sites (Watson et al. 2000). But with available data on site-specific soil and climate conditions, land use history, and other relevant parameters, the changes in the stocks of soil C can be simulated over the long periods of time using biophysical process models (Parton et al.1994; Paustian et al. 1996).

Some studies have explored the impact of global climate change on distribution, condition, species composition, and productivity of forests (Aber et al. 2001, Dale et al. 2001, Hansen et al. 2001, Kirschbaum 2000; Kooten and van Kooten 1990; Lindner et al.1996; Woodward and Lee 1995). These studies have covered many forest types at different regions/countries. The impact of global climate change on the productivity of US forests has been modeled and estimated (Joyce and Birdsey 2000). Although there are uncertainties about the impact of global climate change, these studies have provided some general trends about the potential impact of global climate change on forestry productivity as well as practical approaches for estimating the impact.

3.2 Second Generation Model (SGM)

The Second Generation Model (SGM) is the specific CGE model used herein and is a dynamic neoclassical computable general equilibrium model that breaks the world into 14 global regions. It is designed specifically to address issues related to energy, economy and GHG emissions. SGM focuses on emissions of greenhouse gases including CO2 and non-CO2 greenhouse gases from energy and land-use emissions. The SGM development began in 1991 and was developed as a complement to the Edmonds-Reilly model which is a long-term partial equilibrium model (Edmonds, et al. 1993).

The SGM runs in five-year time steps from 1990 through 2050. It especially address issues associated with economic activity and global change, including (1) projecting baseline carbon-equivalent emissions over time; (2) finding the least-cost way for any particular emissions constraint; (3) providing a measure of the carbon price and overall cost of meeting an emissions target.

Intertemporal optimization and dynamic recursive are typically two types of CGE models. The SGM is a dynamic recursive model. The basic difference between these two types of CGE models is the treatment of savings and gross investment. Intertemporal optimization is more computationally intensive, because all time periods are solved simultaneously. Sectoral details in a multi-regional model are limited. Recursive models treat a multi-period decision problem as a sequence of repeated single period choices and are essentially a sequence of static models. Those choices will affect the respective current period with rules for determining the amount of savings and therefore the total amount of new capital constructed in each time period and has implications for the initial conditions in the next period.

Sands et al (2000) stated “The core of the SGM solution mechanism is a derivative-based Newton-Raphson search procedure. This procedure converges very quickly once prices are in the neighborhood of their equilibrium values. A simple sector-by-sector line search is used first to bring prices that are far from equilibrium close to their equilibrium values.”

3.2.1 Overview of SGMGAMS

In this dissertation a version of the SGM model will be integrated with response function results from the FASOM model. To do this a GAMS version of the SGM model is constructed and hereafter will be called SGMGAMS. SGMGAMS is a dynamic, 60-year, single-country (US), recursive model which uses the data from the SGM 2004 model. The data used in SGMGAMS are mainly obtained from the SGM developers (Sands).

SGMGAMS includes 23 sectors. Production sectors with markets are implemented for the so-called “Everything Else” sector or ETE, three energy production sectors, four energy transformation sectors, five agriculture sectors, six industrial sectors and three traditional factors (labor, capital, and land). There are five sub sectors included in the electricity generation sector based on the type of fuel source (generation using oil, coal, gas, nuclear, and hydropower). In addition, there are 22 intermediate inputs and four vintages of capital stocks represented.

As in other GAMS model, the basic components of the SGMGAMS model consist of Sets, Parameters, Variables, and Equations. Sets are the basic building blocks of GAMS and define the model scope. SGMGAMS contains a number of Sets. The most important Sets used in the model are (1) Sector which defines the 23 producing sectors; (2) Subsector which defines alternatives within the fuel based subsectors; (3) Activity which identifies the type of inputs that can be used; (4) Vintage which identifies the number of periods ago that an energy generating item was installed.

SGMGAMS uses parameters to manage data, input data can be derived directly from the given data entry or from the direct assignment through a calculation within the model. Direct assignments are mostly used in calibrating parameters needed in the model.

We define model variables for government saving or borrowing, quantity and price blocks, household consumption, investment, expected profits, capital stock and government activities. Greenhouse gases are included and depict agricultural sinks, agricultural sources, energy emissions, net emissions, carbon tax rates, and total carbon tax revenues collected from sectors. SGMGAMS also keeps track of four components of value added: labor income, land rental income, indirect business taxes, and other value added. Indirect business taxes, less subsidies, are modeled as a proportional tax on production.

The equations in SGMGAMS are generally standard CGE model equations. Equations represent groups of relationships in the model. We use constant-elasticity-of-substitution (CES) or a fixed-coefficient (Leontief) production function for the production process in the SGMGAMs. In general, the structure of SGMGAMS mirrors the SGM model structure.

3.2.1.1 Production Sector

Because we use intermediate inputs in the production of goods, two-level nested CES and Leontief production functions are used in the model (Figure 3.1). The top level includes the aggregated intermediate inputs. Value-added is represented using a

Leontief production process whereas the bottom level models the aggregated

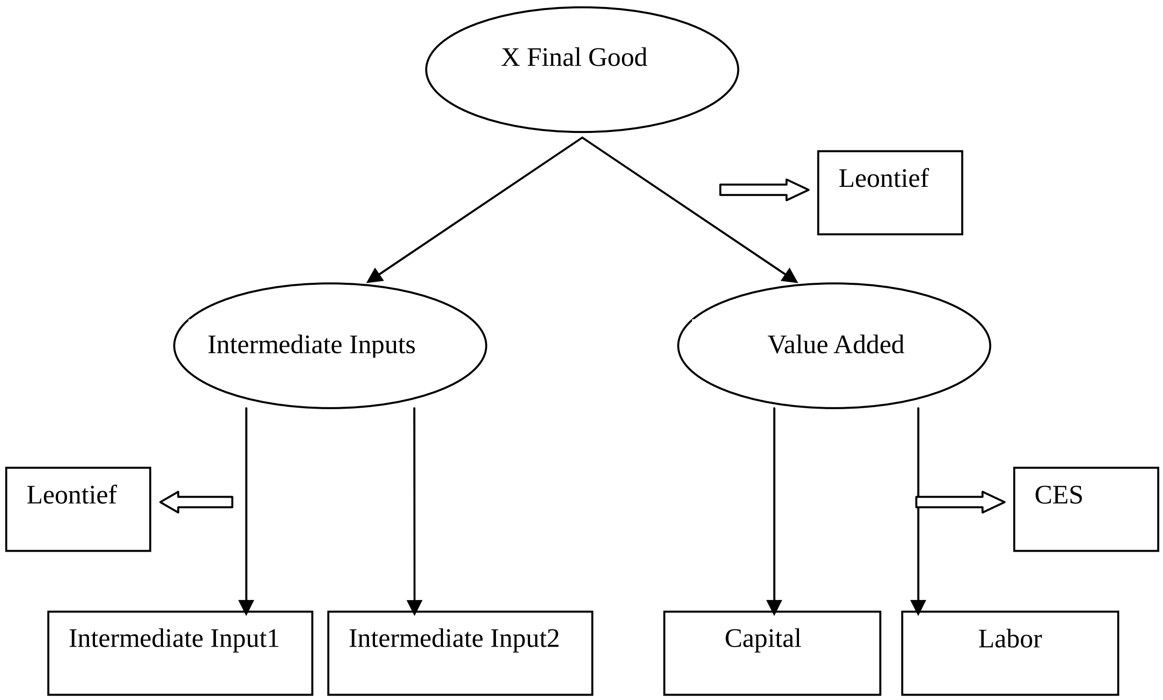

Figure 3.1 Functional forms and structure of production sector in SGMGAMS

intermediate inputs as the Leontief technology of all intermediate inputs but the value-added is represented by the CES production function of the production factors (labor and capital).

There are five equations involved in the production process which included:

A. Quantity Value-Added for the Constant-Elasticity-of-Substitution Bottom Level Technology

The CES production function can be written as:

$$q(\mathbf{x}) = \alpha_0 \left[\sum_{i=1}^{N} (\alpha_i x_i)^{\rho} \right]^{1/\rho}$$

Where gross output q is a function of inputs x and technical coefficients α_0, α_i, i=1, …, N. N is the number of inputs to production. ρ is a parameter that controls the elasticity of substitution σ according to $\sigma = 1/(1-\rho)$. The corresponding CES cost function is:

$$g(\mathbf{p}) = \frac{1}{\alpha_0} \left[\sum_{i=1}^{N} \left(\frac{p_i}{\alpha_i} \right)^{r} \right]^{1/r}$$

where $r = \rho/(\rho - 1)$ and p_i is an element of the price vector **p**.

B. Factor Demand: this first order condition implies that the marginal factor cost (labor and capital) is equal to the marginal revenue product (net of intermediate input costs) of the factor.

C. Quantity Value-Added for the Leontief Top Level Technology

D. Quantity Intermediate Inputs

E. Quantity Intermediate Input Demand

In many cases, we will have fixed inputs to production; the demand for disaggregated intermediate inputs is modeled as a Leontief production. The Leontief, or fixed-coefficient, production function can be written as:

$$q_j(\mathbf{x}) = \alpha_{0j} \min\left(\alpha_{1j} x_{1j}, \ldots, \alpha_{nj} x_{nj}\right)$$

Leontief production is useful for modeling sectors that have a very narrow range for the energy-output ratio (e.g. petroleum refining). The corresponding cost function is linear in prices.

$$g_j(\mathbf{p}) = \frac{1}{\alpha_{0j}} \sum_{i=1}^{n} \frac{p_i}{\alpha_{ij}}$$

where the input-output coefficients are given by $a_{ij} = \frac{1}{\alpha_{0j}\alpha_{ij}}$ note that the input-output coefficients do not depend on prices.

3.2.1.2 Household Sector

Factors such as population, labor and capital endowment, personal saving, and transfer payments are involved in modeling the household consumption. Households supply both labor and land to producing sectors. The supply of labor depends on the price of labor; similarly, the supply of land depends on the price of land.

The household income is the sum of retained earning income, land income, labor income, government transfer payments and a portion of value added minus personal income tax and saving. The household budget is used to make sure that the incomes after tax minus personal saving plus the government transfer payments are exhausted.

The household consumption is allocated across different commodities according to the Linear Expenditure System (LES):

$$P_i Q_i = P_i \gamma_i + \beta_i \left(Y - \sum_i P_i \gamma_i \right)$$

where

P_i is commodity price,

Q_i is commodity quantity,

β_i is the marginal budget share,

γ_i is the minimum requirements subsistence quantity, and Y is the income.

Below shows how this LES is incorporated in the model.

After paying personal income taxes and saving part of income, personal consumption (PCONS) is defined as:

PCONS = (OVA – RE – CIT) + (LABOR – SST) + LAND + GTR – PIT – PSAV

where

LABOR = labor income

LAND = income from rental of land

OVA = other value added

GTR = government transfers to households

PIT = total personal income taxes

PSAV = personal savings

RE = retained earnings

SST = total social security taxes

3.2.1.3 Government Sector

There are six equations depicting the government sector which include the government demands for goods and services, consumption, income, expenditure, transfer payments, and saving.

Government Demand for goods and services are modeled as a constrained optimization problem. Government is assumed to maximize a CES utility function subject to a net income constraint.

Government consumption (GCONS) is equal to tax collections plus a government deficit (GDEF) less government transfers:

GCONS = CIT + PIT + SST + IBT + GDEF – GTR

where

CIT = corporate income taxes

IBT = indirect business taxes – subsidy

The government income is a sum of corporate tax, personal income tax, social security tax, indirect business tax, and carbon tax. Government expenditure is modeled with fixed-coefficient demand functions. Labor is an ever larger component of government expenditure as real wages increase over time. All tax rates are calculated using base-year data and are fixed as the model runs its base year through 2050.

A government budget balance is used to ensure that the government income and expenses are exhausted. The government transfer payments can be modeled in two ways. The transfer payments are assumed to be a function of population:

$$Transfer = \beta_0 Population^{\beta_1}$$

where

β_0 and β_1 are given.

The second alternative model is to make the government transfer payments as a function of expenditure and consumption.

3.2.1.4 Investment Sector

The investment demand function for sectors is a function of last period's investment, a base rate, the growth in working-age population, the expected profit rate, and elasticity of excess profit rate. The base rate represents an overall increase in the amount of capital per worker (or 'capital deepening'). Investment moves toward sectors with higher profit rates.

$$I_{i,t} = I_{i,t-1} * base\_rate * \frac{working\_age\_population_t}{working\_age\_population_{t-1}} * (E\pi_{i,t})^{\varepsilon}$$

The investment demand function for subsector uses the logit function with investment shares sum to 1. Subsectors with the highest profit rate receive the largest share of that sector's investment. The share of investment for subsector j in sector I at time t is given by:

$$s_{ijt} = \frac{\left(E\pi_{ijt}\right)^{\lambda}}{\sum_k \left(E\pi_{ikt}\right)^{\lambda}}$$

where

λ is a rate that investment shares change in response to changes in expected profit rates. Note that crude oil and natural gas sectors have exogenous investment.

Profits are calculated as revenue minus variable costs. Expected profit rates are the expected discounted returns from a $1 investment. An Expected profit rates of 1 means that the investment will break even with both operating and capital costs covered. An expected profit rates of 0 means that only operating costs are covered. The

SGMGAMS will solve for investment based on the expected profit rate and will force capital to stop operating if the profit rate is negative. The expected profit rate is a function of prices and quantities as below:

$$\pi = \alpha_0 p_j \left[1 - (\alpha_0 p_j)^{-r} \sum_{i=1}^{N-M} \left(\frac{p_i}{\alpha_{ij}} \right)^r \right]^{1/r} \left(\sum_{i=N-M+1}^{N} \left(\alpha_{ij} x_{ij} \right)^{\rho} \right)^{1/\rho}$$

where

α_0, and α_{ij} are technical coefficients i=1, …, N

N is the number of inputs to production.

ρ is the elasticity of substitution, $r = \rho/(\rho - 1)$,

p_i is the price of the ith input,

p_j is the price of output j, and

x_{ij} is the amount of input I used in the production of output j

$$x_{ij} = \alpha_{0j}^{1-r} \alpha_{ij}^{-r} \left(\frac{p_j}{p_i} \right)^{1-r} \left(\frac{Y}{Z} \right)^{1/\rho}$$

$$Y = \sum_{i=N-M+1}^{N} (a_{ij} x_{ij})^{\rho}$$

$$Z = 1 - (\alpha_{0j} p_j)^{-r} \sum_{i=1}^{N-M} \left(\frac{p_i}{\alpha_{ij}} \right)^r$$

Carbon taxes increase the fossil fuels price, which are inputs to production, and in turn decrease the profit rate for all production processes that use fossil fuels if other prices don’t change. In the model the greater the consumption of fossil fuels, the greater the decrease in profit rates. The carbon tax, therefore, moves investment away from sectors or subsectors that use fossil fuels as inputs.

The model calculates present values from investment lifetime, real interest rate, sector interest rate, and wedge rate which are directly obtained from SGM. The investment will be converted into a capital stock for the next time period. Capital stocks are modeled as falling into 4 vintage classes. For the next time period, the new vintage of capital stocks operates under the long-run elasticity of substitution while the old vintage of capital stocks operates under the short-run elasticity of substitution.

SGMGAMS is set up as a single country model (only depicting the US). Consequently the quantity of exports and imports are defined as a fixed proportion to the production. The proportions are calculated using data on the quantity exports and imports given in SAM table. Note that when the current model moves from the single region model to global model, these exports and imports will be modified to be traded at world market prices.

3.2.1.5 GHG Modeling

GHG Modeling involves description of both emissions and sinks from all sectors. We discuss separately the agricultural sector and energy/non-energy sectors. The GHG emission limitation is used to put a cap on the carbon net emission under the KP.

We employ response functions estimated using data generated from repeated runs of the US Forest and Agricultural Sector Optimization Model greenhouse gas version (FASOMGHG) to include agricultural emissions and sinks. These response functions are appropriate for modeling agricultural emissions and sink reactions to changes in the general economy. Conceptually, these functions are modeled as follows:

Agricultural Emissions = exp (a_1

\+ a_2 * ln(e_1+Carbon price)

\+ a_3 * ln(e_2*(1+ Δ in US agricultural demand))

\+ a_4 * ln(e_3*(1+ Δ in Energy price))

\+ a_5 * ln(e_4 *(1+ Δ in US agricultural export demand)))

LN (Agricultural Sinks) = exp (b_1

\+ b_2 * ln(e_1+Carbon price)

\+ b_3 * ln(e_2*(1+ Δ in US agricultural demand))

\+ b_4 * ln(e_3*(1+ Δ in Energy price))

\+ b_5 * ln(e_4 *(1+ Δ in US agricultural export demand)))

where

a_i and b_i are estimated parameters associated with carbon price, US agricultural demand, energy price, and US exports; and

e_i are the base for the prices values which are 0 for carbon price and 100 for the others.

These parameters (a_i and b_i) are estimated from FASOMGHG results in the form of a response function with a log-linear function, ln(Y) = A + β*ln(x) where A and β are a vector of intercept terms and a vector of estimated parameters associated with a vector of Y and x, respectively. The base functions with all of the independent variables held at the base level depict the FASOMGHG output under a zero carbon price, and energy price, domestic agricultural product demand, and agricultural export demand.

As for the calculation of GHG emissions in the energy sector, SGMGAMS treats the release of carbon to the atmosphere as proportional to the energy content of the specific fuel by a fixed ratio. We transformed the production levels within the energy input sectors into physical energy units (joules) by using the conversion from SGMGAMS. These physical energy units are multiplied by GHG emission coefficients as shown in equation below and numbers in Table 3.1:

$$\text{Emissions} = c_i * g_{ig} * \text{ values of production}$$

where

c_i is the physical energy conversion and

g_{ig} is the emission coefficient by GHG and energy input types and are included with each technology description.

Table 3.1 Conversion and GHG Emission Coefficients of Energy Sector

Energy Sector	Conversion (ci)	GHG emission coefficients (gig)		
		CO2	CH4	N2O
Crude oil	0.000436	18.81	0.187	0.01
Natural gas	0.000436	14.28	0.187	0.007
Coal	0.001045	23.74	0.354	0.014

The net emissions are defined as the sum of the agricultural and energy emissions minus the agricultural sinks. In the base case, the amount of greenhouse gases is not limited and therefore the US net emissions are in the neighborhood of the 1990 net emissions and the carbon price is zero. The model will search for a carbon price at the equilibrium to meet greenhouse gas constraint like the KP. SGMGAMS get a carbon price from $12 to $50 per metric ton of carbon equivalent under trial runs at the KP limits.

The carbon net emission cap imposes a cost on sectors that use inputs involving with the GHG. We calculate the carbon tax rate and then use it to estimate the total carbon tax value which is considered as revenues to the government but costs to sectors. This total carbon tax values is then included into zero profit condition as costs.

3.2.1.6 Technical Change

Technical change is an important issue in understanding climate change. In SGMGAMS we solve for technical coefficients as a function of input-output coefficients, prices, and the elasticity of substitution:

$$a_{ij}(p) = [\alpha_{0j} * \alpha_{ij}]^{\rho/(1-\rho)} * [\frac{p_j}{p_i}]^{1/(\rho-1)}$$

where

a_{ij} is the input-output coefficient when dealing with input-output matrices, it is the amount of input I required per unit of output j;

α_{0j} is a production sector-specific technical coefficient that can incorporate a Hick's neutral technical change parameter;

α_{ij} is a technology-specific technical coefficient that can incorporate a technology-specific (i.e., non-neutral) technical change parameter;

ρ is a function of the substitution elasticity; $\rho = (\sigma - 1)/\sigma$, where σ is a production sector-specific elasticity of substitution;

p_j is the price received for the commodity produced, and p_i is the price paid by the producer for input.

All of the parameters in the CES production function, and Leontief fixed-coefficient production can be specified to have a growth rate during each of the SGMGAMS five-year time steps, exogenous rates of technical change can be specified for all inputs to production. Technical change growth rates can either grow smoothly over time or vary between time steps.

3.2.1.7 Equilibrium Conditions

By Walras' law, an equilibrium exists when a set of non-zero prices can be found for which all excess demands are zero for any period. This set of prices is not unique. Walras' Law proved that any positive scalar multiple of an equilibrium set of prices is also an equilibrium set of prices. Any commodity in output and input markets, production, consumption levels, production levels, and factor usages can be chosen as a numeraire and its price determined arbitrarily, set for example to one.

A set of price constitutes an economic equilibrium solution and a solution to a CGE if the following conditions are satisfied:

(1) Factor Market Balance --- Total factors usage in production is less than or equal

to the total supply in every factor input markets (labor and capital) which is composed from the household endowments;

(2) Commodity Market Balance --- This condition implies that the total demand in every output market including consumer and intermediate production usage is less than or equal to total supply in that market. In other words, the excess demand in each output market is less than or equal to zero;

(3) Zero Profit Condition --- For each production sector revenues are less than or equal to costs with in effect all rents allocated to factors.

3.2.1.8 Solving the SGMGAMS Model

SGMGAMS falls into the so-called mixed complementarity class (an MCP) in GAMS. To solve such models we must have a model with complementarity requirements associated with each equation as shown in the Table 3.2 below.

Table 3.2 Complementary Items in SGMGAMS

Variable Name	Equation Name
Quantity block:	
QValAdd(Sector, SubSector)	CESQVAEq(Sector, SubSector)
FactPriceNation(Factor)	CESQVAFOC(Factor)
QintA(Sector, SubSector)	QintAEq(Sector, SubSector)
QintC(Activity, Sector, SubSector)	QintCEq(Activity, Sector, SubSector)
Pimp(Commodity)	ImpBal(Commodity)
Pexp(Commodity)	ExpBal(Commodity)
Qimport(Sector, SubSector)	ImportEq(Sector, SubSector)
Qexport(Sector, SubSector)	ExportEq(Sector, SubSector)
Price block:	
FactPriceSec(Factor, Sector, SubSector)	FactPriceSecEq(Factor, Sector, SubSector)
PvalAdd(Sector, SubSector)	PVAEq(Sector, SubSector)
PintA(Sector, SubSector)	PintAEq(Sector, SubSector)
PricePaid(Activity, AllSecAllSub)	PricePaidEq(Activity, AllSecAllSub)
PriceReceive(AllSecAllSub)	PriceReceivEq(AllSecAllSub)

Table 3.2 Continued

Variable Name	Equation Name
Household consumption:	
HhExpend(HouseholdH)	HhExpendEq(HouseholdH)
Hhincome(HouseholdH)	IncomeEq(HouseholdH)
GoodsDemand(Commodity, HouseholdH)	GoodsDemandEq(Commodity, HouseholdH)
Investment:	
Qinvest(AllSecAllSub)	InvestDem(AllSecAllSub)
AlphaInv1(Activity, AllSecAllSub)	AlphaInv1Eq(Activity, AllSecAllSub)
AlphaInv2(AllSecAllSub)	AlphaInv2Eq(AllSecAllSub)
AlphaInv3(Activity, AllSecAllSub)	AlphaInv3Eq(Activity, AllSecAllSub)
AlphaInv(Activity, AllSecAllSub)	AlphaInvEq(Activity, AllSecAllSub)
IbigAij(Activity, AllSecAllSub)	IbigAijEq(Activity, AllSecAllSub)
Zvalue(AllSecAllSub)	ZvalueEq(AllSecAllSub)
SubInvSh1(AllSecAllSub)	SubInvSh1Eq(AllSecAllSub)
SubInvSh3(AllSecAllSub)	SubInvSh3Eq(AllSecAllSub)
ExpProfSec(AllSecAllSub)	ExpProfSecEq(AllSecAllSub)
ExpProfSub(AllSecAllSub)	ExpProfSubEq(AllSecAllSub)
Kstock(AllSecAllSub, Vintage)	KstockEq(AllSecAllSub, Vintage)
Government:	
GovSaving	GovBudgetEq
GovIncome	GovIncomeEq
GovTrnsfPaymt	GovTrnsfEq
GovDemand(HouseHoldG)	GovDemandEq(HouseHoldG)
GovConsumption(Sector, HouseHoldG)	GovConsumpEq(Sector, HouseHoldG)
GovExpend	GovExpendEq
Greenhouse gas:	
AgEmitQ(Ghg, Vintage)	AgEmitQEq(Ghg, Vintage)
AgSinkQ(Ghg, Vintage)	AgSinkQEq(Ghg, Vintage)
EnergyEmitQ(Sector, Ghg, Vintage)	EnergyEmitQEq(Sector, Ghg, Vintage)
NetEmiTQ(Region, Ghg)	NetEmisQEq(Region, Ghg)
Pcarb(Region)	EmisQLimitEq(Region)
CarbTaxRate(Sector, Ghg)	CarbTaxRateEq(Sector, Ghg)
CarbTaxTot(Sector, Ghg)	CarbTaxTotEq(Sector, Ghg)
Equilibrium Condition:	
FactorQ(Factor, Sector, SubSector)	FactorMkt(Factor, Sector, SubSector)
ComPrice(Sector)	SupplyDemandEq(Sector)
Production(Sector, SubSector, Vintage)	Profit(Sector, SubSector, Vintage)

SGMGAMS is solved with the PATH solver. Details on PATH solver can be found at http://www.gams.com/solvers/solvers.htm#PATH. In turn, a solution arises and it can be used in the normal report writing, graphics etc as with any other model.

Our Dynamic SGMGAMS model includes:

Table 3.3 SGMGAMS Model Files and Descriptions

SGMGAMS structure files	Descriptions
sgmdat.gms	containing sets, parameters, scalars, and data
sgmcalib.gms	Dynamic data set
sgmmodel.gms	calculating some predetermined parameters needed to calibrate the model and other exogenous values
sgmdat_dy.gms	containing the equation structure
sgmmodel_dy.gms	containing the recursive equation structure and dynamic process
sgmparm_dy.gms	containing declaration of sets and parameters used for report writing
sgmreport_dy.gms	report writing code
sgmloop_dy.gms	containing codes for comparative analysis and writing out comparative results. Here, emission reductions from the agriculture are considered.
Sgmdynamic.gms	containing the dynamic recursive loop for the model

Details on that solver can be found at http://www.gams.com/solvers/solvers.htm# PATH. In the model, it is expressed as below:

OPTION MCP = PATH;

SOLVE SGMCGE USING MCP.

3.3 AF Sector Modeling of GHG EMISSION Mitigation

Several studies have addressed AF sector contributions to mitigation.

- In a team led by McCarl the Forest and Agricultural Sector Optimization Model FASOM (Adams et al 1988, Lee 2002) has been and is being applied to investigate economic impacts of alternative carbon sequestration policies, climate change impacts on the AF sectors, and other AF sector-associated policies (McCarl et al. 2000).
- Sohngen and Mendelsohn (2003) explored the potential role of forests in GHG mitigation with an optimal control model of C sequestration and energy abatement which integrates the DICE CGE model of GHG and found that the two most important factors in C sequestration are land-use change and lengthening rotations. But the sequestration model does not consider the effect of climate change on AF sector and agricultural sequestration activities were not included.
- Sands and McCarl (2003) examined the appropriate role of sequestration and other actions in terrestrial ecosystems using response functions from a non dynamic AF Sector Optimization Model linked to the CGE Second Generation model (Edmonds et al.) incorporating carbon sequestration in soils and forests. However, they did not include dynamic concerns like saturation or lagged response.

Studies on global climate change pertaining to forestry have concentrated on carbon accounting methods, the role of forests as carbon sinks, the benefits and costs of forest carbon sinks, and the effect of carbon emission trading on timber market and price.

Several forest carbon accounting methods have been proposed (Birdsey 1992). The carbon storage capacity of US forests has been modeled and projected (Joyce and Birdsey 2000). Sohngen and Sedjo (2000) estimated the amount of carbon stored from harvests and management of various types of industrial forests in nine regions around the world using a dynamic optimization model. Boscolo, Buongiorno, and Panayotou (1997) simulated carbon sequestration options through improved management of a tropical rainforest. The role of forests as carbon sinks has been studied worldwide (Sampson and Hair). Okogu and Birol (1994) valued carbon sequestration services of forests using examples from Africa, Asia, and Latin America. The role and economics of both natural forests and new plantations as carbon sinks have been investigated as well (Binkley, Apps, and Nilsson; Sampson and Sedjo; Wright, DiNicola, and Gaitan). Literature on the costs of managing forests as carbon sinks (Creedy and Wurzbacher; Huang and Kronrad; Newell and Stavins; Pfaff et al.; Plantinga; Sedjo et al.; Swisher 1994, 1997) and effects of forest carbon sinks on timber supply, demand, and price (Sedjo and Libby; van Kooten, Binkley, and Delcourt) has appeared. Efficient subsidies to carbon sinks and taxes on GHG emissions have been explored (Binkley et al.; Ley and Sedjo; Pohjola; Reilly et al.; Tahvonen). Uncertainties of carbon sequestration have also been studied (Reddy and Price; van Kooten, Grainger, and Solberg). These existing studies have provided preliminary data and information on forest carbon sequestration rates, estimated costs of managing forests as carbon sinks, resulting timber price changes, and appropriate carbon taxes/subsidies. These findings make it possible to quantify the benefits of and subsidy rates for forest carbon sinks as needed in this study.

3.3.1 FASOM Overview

The Forest and Agricultural Sector Optimization Model (FASOM) will be used herein to examine mitigation actions in the AF sectors. FASOM is a dynamic, intertemporal, price-endogenous, nonlinear and spatial equilibrium model of the AF sectors in the United States. The model depicts the allocation of land over time to competing activities in both the AF sectors. FASOM maximize the present value of aggregated producers' and consumers' surpluses in both AF sectors and find the equilibrium prices and production.

FASOM is a unification of developments in the two sectors based on the Timber Assessment Market Model (TAMM) (Adams and Haynes, 1980) and the agricultural sector model (ASM) (McCarl et al. 1993). FASOM employs 11 supply regions and a single national demand region. The supply regions are: Pacific Northwest-West, Pacific Northwest-East, Pacific Southwest, Rocky Mountains, Northern Plains, Southern Plains, Lake States, Corn Belt, South Central, Northeast, and Southeast.

FASOM is dynamic in that it solves jointly for the multi-market, multi-period, equilibrium in each agricultural and stumpage product market included in the model, over time, and for the intertemporal optimum in the asset market for land. FASOM is nonlinear in that it contains a nonlinear objective function, representing the sum of producers' and consumers' surpluses in the final markets included in the model.

FASOM is price-endogenous in that the prices of the products produced in the two sectors are determined in the model solution. Finally, FASOM is a mathematical programming model because it uses numerical optimization techniques to find the multi-market price and quantity vectors that maximize the value of the objective function, subject to a set of constraints and associated right-hand-side (RHS) values that characterize: the transformation of resources into products over time, initial and terminal conditions, the availability of fixed resources, and policy constraints.

3.3.2 FASOMGHG Overview

Forest and Agricultural Sector Optimization Model—Green House Gas version (FASOMGHG) is a multi-period, intertemporal, price-endogenous, mathematical programming model depicting land transfers and other resource allocations between and within the AF sectors in the US. The model evaluate the welfare and market impacts of public policies that cause land transfers between the sectors and alterations of activities within the sectors and simulate prices, production, management, consumption, GHG effects, and other environmental and economic indicators within these two sectors. FASOMGHG and its predecessor model FASOM have been and are being used to investigate the economic effects of GHG mitigation policy, global climate change impacts, public timber harvest policy, federal farm program policy, biofuel prospects, and pulpwood production by agriculture (Alig et al. 1998; Adams et al. 1999; McCarl, 2000; McCarl and Schneider, 2001, Alig et al. 2001, Reilly et al. 2000, 2002). It can also aid in the appraisal of a wider range of forest and agricultural sector policies.

Lee's dissertation (2002) built the first version of FASOMGHG by modifying FASOM to include desirable mitigation strategies and incorporate the available mitigation strategies in the agricultural sector with the additional coverage of dynamics. The second version of FASOMGHG was undertaken in 2004 updating the biophysical and economic data and the standing forest and carbon accounting which include wood product and forest use of fossil fuels; complete restructuring of the computer implementation, expansion in the forest sector to include product as well as log markets and expansion of the scope of agricultural sector GHG emission source and mitigation strategy coverage, incorporation of wood products processing, improvement of the modeling of agricultural carbon sequestration dynamics, alteration of the model time step from 10 to five-years and improvement of model execution time characteristics.

FASOMGHG covers crop land, pasture land and private timberland in production across the conterminous US, broken into 11 market regions meshed with 63 subregions for agricultural sector coverage. Agriculture is explicitly modeled in all 63 regions for the initial 20 years in the model run to provide maximum regional detail for the near to intermediate term and is collapsed back to 11 regions after the first 20 years of the model run for model size control purposes. Each of the 63 regions is uniquely mapped to the overall 11 regions.

3.3.3 FASOMGHG Modeling

The model solves by searching equilibrium in each affected market, which clears the market. The model runs in a 5-year step for 100 years with a mixture of both implicit and explicit demand and supply curves in each five-year period. The model encompasses four submodels which are forestry sector, agricultural sector, intersectional transfers, GHG submodels and an integrating objective function. (Adams et al 2005)

The Forestry sector submodel depicts forestry production and consumption, manufacturing, input supply, interregional transport, international trade, and terminal forest inventory valuation. Forested land is differentiated by region, site condition, the age cohort of trees, ownership class, cover type, management regime, and suitability of land for agricultural used. The feasible solution for this submodel is constrained by forest inventory; land; input/factor supply; log supply/demand balances; intermediate and final product balances; processing capacity; and terminal inventory valuation.

The agricultural sector submodel covers agricultural sector crop and livestock production, processing, feed blending, factor supply, consumption, interregional transport and international trade including terminal valuation of land remaining in agriculture. This sub-model incorporates constraints on crop and pasture land; factor supply; supply/demand balances for crop, livestock, processed and blended feed products; and crop/livestock mixes.

The intersectoral transfers submodel depicts transfers of land and commodities between the forestry and agricultural sectors. The flow of land between agriculture and forestry is an endogenous element of the model. The model compare the net present value of the future returns to land in the sector with those earned if land transfer to the other sector plus adjustment costs with land transfers

The GHG submodel covers GHG accounting and payments to net GHG emission reductions from agriculture and forestry. The GHG accounts reflect sequestration activity, emission activity, and biofuel related offset activity. The integrating objective function computes total consumers' and producers' surplus across all four submodels and is maximized in the FASOMGHG solution.

3.3.3.1 Greenhouse Gas Modeling

FASOMGHG accounts for changes in AF related net GHG emissions in some categories. These categories involved with forest, agriculture, and biofuel feed stocks. The types of net GHG gains include carbon sequestration, direct emissions and biofuel offsets. Carbon sequestration refers to storage of the GHGs for more than one year. The FASOMGHG output thus provides the simulation of GHG emissions and sequestration in both the AF sectors. Three GHGs – CO_2, CH4 and N_2O are covered in FASOMGHG. FASOMGHG depicts positive credits for sequestration and when the amount of carbon sequestered is reduced by harvesting forests or changing land uses. This in effect corresponds to an emission of the sequestered carbon and is thus "penalized" as a GHG emission debit. FASOMGHG give credits for activities which cause an offsetting reduction in GHG emissions by use of agricultural commodities as biofuel feed stocks.

FASOMGHG includes discounts of the GHG accounts on a national basis. The use of a discount means that a portion of the GHG sequestration quantity in a particular account may not be considered a recipient of incentive payments or counted as part of the mitigation total. Saturation, permanence, leakage, additionality and uncertainty are generally reasons for discounting GHG accounts. These features are not used herein.

The supply and appropriate role of agricultural and forest actions involves dynamic considerations. In particular one need to recognize that saturation will occur. Some changes in land use and management practices can increase the stock of C in the soil up to a new equilibrium state. As the soil C level increases, the rate of soil absorption of C eventually decreases and gains stop. West et al. (2000) reviewing over 267 experiments show this occurs after approximately 10-15 years for tillage changes and 30 years for rotation changes. Furthermore, if the management changes, the soil and forest would become an emissions source thereby indicating that the GHG benefits are only temporary, so policy needs to be designed not only to encourage sequestration but also to maintain it over time. These concerns have collectively become known as the permanence issue in the international debate over inclusion of soil C as an allowable sink under the Kyoto Protocol.

Kim, McCarl and Murray (2005) derive the permanence discount using a net present value that considers the relative value of nonpermanent GHG reduction with that of the perfect permanent GHG reduction. FASOMGHG doesn’t adopt this rate because it is a multi-period net present value maximizing model that considers the exact same features. Carbon leakage refers to the increase in GHG emissions in some countries which are stimulated by an emission reduction in other countries with climate policy. Additionality means that some of the GHG emission reductions and increased sequestration is considered part of the baseline, rather than induced by the policy. Uncertainty is also an important issue, in reality, natural and economic factors could cause variation from the expected GHG effects. GHG payments will generally be discounted based on underlying uncertainty. An uncertainty discount reduces the creditable amount of GHG activity, it constitutes offsets at a confidence level such as a 90% confidence interval proposed by the Canadians in the Kyoto negotiations. FASOMGHG considers net GHG emission activity at the average or point estimate level so a discount is not otherwise covered in FASOMGHG.

3.3.3.2 GHG Mitigation Alternatives

As we showed above, there are numerous management alternatives to reduce net GHG emissions below baseline levels in the AF sector. Table 3.4 gives us the mitigation strategies we adapted in FASOMGHG, data source and the associated GHG, for example, crop mix will reduce both CO2 and N2O emissions since different crop demands different level of input use, such as fertilizer and energy.

We modeled the net GHG mitigation contribution of modeled activity dynamically because the multi-period nature of FASOMGHG. We chose to model the cumulative amounts of sequestration or emissions incurred during each model time period

Table 3.4 Mitigation Strategies in FASOMGHG

Mitigation strategy	Strategy Nature	GHG affected		
		CO_2	CH_4	N_2O
Forest management	Offset	X		
Forest land conversion	Sequestration	X		
Biofuel production	Offset	X	X	X
Crop mix alteration	Emission, Sequestration	X		X
Rice acreage reduction	Emission		X	
Crop fertilizer rate reduction	Emission	X		X
Other crop input alteration	Emission	X		
Crop tillage alteration	Sequestration	X		
Grassland conversion	Sequestration	X		
Irrigated /dry land conversion	Emission	X		X
Livestock management	Emission		X	
Livestock herd size alteration	Emission		X	X
Livestock system change	Emission		X	X
Liquid manure management	Emission		X	X

3.4 Response Functions

The potential for the AF sector to mitigate GHG emissions has been the subject of intensive study recently, McCarl and Schneider (2000) shows that emission mitigation can be achieved through a number of AF mitigation strategies such as sink strategies, biofuel production or emissions management relative to carbon, methane (CH4) or nitrous oxide (N2O) and suggests the usage of these low cost strategies. In addition, Watson (2000) argues that there are many options where cost-effective AF sector interventions could reduce net GHG emissions and have a wide range of co-benefits consistent with sustainable development.

FASOMGHG is too large and complex to be directly incorporated into a general economy wide computable general equilibrium model. Consequently, this dissertation simulates the model under many alternative possible signals from SGMGAMS model to generate data on responses, and then econometrically estimated response functions are derived to encapsulate that data into SGMGAMs.

The signals we chose to use from the rest of the economy are carbon and fuel prices plus the level of agricultural demand domestically and internationally and one period lag variables. These signals will constitute the Independent variables in the response functions.

3.4.1 Methodology

The response functions will represent conditional response in later time periods based on price expectations and resultant actions in earlier time periods. The response functions will be estimated based on results of an AF sector model. They will provide estimates of sequestration and emission reductions in AF 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. Gillig et al.(2002) estimated all functions with a multiplicative functional form:

$$\mathrm{Y}_{\mathrm{kt}} = \mathrm{A}_{\mathrm{kt}} \prod_{i} \mathrm{x}_{\mathrm{i}}^{\beta_{kit}} \varepsilon_{kt}$$

where

Y is a vector of dependent variables like CO2 emissions,

x is a vector of independent variables like carbon price,

A_k is the intercept term associated with the kth response function

β_{ki} is a vector of estimated parameters associated the vector x of signals and

ε is a vector of error terms.

A multiplicative shifter for time period was also employed to use these functions about how saturation causes the GHG offsets to drop off over time.

Initially models were estimated for the net emissions and sinks for agriculture assuming that at a zero price and 100% for each of the other three factors that the output was zero. We modeled them as lagged process because it takes time for adjustment, so is modeled as a lagged process. The estimated models are then conceptually set up as follows:

$$SE_i = f_i(Tax, FuelP, AgQ, ExpQ, LagSE_i) \qquad i = CO_2,\ CH_4 \text{ and } N_2O$$

$$KE_i = f_i(Tax, FuelP, AgQ, ExpQ, LagKE_i) \qquad i = CO_2,\ CH_4 \text{ and } N_2O$$

where

SE_i refers to quantity of emissions of type i in 1000 metric tons of carbon equivalent generated on an annual basis;

KE_i refer to quantity of sink absorption of type i in 1000 metric tons of carbon equivalent generated on an annual basis;

Tax is the carbon tax in $/ton carbon equivalent;

FuelP is the price of fuel in percent relative to the base;

AgQ is the quantity of domestic agricultural demand in percent relative to the base;

ExpQ is the quantity of export demand in percent relative to the base;

$LagKE_i$ and $LagSE_i$ are the one period (5 years on our model) lag of the KE_i and KE_i

The CO_2 emissions data we use here come from fuel, tillage change, fertilizer manufacture, irrigation pumping, pesticide manufacture, ethanol/biofuel production and offsets, grassland development, and afforestation/forest management. N2O emissions are from fertilizer, manure, residue burning, biomass production and use and corn ethanol processing. Enteric fermentation, manure, rice, biomass power plant use, and corn ethanol processing produce CH4 emissions. The dependent variables include source and sink emissions which are reported in 1000 metric tons of carbon equivalent. All equations were estimated with Cobb-Douglas (Cobb) and Box-Cox constant elasticity of substitution (Box-CES).

3.4.2 Data Generation

We developed response functions from a wide variety of scenarios. In particular, the aggregated FASOMGHG was used to simulate results under three cases each for 559 scenarios. Of these 459 scenarios result from running FASOMGHG under all combinations of 17 levels of carbon taxes, 3 levels of fuel prices, 3 levels of agricultural production, and 3 levels of exports. Specifically the carbon dioxide tax levels used in $/ton were 0, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 300, and 400. The fuel prices (net of influence of carbon taxes) were applied to ethanol and energy prices in

FASOMGHG and were set at 90%, 100%, and 110% of Base levels. Domestic agricultural demand was varied through 80%, 100%, and 120% of Base levels. Export Demands are varied to be 80%, 100%, and 120% of the Base levels.

Another 100 random scenarios were drawn randomly over a uniform distribution spanning the ranges specified above for each of the 4 variables. These 100 scenarios are used to build degrees of freedom for the estimation of regression parameters applied to each of the 4 varied factors. Thus the total number of observations used in the estimation procedure is 559.

On each of these 559 scenarios, 3 cases were run, these additional scenarios also have carbon price drawn randomly by uniform distribution but from the neighborhood of the previous carbon price level in the first 20 years in model. For example, if carbon price is $15 in one of these 559 scenarios, then 3 additional cases will have carbon price randomly from the neighborhood of $15. These additional scenarios will make carbon price totally unpredictable to solve the perfect foresight problem of FASOMGHG. Therefore this makes our total 1667 scenarios.

3.4.3 Response Functions Estimated and Functional Form

We estimated response functions for three classes of outputs: GHG emissions sequestration implications, economic performance and environmental indicators.

3.4.3.1 Response Functions for GHG Emissions and Sequestration

GHG response functions were estimated for CO_2, CH_4, and N_2O emissions, offsets and sinks. Note that the different gases are reported since they can move in different directions with the change of a carbon price. CO_2 functions are estimated for emissions and sequestration changes associated with fuel, tillage change, fertilizer manufacture, irrigation pumping, pesticide manufacture, ethanol/biofuel offsets, grassland development, and afforestation/forest management. N_2O emissions functions are estimated for fertilizer, manure, residue burning, biomass powered electricity generation and corn ethanol processing. CH_4 emissions functions are estimated for enteric fermentation, manure, rice, biomass power plant use, and corn ethanol processing. CO_2 sinks functions are estimated for forests, grassland expansion and tillage change.

3.4.3.2 Response Functions for Economic Performance

These response functions give predictions of agricultural market characteristics, land use, allocation and valuation, and welfare. Agricultural market characteristics cover levels of production, exports, imports and prices. We develop and use Fisher index numbers due to that fact that the agricultural production and prices are heterogeneous such that quantities and prices are in different measures. These 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 2001 market conditions without carbon prices.

AF GHG mitigation strategies involve summaries of the changes in tillage practices or land conversion between cropped land, biofuel land use, pasture/grassland, and forest land. We also estimate functions for land rental rates and area under tillage practices. Finally we estimate functions for US consumers' surplus, US producers' surplus and foreign welfare.

3.4.3.3 Environmental Indicators

Environmental externalities and co-benefits are considered in our response function estimation. As an example of negative externality, more GHG emissions will come from economic and population expansion, which will increase agricultural food consumption and agricultural production and then lead to more management intensification (more fertilizer or pesticide). On the contrast, co-benefits exist with the mitigation policy; carbon taxes on fertilizer usage to reduce GHG emissions also increase other environmental indicators such as water or air quality improvement. 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.

3.4.3.4 Cobb-Douglas Functional Form

We use a non-linear Cobb-Douglas function for the ease of estimation procedure as below:

$$\text{Emisssion} = A * \text{Tax}^{\alpha_1} * \text{FuelP}^{\alpha_2} * \text{AgQ}^{\alpha_3} * \text{ExpQ}^{\alpha_4} * \varepsilon,$$

where

ε is a random disturbance,

α_0, α_1, α_2, α_3, and α_4 are parameters,

This is transformed to a log-linear function:

$$\log(\text{Emission}) = \alpha_0 \log(\text{constant}) + \alpha_1 \log(\text{Tax}) + \alpha_2 \log(\text{FuelP}) + \alpha_3 \log(\text{AgQ}) + \alpha_4 \log(\text{ExpQ}) + \log(\varepsilon),$$

where log(ε) is treated as a additive random error with a zero mean.

Here since the carbon tax starts from $0 to $400, log(x+1) is used

where

x = carbon tax at $0, and

the value of log(x+1) is equal to zero.

3.4.3.5 Box-Cox CES Functional Form

Put in words

$$(E^{\lambda}-1)/\lambda = \alpha_0 + \alpha_1 * (Tax^{\lambda}-1)/\lambda + \alpha_2 * (FuelP^{\lambda}-1)/\lambda + \alpha_3 * (AgQ^{\lambda}-1)/\lambda + \alpha_4 * (ExpQ^{\lambda}-1)/\lambda,$$

where

E refers to emissions,

all the other variables are defined as above.

According to Bariam (1991), as long as the value of λ is less than unity, this Box-Cox functional form is a CES function. The elasticity of substitution, σ, is equal to 1/(1-λ), and the return to scale, ν, is equal to $\alpha_1+\alpha_2+\alpha_3+\alpha_4$.

CHAPTER IV

FASOM RESULTS AND RESPONSE FUNCTIONS

This chapter illustrates the FASOMGHG results and a set of estimated response functions plus the data generation process.

4.1 Data Development

We developed response functions from a wide variety of scenarios. In particular, the aggregated FASOMGHG was used to simulate results under 1667 scenarios. 459 scenarios result from combinations of 17 levels of carbon taxes, 3 levels of fuel prices, 3 levels of agricultural production, and 3 levels of exports. Specifically the carbon dioxide tax levels used in $/ton were 0, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 300, and 400. The fuel prices (net of influence of carbon taxes) were applied to ethanol and energy prices in FASOMGHG and were set at 90%, 100%, and 110% of Base levels. Domestic agricultural demand was varied through 80%, 100%, and 120% of Base levels. Export Demands are varied to be 80%, 100%, and 120% of the Base levels.

Another 100 random scenarios were drawn by uniform distribution from the ranges specified above for each of the 4 variables. These 100 scenarios are used to build degrees of freedom for parameters applied to each of the 4 varied factors. Thus the total number of observations used in the estimation procedure is 559.

On each of these 559 scenarios, 3 additional scenarios are developed, the additional scenario has carbon price drawn randomly by uniform distribution from the neighborhood of the previous carbon price level in the first 20 years in model. Therefore this makes our total 1667 scenarios.

4.2 Handling Dynamic Adjustments and Perfect Information

One of the limitations of FASOMGHG is ‘perfect information’ and foresight in that current plans are made with full information on future carbon prices. In this dissertation; we partially relax this assumption and consider the complex dynamic adjustment issue.

“FASOMGHG incorporates the multi-period path of future prices. Farmers and timberland owners are able to foresee the consequences of their behavior (when they plant trees or crops) on future stumpage and agricultural product prices and incorporate that information into their behavior. The FASOMGHG model uses deterministic expectations, or "perfect foresight”, whereby expected future prices and the prices that are realized in the future are identical.” (Adams, Alig, McCarl et al. 2005).

As we shown above, carbon prices are exogenously specified by five year period. Although this input can reflect the pattern of increasing GHG prices through time, the perfect foresight assumption and rising prices are changing model’s economic behavior in complex ways and introduce some problem.

To solve the perfect foresight problem, the carbon dioxide price as a signal and independent variable changed randomly after the first two decades. This is realized by the three additional scenarios run from each of the 559 scenarios. The variation of the carbon price by decade enables us to look at dynamic issues associated with that and some effects of earlier decisions on later outcomes.

4.3 Basic Results

Results were obtained for many variables, more than can be included here. Below we present results on the following key items of

- GHG abatement levels
- Welfare implications
- Environmental indicators
- Market prices, quantities and production levels

4.3.1 GHG Abatement

Here, we convert tons of CO_2, CH_4, and N_2O into tons of carbon dioxide equivalent (CDE) using IPCC (1995) 100-year GWPs allowing the model to consider tradeoffs among the GHGs. All the mitigation incentive payments are in dollars per ton of carbon dioxide equivalent. FASOMGHG is initially run with a zero carbon equivalent price which we refer to the business-as-usual (BAU) scenario. In the first two decades, several constraints are used to limit all the agricultural and forest production to year 2000 level including the BAU scenario.

4.3.2 Welfare Implications

In the first two decades, the aggregate agricultural and forest sector surplus increases as the mitigation program is going on. After that, the aggregate agricultural and forest sector surplus experiences a loss every year (Table 4.1). Table 4.1 shows the model results of the total welfare, producer welfare, consumer welfare, foreign welfare, forest and agriculture welfare in each model year, although we ran over 17 levels of carbon price, we choose to report four major carbon price scenarios which are $10, $25, $50 $100 per ton and also report the annuity welfare equivalent in billion 2001 dollars. The higher the carbon price, the more total surplus, the longer that total surplus is increasing though there is some variation from year to year. When the price is $10/ton, the aggregate surplus annually increases 2.889 billion dollars and this surplus gain is up to 17.02 billion dollars when the price is $100/ton in year 2000. Producers' surplus increases in the first 25 years when price is less than $100/ton then experience losses while consumers lose all the time, when the price is $100/ton. Producers gain in the first 30 years then experience losses. When the price is $10/ton, the producer surplus annually increases 3.01 billion dollars and this surplus gain is up to 24.977 billion dollars when price is $100/ton in year 2000. Foreign producers and consumers experience losses all the time. The magnitude of the loss increases as the price increases and goes up to a 1.297 billion dollars annual loss in year 2000.

We observe quite different welfare distributions between the agricultural and forest sectors. The surplus in agricultural sector only increases in years 2000 and 2025 and experiences losses in all the other time periods, the higher the price, the more the loss. Surplus in the forest sector gains in the first 25 years and in the end of modeling period and experience loss in the late modeling period. The surplus changes in the forest sector are not dramatic while the agricultural surplus accrues with time at an increasing speed.

Table 4.1 Welfare Change Relative to Business-as-usual Scenario (no GHG policy)

Time	Welfare Items	$10	$25	$50	$100
		--------------- Billion Dollars/Year ---------------			
2000	Total Welfare	2.889	5.244	9.170	17.021
2005		0.131	0.104	0.058	0.051
2010		1.217	1.192	1.153	1.076
2015		-0.034	-0.080	-0.157	-0.305
2020		-0.004	0.005	0.052	0.276
2025		0.187	0.466	0.966	1.988
2030		-0.034	-0.071	-0.106	-0.081
2035		-0.046	-0.126	-0.152	-0.225
2040		-0.056	-0.139	-0.339	-0.273
2045		-0.027	-0.049	-0.178	-0.542
2050		-0.031	-0.040	-0.084	-0.269
2055		-0.072	-0.140	-0.308	-0.716
2060		-0.075	-0.150	-0.304	-0.752
2065		-0.125	-0.292	-0.612	-1.233
2070		-0.011	0.097	0.132	0.247
2000	Producer Welfare	3.012	5.361	17.133	24.977
2005		0.600	0.571	0.526	3.233
2010		2.578	2.554	2.517	2.444
2015		-0.025	-0.069	-0.152	-0.298
2020		0.010	0.033	0.111	0.396
2025		0.200	0.504	1.030	2.127
2030		-0.020	-0.030	-0.034	0.052
2035		-0.032	-0.087	-0.076	-0.085
2040		-0.052	-0.127	-0.319	-0.190
2045		-0.023	-0.046	-0.160	-0.494
2050		-0.028	-0.057	-0.095	-0.257
2055		-0.071	-0.151	-0.332	-0.734
2060		-0.073	-0.145	-0.287	-0.692
2065		-0.127	-0.278	-0.598	-1.189
2070		0.035	0.190	0.294	0.535

Table 4.1 Continued

		$10	$25	$50	$100
Time	Welfare Items	--------------- Billion Dollars/Year ---------------			
2000	Consumer Welfare	-0.124	-0.117	-7.962	-7.955
2005		-0.469	-0.467	-0.468	-3.182
2010		-1.361	-1.362	-1.364	-1.367
2015		-0.010	-0.011	-0.004	-0.007
2020		-0.013	-0.028	-0.059	-0.120
2025		-0.013	-0.038	-0.064	-0.139
2030		-0.014	-0.041	-0.073	-0.133
2035		-0.014	-0.039	-0.076	-0.139
2040		-0.004	-0.011	-0.020	-0.083
2045		-0.004	-0.003	-0.018	-0.048
2050		-0.003	0.017	0.011	-0.011
2055		-0.001	0.011	0.025	0.018
2060		-0.001	-0.005	-0.017	-0.060
2065		0.003	-0.013	-0.014	-0.044
2070		-0.046	-0.093	-0.162	-0.289
2000	Foreign Welfare	-1.295	-1.296	-1.296	-1.297
2005		-0.150	-0.150	-0.150	-0.230
2010		-1.234	-1.235	-1.235	-1.235
2015		0.004	0.004	0.004	0.004
2020		-0.003	-0.006	-0.011	-0.021
2025		-0.002	-0.009	-0.016	-0.028
2030		-0.002	-0.011	-0.017	-0.026
2035		-0.002	-0.004	-0.029	-0.038
2040		-0.002	-0.005	-0.006	-0.103
2045		-0.002	-0.005	-0.008	-0.012
2050		-0.002	-0.004	-0.007	-0.009
2055		-0.001	-0.002	-0.002	-0.001
2060		-0.002	-0.005	-0.009	-0.016
2065		-0.002	-0.006	-0.008	-0.013
2070		-0.013	-0.028	-0.050	-0.084
2000	Forest Welfare	2.833	5.105	8.894	16.470
2005		0.134	0.111	0.073	0.079
2010		1.220	1.201	1.170	1.108

Table 4.1 Continued

Time	Welfare Items	$10	$25	$50	$100
		------------------ Billion Dollars/Year			------------------
2015		-0.031	-0.069	-0.136	-0.267
2020		0.000	0.019	0.091	0.345
2025		0.001	0.020	0.105	0.336
2030		-0.003	0.015	0.091	0.292
2035		-0.015	-0.026	0.054	0.181
2040		-0.003	-0.015	-0.045	0.125
2045		-0.010	-0.028	-0.051	-0.045
2050		-0.011	-0.018	-0.013	0.068
2055		-0.037	-0.081	-0.168	-0.288
2060		-0.025	-0.065	-0.114	-0.157
2065		-0.057	-0.193	-0.371	-0.681
2070		0.060	0.180	0.374	0.755
2000	Agricultural Welfare	0.056	0.139	0.276	0.552
2005		-0.002	-0.007	-0.015	-0.028
2010		-0.003	-0.009	-0.017	-0.031
2015		-0.004	-0.011	-0.020	-0.038
2020		-0.003	-0.014	-0.039	-0.069
2025		0.186	0.445	0.862	1.653
2030		-0.031	-0.086	-0.197	-0.373
2035		-0.031	-0.100	-0.206	-0.406
2040		-0.053	-0.124	-0.294	-0.397
2045		-0.017	-0.021	-0.126	-0.498
2050		-0.020	-0.021	-0.071	-0.336
2055		-0.035	-0.058	-0.140	-0.428
2060		-0.050	-0.084	-0.190	-0.595
2065		-0.068	-0.098	-0.241	-0.553
2070		-0.071	-0.083	-0.242	-0.509

Around a $2.83 billion dollar annual gains in year 2005 when the price is $10/ton, the welfare in the forest sector increase to 16.47 billion dollar when price is $100. The welfare in the agriculture sector is 56 million dollar when price is $10 and increase 10 times to 0.552 billion dollars when the price is $100/ton. Similarly, at the end of molding period which is year 2070, the loss in the agricultural sector is 10 times larger when the price increases from $10 to $100, amounting to more than 500 million dollars in 2070 for the $100/ton scenario.

4.3.3 Environmental Impacts

GHG mitigation has environmental impacts. Agricultural management strategies to offset GHG emissions can have significant co-benefits such as cleaner water, reducing erosion and increased recreational land. For example, adoption of conservative tillage practices can reduce CO2 emission from the soil and prevent soil erosion, it also increase some input like herbicide. Burtraw et al. (2003) find carbon emissions tax would yield NOx-related health benefits, greater total benefits are achieved with greater carbon tax. In addition, the consequences of mitigation actions are strongly influenced by local climate and physical conditions.

In the first two decades, several constraints are used to limit all the agricultural and forest production to year 2000 level including the BAU scenario, so all the environmental indicators have no change in the first 2 decades. In a joint implementation environment, the overall Phosphorus Fertilizer application decreases all the time, overall nitrogen fertilizer application fluctuate with time, it decrease in the earlier modeling period and then increase in the next 15 years and this pattern continues, potassium application decrease in the earlier modeling time and increase in the later modeling period (Table 4.2). Soil erosion is greatly reduced annually in the first 2 decades but increase dramatically after that. The higher the price, the more change for environmental impact. Moreover, most environmental benefits last over time.

Table 4.2 Environmental Impacts Relative Change to the BAU Scenario

Time	Welfare Items	$10	$25	$50	$100
		--------------- percentage ----------------			
2000	Nitrogen Fertilizer	0.00	0.00	0.00	0.00
2005		0.00	0.00	0.00	0.00
2010		0.00	0.00	0.00	0.00
2015		0.00	0.00	0.00	0.00
2020		-11.68	-18.55	-27.36	-33.58
2025		-12.63	-21.62	-24.39	-34.14
2030		-12.68	-22.96	-25.96	-32.97
2035		-9.72	-22.74	-25.05	-34.74
2040		1.88	6.08	16.24	35.09
2045		3.19	9.86	16.31	37.58
2050		0.08	4.27	17.56	31.65
2055		-1.30	1.85	15.34	30.43
2060		-2.04	1.81	10.84	20.88
2065		0.55	1.46	12.93	21.73
2070		2.95	4.83	15.17	26.20
2000	Phosphorus Fertilizer	0.00	0.00	0.00	0.00
2005		0.00	0.00	0.00	0.00
2010		0.00	0.00	0.00	0.00
2015		0.00	0.00	0.00	0.00
2020		-4.85	-12.02	-14.98	-19.78
2025		-5.19	-15.28	-14.23	-20.58
2030		-5.47	-15.00	-18.18	-20.96
2035		-4.08	-11.90	-17.01	-24.16
2040		-2.79	-4.80	3.32	12.53
2045		-0.60	0.00	4.58	14.27
2050		-1.13	1.35	9.56	16.55
2055		-1.66	0.32	8.66	16.03

Table 4.2 Continued

Time	Welfare Items	$10	$25	$50	$100
		---------------- percentage			----------------
2060		-1.52	-0.96	5.38	9.37
2065		-1.38	-3.19	4.91	6.81
2070		-0.29	-0.99	3.57	8.14
2000	Potassium	0.00	0.00	0.00	0.00
2005		0.00	0.00	0.00	0.00
2010		0.00	0.00	0.00	0.00
2015		0.00	0.00	0.00	0.00
2020		-8.77	-13.26	-16.05	-20.07
2025		-2.04	-7.86	-4.41	-14.36
2030		-3.02	-6.43	-8.06	-15.44
2035		-0.77	-6.02	-7.71	-21.06
2040		5.97	-2.61	16.39	81.11
2045		-2.29	5.31	15.41	69.31
2050		6.72	14.41	33.89	91.92
2055		4.24	9.36	32.48	91.31
2060		3.41	13.82	25.32	32.52
2065		7.45	23.44	33.31	41.96
2070		3.89	16.17	8.65	37.77
2000	Fossil Fuel	0.00	0.00	0.00	0.00
2005		0.00	0.00	0.00	0.00
2010		0.00	0.00	0.00	0.00
2015		0.00	0.00	0.00	0.00
2020		-3.05	-12.87	-15.36	-19.06
2025		-5.46	-15.81	-16.08	-23.22
2030		-5.52	-15.87	-20.45	-24.46
2035		-4.53	-12.81	-19.23	-26.81
2040		-2.22	-3.08	3.22	21.71
2045		-0.14	2.23	2.40	5.54
2050		3.80	9.77	9.25	12.86
2055		4.61	10.68	9.87	12.82
2060		5.39	11.45	8.63	4.03
2065		4.50	12.16	8.40	4.49
2070		2.78	4.09	5.66	-2.00

Table 4.2 Continued

Time	Welfare Items	$10	$25	$50	$100
		--------------- percentage ----------------			
2000	Erosion	0.00	0.00	0.00	0.00
2005		0.00	0.00	0.00	0.00
2010		0.00	0.00	0.00	0.00
2015		0.00	0.00	0.00	0.00
2020		-4.94	-14.44	-15.72	-24.64
2025		-8.31	-16.73	-20.33	-31.86
2030		-7.37	-19.22	-22.49	-30.07
2035		-6.07	-14.78	-19.00	-29.22
2040		10.58	15.05	34.21	45.01
2045		1.21	16.95	44.84	45.64
2050		25.01	74.96	120.88	115.98
2055		26.67	80.45	131.00	123.99
2060		28.81	99.52	137.60	106.38
2065		23.68	89.79	132.49	106.19
2070		-1.20	25.75	42.09	53.88

4.3.4 Market Impacts on Agricultural and Forest Sectors

When price is lower than $100, FASOMGHG shows that crop production decreases over time as of result of crop management adjustments and land use change. The aggregate production is close to the baseline level and the price indices are close to the baseline over the modeling period, and the higher price, the lower production (Table 4.3). The aggregate crop production highly diminishes when price is $100 which falls down to 80% of the baseline lever in 10 years but increase dramatically in the later period. The aggregate crop price increases as a result of the rise of mitigation incentive and the higher TCE price, the higher aggregate crop price. When TCE price is $10, the aggregated crop price is about 2% higher in the first decade, 44% in the second decade, and is 5.55% higher by 2070 than the baseline level. When TCE price is $100, this number goes to 30%, 232% and 24% accordingly.

Table 4.3 Effects on Overall Crop Production Relative to the BAU Scenario

Time	US Crop	$10	$25	$50	$100
		--------------- percentage ---------------			
2000	Quantity	100.00	100.00	100.00	100.00
2005		100.00	100.00	100.00	100.00
2010		99.64	99.84	99.93	99.97
2015		99.96	99.96	99.96	99.98
2020		96.43	88.02	85.13	82.07
2025		95.33	84.72	86.03	82.40
2030		95.15	85.39	81.99	81.86
2035		96.13	88.82	83.39	77.85
2040		94.12	89.66	104.27	139.07
2045		98.30	97.06	98.92	135.23
2050		95.14	96.61	99.34	138.13
2055		93.78	94.85	97.32	138.48
2060		93.59	91.73	91.91	134.33
2065		95.56	87.49	94.22	126.81
2070		93.76	91.16	98.41	125.17
2000	Price	99.79	105.77	112.45	126.06
2005		100.11	105.90	114.50	128.28
2010		102.29	112.96	119.06	130.86
2015		105.67	116.22	135.67	172.64
2020		124.16	150.60	191.42	282.56
2025		144.15	188.87	217.35	332.43
2030		141.14	184.07	225.61	296.04
2035		126.96	167.52	199.64	256.39
2040		100.38	106.67	113.96	172.52
2045		100.28	102.12	104.50	120.28
2050		98.48	91.81	92.57	100.95
2055		101.85	99.64	95.38	99.40
2060		100.19	100.36	99.41	114.30
2065		96.90	104.06	100.62	113.58
2070		105.55	108.53	106.10	124.90

Similarly, the livestock production is sensitive to the TCE price, the higher the price, the higher the impact on livestock production (Table 4.4). In a low TCE price, the overall livestock production has not changed significantly over time relative to BAU scenario. When TCE price is $10, for example, the aggregate livestock production increase 0.15% in the first decade decrease 0.01% by year 2007, the biggest change is 5% but 1% change is maintained over time. When TCE price is $100, the reduction goes up by 12.3% in the first decade and 22.8% in the second decade. The livestock production increases in later modeling period. Consequently, on the contrast, the aggregate livestock prices increase as the given mitigation incentive increases in the first several decades. When TCE price is low, the livestock price changes are small, but such changes become significant as the TCE price goes. The aggregate livestock price increases 1.06% in the first decade without the constraint when the price is $10 and goes up to 8.5% when the price is $100. The aggregate price index bounces back to the baseline level by year 2070. The aggregate livestock price has a negative correlation with the aggregate livestock production.

Table 4.4 Effects on Overall Livestock Production Relative to the BAU Scenario

Time	US Livestock	$10	$25	$50	$100
		percentage			
2020	Quantity	99.00	99.60	95.10	87.24
2025		100.15	96.59	93.18	83.73
2030		98.96	96.76	89.57	83.37
2035		95.09	90.66	85.84	77.34
2040		98.59	96.48	100.95	105.04
2045		97.74	98.33	100.05	106.34
2050		99.99	100.03	100.37	105.50
2055		100.02	102.03	102.99	107.63
2060		100.13	102.01	101.41	102.13
2065		100.07	101.69	100.66	102.14
2070		99.99	102.01	102.05	104.82
2020	Price	105.85	111.31	123.07	132.75
2025		101.06	104.14	106.02	108.50
2030		102.63	104.95	115.45	117.07
2035		98.67	99.20	114.06	133.24
2040		100.97	102.29	101.27	134.10
2045		100.46	100.35	100.76	100.69
2050		99.89	100.50	100.69	100.25
2055		99.94	99.86	100.38	100.22
2060		99.78	99.70	100.12	101.30
2065		99.75	99.71	100.20	100.84
2070		99.99	99.69	100.24	100.36

4.4 Result from Response Function

Following the procedure we described in the previous chapter and using the data we simulated from the FASOMGHG, we estimated response functions. Definitions of the dependent and independent variables along with their corresponding values at the 1997 base year are presented in Table 4.5. We estimated 60 response functions for the with-saturation scenario using the data from first model period (2000-2020). with-saturation scenario is normal scenario, FASOMGHG already include the approach to saturation and produces unequal and ultimately diminishing sequestration contributions over time, here we assume that the agricultural soil will reach saturation in 20 years and thus we use the data from model period 2000 to 2020. The results are presented in Table 4.6. Because the saturation and volatility characteristics of agricultural soil carbon sequestration are an important consideration in this research, we estimated another 60 response functions for the without-saturation scenario to be later incorporated into CGE model. The without-saturation scenarios are using data from the whole model periods, we assume that the sequestration will not decrease over time and take effect in the whole model period. All the response functions are using an ordinary least squares estimation procedure and the main results are reported in the Table 4.7. The time trend is used as an independent variable for all the response function estimation.

In general, the regressions had good structural fits according to the goodness-of-fit statistic (R squared) and all the efficient are significant at the 5% significant level. There is some exception and the few poor fits are likely caused by functional form choice (McCarl and Schneider, 2000). The other reason is that our data contain irreducible error, for example, one dependent variable corresponds to 2 or more independent variable, and the limiting value of R squared can't be improved in this case.

Table 4.5 Dependent and Independent Variable Definitions, Units, Base Levels, and Average Values

Dependent Variable	Definition	Unit	Base	Average
Total GHG Emissions and sink in AF				
CO_2	CO_2 emissions	MMTCE	180.36	2681.522
CH_4	CH_4 emissions	MMTCE	861.562	17631.72
N_2O	N_2O emissions	MMTCE	415.66	7098.87
CO_2	CO_2 sequestration	MMTCE	-32172.81	5590.261
Agricultural Market conditions:				
Agricultural Price Index	Fisher index of prices of US Agricultural goods including crop and livestock commodities	Fisher index	100	317.34
Agricultural Production Index	Fisher index of production of US Agricultural goods including crop and livestock commodities	Fisher index	100	685.16
Agricultural Exports Index	Fisher index of exports for US Agricultural goods including crop and livestock commodities	Fisher index	100	329.74
Agricultural Imports Index	Fisher index of imports for US Agricultural goods including crop and livestock commodities	Fisher index	100	247.59
Agricultural and Forestry Land related data:				
Crop land	Area of crop land farmed	10^6 hectares	122.34	75.81
Crop land rent	National average crop land rental rate	$/hectare	11.50	694.993
Pasture land	Area of pasture land used	10^6hectares	95.71	120.86
Pasture land rent	National average pasture land rental rate	$/hectare		92.293
Afforested land	Area afforested	10^6 hectares	9.81	8.75
Biofuel land	Area devoted to biofuel crops for power plants	10^6 hectares	2.12	40.37
Conventional tillage	Crop Area treated with conventional tillage	10^6 hectares	76.39684	24.16616
Conservation tillage	Crop Area treated with conservation tillage	10^6 hectares	25.44364	5.690172
No-tillage	Crop Area treated with no-till practices	10^6 hectares	20.49566	45.94942
Welfare:				
Producer Welfare	US producer welfare	Million $	13501.25	1772.77
Consumer Welfare	US consumer welfare	Million $	21050.85	42887.2
Rest of the World	Rest of the world welfare	Million $	-1650.18	288.566
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 hectares	8.61	7.41

Table 4.5 Continued

Dependent Variable	Definition	Unit	Base	Average
Nitrogen fertilizer	Total nitrogen fertilizer use	10^6 tons	1.162502	1.01
Phosphorus fertilizer	Total phosphorus fertilizer use	10^6 tons	0.904005	0.61
Potassium fertilizer	Total potassium fertilizer use	10^6 tons	0.465745	0.1993
Fossil fuel	Fossil fuel expenditures	10^6 dollars	3.182941	1.728
Erosion	Water and wind erosion	10^6 tons	1.468432	0.44
Lag of all dependent variables above				
Lag	1 period lag	-	-	-
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	-

(Source: Gillig D., B.A. McCarl, R.D. Sands, 2004.)

Table 4.6 Estimated Response Function Parameters for First Period (without Saturation)

Dependent Variables	Intercept	Carbon Price	Fuel Price	Agricul-ture Demand	Exports	Trend	Lag of carbon price	R^2
GHG Accounts:								
Total CO_2 emissions[a]	-161.520	-0.003	-0.004	-0.038	0.080	-0.039	0.003	0.954
CO_2 from fert. irrig. and fuel use[b]	-162.987	-0.002	0.000	-0.001	0.081	0.000	0.003	0.955
Total CH_4 emissions	-157.799	-0.004	-0.005	-0.031	0.078	-0.041	0.003	0.940
Total N_2Oemissions	-164.424	-0.002	-0.003	-0.040	0.081	-0.039	0.003	0.957
Total CO_2 sinks[c]	6.956	0.001	-0.019	0.037	-0.003	-0.016*	0.001*	0.030
CO_2 offset from biofuel	-262.329	0.110	0.051	-0.151	0.129	-0.137	-0.001*	0.848
Agricultural Prices and Production:								
Price	105.719	-0.023	0.423	-4.095	-0.054	-0.197	-0.010	0.035
Production	-18.069	-0.0001*	0.017	-0.034	0.009	0.0078*	-0.000*	0.652.
Exports	-39.930	0.001	0.004	-0.088	0.019	-0.018	0.000	0.757
Imports	-15.693	0.002	0.003	-0.146	0.007	-0.013	0.001	0.543
Welfare:								
U.S. Producer Welfare	312.299	0.057	0.156	-0.022	-0.155	-0.039	0.003	0.388
U.S. Consumer Welfare	13.257	0.027	0.011	0.074	-0.007	-0.086	-0.019	0.149
Rest of the World Welfare	0.03*	0.008	0.003	0.006	0.000	-0.018*	0.001	0.301
Agricultural and Forestry Practices:								
Cropped land	-0.336	0.000	0.001	-0.001	0.000	0.001	0.000	0.031
Cropped land rent	-244.628	0.064	-1.534	0.437	0.119	0.936	-0.023	0.145
Pasture land	10.485	-0.002	-0.004	0.013	-0.005	-0.002	-0.001	0.493
Pasture land rent	875.078	0.400	0.489	-2.608	-0.434	-1.663	-0.387	0.448
Forest land	-20.679	-0.008	0.071	-0.057	0.010	-0.008	-0.008	0.057
Biofuel crop land	-240.968	0.036	0.064	-0.142	0.119	-0.075	-0.001	0.365
Conventional tillage	11.146	-0.003	-0.016	0.008	-0.005	0.018	-0.001	0.276
Conservation tillage	42.091	-0.007	-0.033	0.073	-0.021	0.025	-0.001	0.298

Table 4.6 Continued

Dependent Variables	Intercept	Carbon Price	Fuel Price	Agricul-ture Demand	Exports	Trend	Lag of carbon price	R^2
No-tillage	-52.023	0.007	0.050	-0.033	0.026	-0.032	0.000	0.471
Environmental Indicators:								
Irrigated land	0.171	0.008	-0.005	0.309	0.000	-0.313	0.002	0.503
Nitrogen fertilizer	-103.580	0.004	-0.002	0.472	0.052	-0.538	0.012	0.106
Phosphorus fertilizer	10.342	0.001	-0.008	0.037	-0.005	-0.024	0.000	0.380
Potassium fertilizer	10.172	0.001	-0.008	0.032	-0.005	-0.020	0.000	0.378
Fossil fuel	13.953	-0.003	-0.006	0.022	-0.007	-0.005	-0.001	0.314
Erosion	18.287	-0.004	-0.008	0.017	-0.009	0.005	-0.001	0.325

[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 and irrigation pumping that maybe accounted elsewhere in and integrated Total CO_2 sinks adds up CO_2 in forests and CO_2 in agricultural soil.

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

Table 4.7. Estimated Response Function Parameters for Whole Period (with Saturation)

Dependent Variables	Intercept	Carbon Price	Fuel Price	Agriculture Demand	Exports	Trend	lag of carbon price	R^2
GHG Accounts:								
Total CO_2 emissions[a]	-1.499	-0.006	0.012	0.01*	-0.006*	0.165	0.011	0.860
CO_2 from fert. irrig. and fuel use[b]	-1.506	-0.005	0.016	-0.003*	-0.0095*	0.166	0.012	0.858
Total CH_4 emissions	-1.769	-0.014	-0.023	0.103	0.050	0.186	-0.001*	0.917
Total N_2O emissions	-1.610	-0.005	0.018	0.019*	-0.011*	0.176	0.011	0.880
Total CO_2 sinks[c]	0.185	2.368	-0.025	0.049	0.239		-0.011	0.924
Total CO_2 sinks with saturation	0.366	0.001	-0.001	0.000	0.001			0.260
CO_2 offset from biofuel	1.212	0.672	0.034	-0.133	-0.039		0.025	0.960
Agricultural Prices and Production:								
Price	1.099	-0.007	0.013	-0.303	0.063		0.800	0.949
Production	-0.643	-0.004	0.011	0.138	0.01*	0.073	-0.004	0.820
Exports	-1.577	0.011	0.016	-0.399	-0.092	0.169	-0.007	0.926
Imports	-1.027	0.009	0.012	-0.724	-0.031	0.115	-0.004	0.885
Welfare:								
U.S. Producer Welfare	0.015	4.250	-0.231	0.388	0.516		0.015*	0.905
U.S. Consumer Welfare	-0.202	-0.001	-0.001	0.032	0.001*		0.000	0.650
Rest of the World Welfare	0.955	-0.024	-0.031	0.084	0.561		0.183	0.431
Agricultural and Forestry Practices:								
Cropped land	0.332	0.005	0.025	0.051	-0.0086*	-0.043	0.006	0.649
Cropped land rent	-5.337	0.067	-0.496	-0.516	-0.685	0.376	-0.013	0.500
Pasture land	-0.239	-0.007	-0.022	0.0001*	0.038	0.026	-0.006	0.450
Pasture land rent	1.169	0.463	-0.017	-0.014	0.004		-0.00*	0.910
Forest land	-1.275	-0.089	0.265	-0.52*	-0.327*		0.000	0.060
Biofuel crop land	1.196	0.375	0.022	0.066	0.002		0.020	0.914
Conventional tillage	-0.113	0.011	-0.011	0.144	-0.038		0.000	0.200
Conservation tillage	-0.621	0.248	-0.230	-0.882	-0.516		0.000	0.260

Table 4.7 Continued

Dependent Variables	Intercept	Carbon Price	Fuel Price	Agriculture Demand	Exports	Trend	lag of carbon price	R^2
No-tillage	*-0.127*	*-0.003*	*0.071*	*0.208*	*0.036*		*0.000*	*0.065*
Environmental Indicators:								
Irrigated land	1.038	0.021	0.032	0.004	-0.040		0.265	0.380
Nitrogen fertilizer	1.030	0.016	0.012	0.206	0.055		0.281	0.450
Phosphorus fertilizer	1.014	0.007	0.007	0.149	-0.024		0.275	0.330
Potassium fertilizer	1.173	0.458	0.006	0.295	0.016		0.056	0.830
Fossil fuel	*-0.205*	*0.007*	*-0.003*	*0.170*	*-0.002*		*0.000*	*0.300*
Erosion	1.030	0.014	-0.010	0.111	-0.071		0.604	0.470

[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 and irrigation pumping that maybe accounted elsewhere in and integrated Total CO_2 sinks adds up CO_2 in forests and CO_2 in agricultural soil.

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

Notes:

All of estimated regression parameters, except for the intercept terms, could be interpreted as elasticities because of the multiplicative Cobb-Douglas functional form. The elasticity is the ratio of the percentage change in dependent with respect to a percentage change in independent variables. For example, Table 4.6 indicates that carbon price elasticity for the total CO_2 sinks is 2.37. Hence, a one percent increase (decrease) in a carbon price will increase (decrease) the quantity of CO_2 sinks by 2.37 percent.

All the estimation parameters with blue color are estimated using log linear Cobb-Douglas functional form and the rest are using Non linear estimation procedure.

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

The important part to be integrated into CGE model works well which includes the GHG emissions and sequestration, commodity production and price. As we expected, when the carbon price goes up,

- sequestration increases
- GHG emissions diminish,
- agricultural prices and imports increase
- agricultural production and exports decrease,
- pasture and afforested land increases while
- crop and biofuels land shrinks,
- land values increase,
- conventional and conservation tillage rise while no-tillage falls,
- producers surplus increases while consumers surplus and the warfare of Foreign producers and consumers experience falls,
- all environmental indices including total cropped land, irrigated land, erosion and fertilizer usage are reduced indicating an environmental improvement.

Domestic demand has significant effect on GHG emissions and sinks. The upshift of domestic demand lead to the increase of the GHG emissions and decrease of GHG sinks, rise of all environmental indices while falling of export production and prices.

Export increases tend to decrease nitrous oxide and carbon dioxide emissions while increase the livestock related methane emissions. Production and prices rise as does all welfare. The environmental impact shows some improvement except for Nitrogen and

Potassium fertilizer.

Fuel prices have positive impact on the levels of agricultural prices and production, CO_2 emissions increase while have negative impact on sinks. Fuel price as well as other independent variable has the larger magnitude of the effect on sinks than that on emissions. Not all the results follow our expectation, further investigation should be demanded.

We add time trend as an independent variable due to the dynamic feature of our data and shows the fitness of the function improves dramatically. All the GHG emissions are increasing over time at around 16% rate every five years. This happens in reality due to the increase using of energy and permanent issue of GHG mitigations.

In the with-saturation scenario, carbon price and fuel price has greater effect on the GHG emissions and sinks, agricultural prices and production as well as welfare. The coefficients of carbon price and fuel price increase significantly in the with-saturation scenario. Domestic demand has greater effect on GHG emissions and sinks while export has less impact in the with-saturation scenario. This results proves that ignorance of saturation will overestimate the role of agricultural and forestry carbon sequestration activities. But in overall, saturations won’t discourage AF carbon sequestration as a short run strategy to buy time for new technology developments. More comparisons for the two period’s scenarios will be elaborated in the next sessions with CGE results.

CHAPTER V

INTEGRATION INTO CGE MODEL

This chapter illustrates the results from integrating FASOMGHG results into the SGM CGE model using the response functions estimated above. FASOMGHG is a large and complex model with around 255,000 variables and 35,000 constraints and this size makes it unsuitable for direct integration into a computable general equilibrium model. Thus, the response functions discussed above are used and since we use a log form we enter a one for the zero carbon price case rather than a zero. All SGMGAMS regions are adjusted to for base year energy consumption, economic activity and GHG emissions. Our base year is 1990. Table 5.1 illustrates the variable values at year 2035 which is end of our model period when carbon price is $11.

The bridge we use to connect the FASOMGHG and SGMGAMS are response functions. Specifically, we incorporate these two sets of response functions

$$SE_i = f_i(Tax, FuelP, AgQ, ExpQ, LagSE_i) \quad i = CO_2, CH_4 \text{ and } N_2O$$

$$KE_i = f_i(Tax, FuelP, AgQ, ExpQ, LagKE_i) \quad i = CO_2, CH_4 \text{ and } N_2O$$

where

SE_i refers to the quantity of emissions of type i in 1000 metric tons of carbon equivalent generated on an annual basis;

KE_i refer to quantity of sink absorption of type i in 1000 metric tons of carbon equivalent generated on an annual basis;

Tax is the carbon tax in $/ton carbon equivalent;

FuelP is the price of fuel in percent relative to the base;

AgQ is the quantity of domestic agricultural demand in percent relative to the base;

ExpQ is the quantity of export demand in percent relative to the base;

$LagKE_i$ and $LagSE_i$ are the one period (5 years on our model) lag of the KE_i and KE_i

The two sets of response functions are incorporated using with a log-linear function, ln(Y) = A + β*ln(x) where A and β are a vector of intercept terms and a vector of estimated parameters associated with a vector of Y and x, respectively

These are used to incorporate agricultural emissions and sink reactions to changes in the general economy into the CGE model. These functions are integrated into Greenhouse Gas Module in SGMGAMS, That module portrays both emissions and sinks from all sectors. We deal with the agricultural sector, energy sectors as well as non-energy sectors separately.

The response functions from both periods above are both integrated into SGMGAMS respectively. With the response functions from the first periods, we run the SGMGAMS in with-saturation scenarios; the results for without-saturation scenario are obtained by integrating the response functions from whole FASOMGHG model period into our SGMGAMS model. In the with-saturation scenario, the same response functions are employed throughout the whole SGMGAMS model periods, in other words, we

Table 5.1 Variable Values at Year 2035 When Carbon Price Is $11

Sectors	Market # (m)	Market Production	Commodity Price	Revenue
1 Other Agricultural	1	651.9755	1.01	657.93
2 Service	2	70798.2991	1.00	70798.30
3 Crude Oil	3	374.7559	0.88	328.25
4 Natural Gas	4	452.9253	0.85	383.99
5 Coal Production	5	248.6306	0.91	227.42
6 Products from Coal	6	22.1803	1.68	37.31
8 Electricity Generation	8	2654.5036	0.89	2368.96
9 Oil Refining	9	1275.2048	1.06	1349.64
10 Distributed Gas	10	1023.3284	0.99	1009.91
11 Paper and Pulp	11	1717.8106	1.12	1925.66
12 Chemicals	12	2644.4405	1.03	2733.91
13 Cement	13	482.3122	1.23	592.89
14 Primary Metals (i.e., iron and steel)	14	429.6600	1.36	585.31
15 Metals	15	359.5601	1.29	464.76
16 Other Industry and Construction	16	12114.4078	1.48	17889.86
17 Passenger Transport	17	1717.8125	1.12	1931.11
18 Freight Transport	18	2357.0496	1.12	2650.72
19 Grains and Oil Crops	19	749.8303	0.78	583.98
20 Animal Products	20	1103.4240	0.93	1021.48
21 Forestry	21	91.7598	0.69	62.89
22 Food Processing	22	4584.1508	0.97	4454.74

assume that the agricultural GHG sequestration will remain the same over time once the saturation occurs.

5.1 Basic Results

Figure 5.1 to Figure 5.3 show carbon dioxide, methane and nitrous oxide from Oil, Coal, and Gas combustion respectively. Carbon price is an endogenous variable in our model and it is solved simultaneously with other variables when the equilibrium is reached. Table 5.2 reports the methane emissions and share from Oil, Coal, and Gas combustion, The results shows that Coal is the biggest emission source accounting for more than 50% of the methane and nitrous oxide emissions and more than 40% of the carbon dioxide emissions. Figures 5.4 and 5.5 show the carbon dioxide emission and carbon price across a 50-year model analysis. Carbon price is zero in the earlier years and increases in the last 6 periods, but carbon dioxide emissions from agriculture are basically constant; the net emissions from all the sectors increase in the first 5 periods then reach equilibrium and stabilize. Figure 5.6 illustrates the relationships between production and carbon emissions in various sectors; the highest increase is coal production.

McCarl et al. (2001) argued that “Omitting consideration of select strategies can overstate the importance of the remaining strategies and understate total mitigative potential.” and “Appraisals of the importance of strategies should depend on economic consideration of resource substitution possibilities, costs, economies of scale up and local suitability ”. Thus the AF alternatives should be examined in a full economy context. Figure 5.7 shows that the AF mitigation increases as the carbon price increase over time. In the earlier model period, while the carbon price is zero as determined by SGMGAMS, AF emissions and sink are quite small compare to energy sector, as carbon price increase over time, AF sink contribute about 25% off the net emissions. As McCarl et al. (2001) also pointed out that AF sectors "may be very important in a world that requires time and technological investment to develop low-cost greenhouse gas emission offsets."

Table 5.2. Methane Emissions and Share from Oil, Coal, and Gas Combustion

	Emissions (BTCeq)			Share		
Year	CrudeOil	NatGas	Coal	CrudeOil	NatGas	Coal
1995	0.04	0.02	0.07	30.77	15.38	53.85
2000	0.04	0.03	0.08	26.67	20.00	53.33
2005	0.06	0.04	0.11	28.57	19.05	52.38
2010	0.08	0.05	0.15	28.57	17.86	53.57
2015	0.11	0.08	0.22	26.83	19.51	53.66
2020	0.17	0.11	0.32	28.33	18.33	53.33
2025	0.24	0.16	0.43	28.92	19.28	51.81
2030	0.28	0.19	0.49	29.17	19.79	51.04
2035	0.32	0.23	0.56	28.83	20.72	50.45
2040	0.27	0.19	0.49	28.42	20.00	51.58
2045	0.33	0.24	0.58	28.70	20.87	50.43
2050	0.27	0.19	0.5	28.13	19.79	52.08

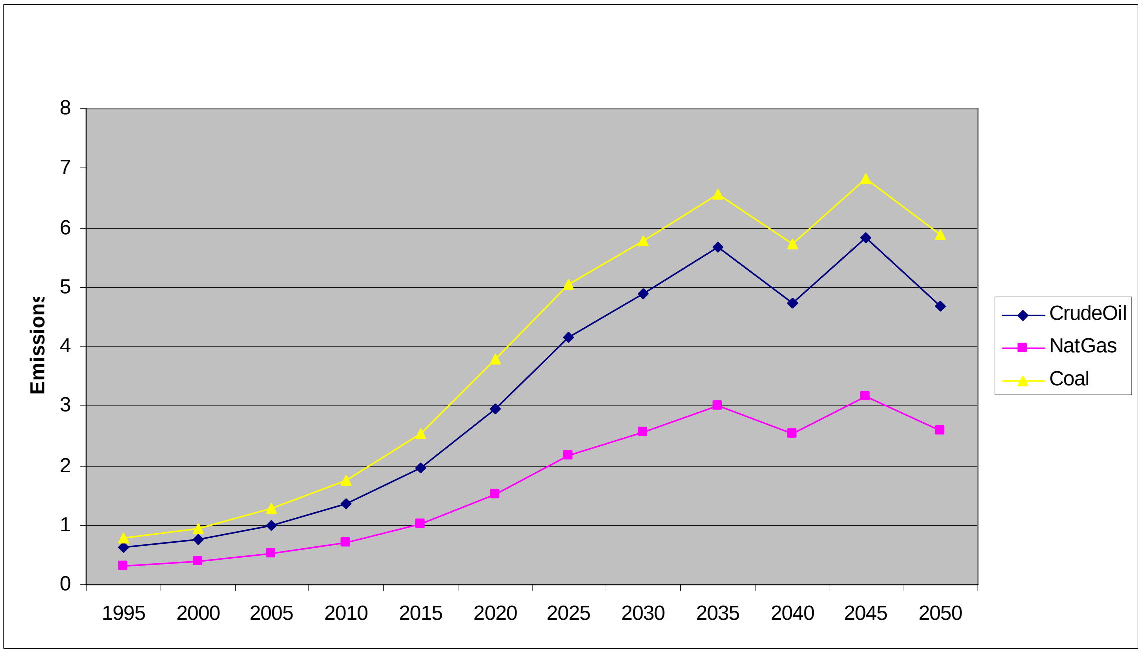

Figure 5.1 Carbon dioxide emissions from oil, coal, and gas combustion in BTCEq

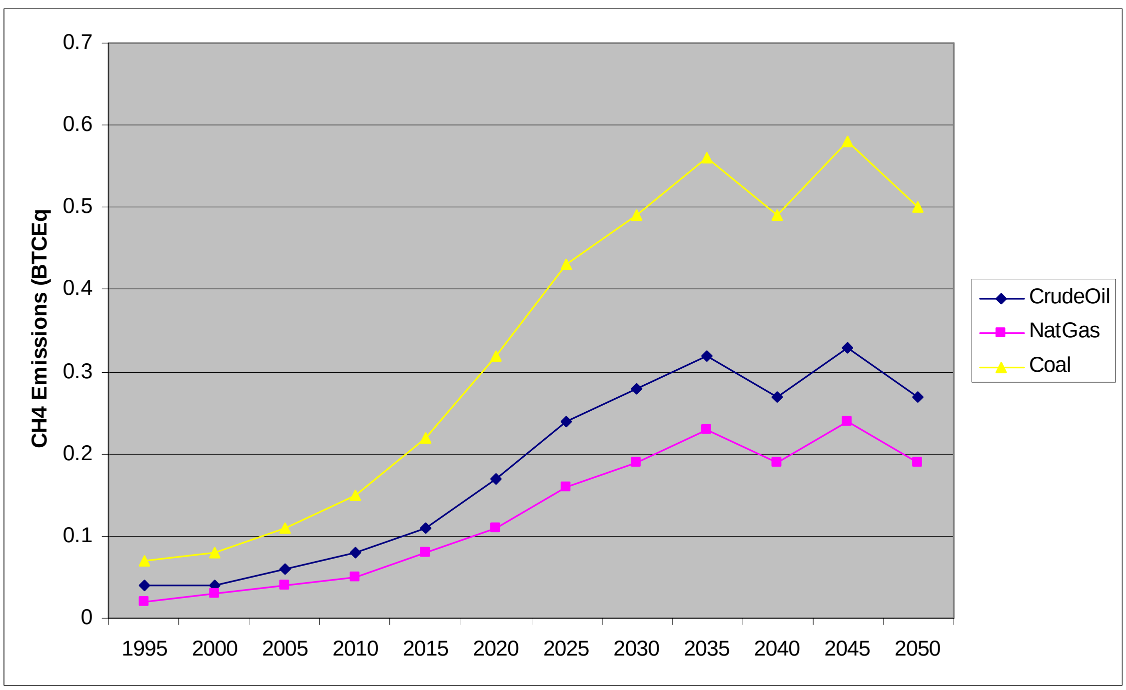

Figure 5.2 Methane emissions from oil, coal, and gas combustion

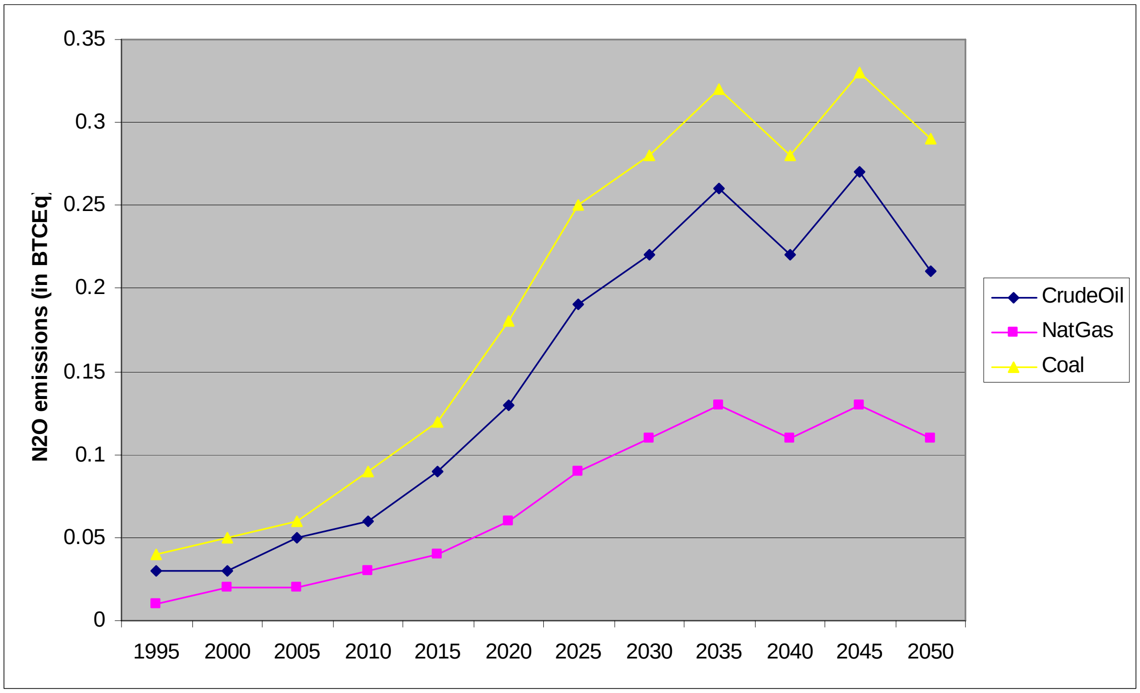

Figure 5.3 Nitrous oxide from oil, coal, and gas combustion from SGMGAMS

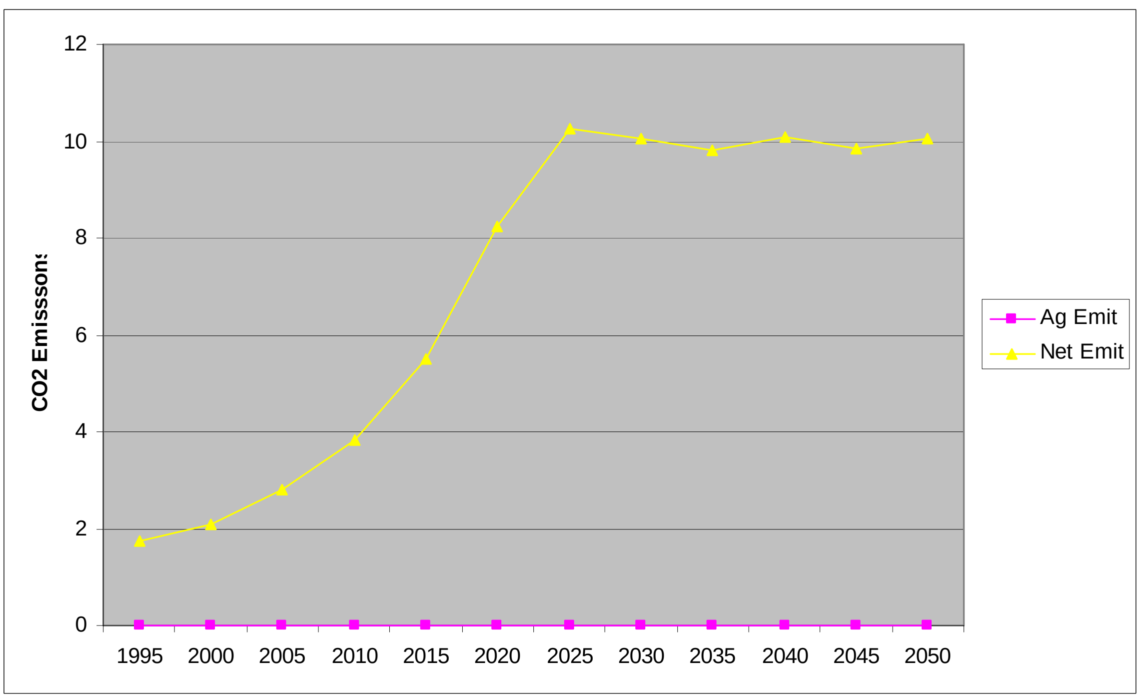

Figure 5.4 Forecasting carbon dioxide emissions from agriculture and net emissions

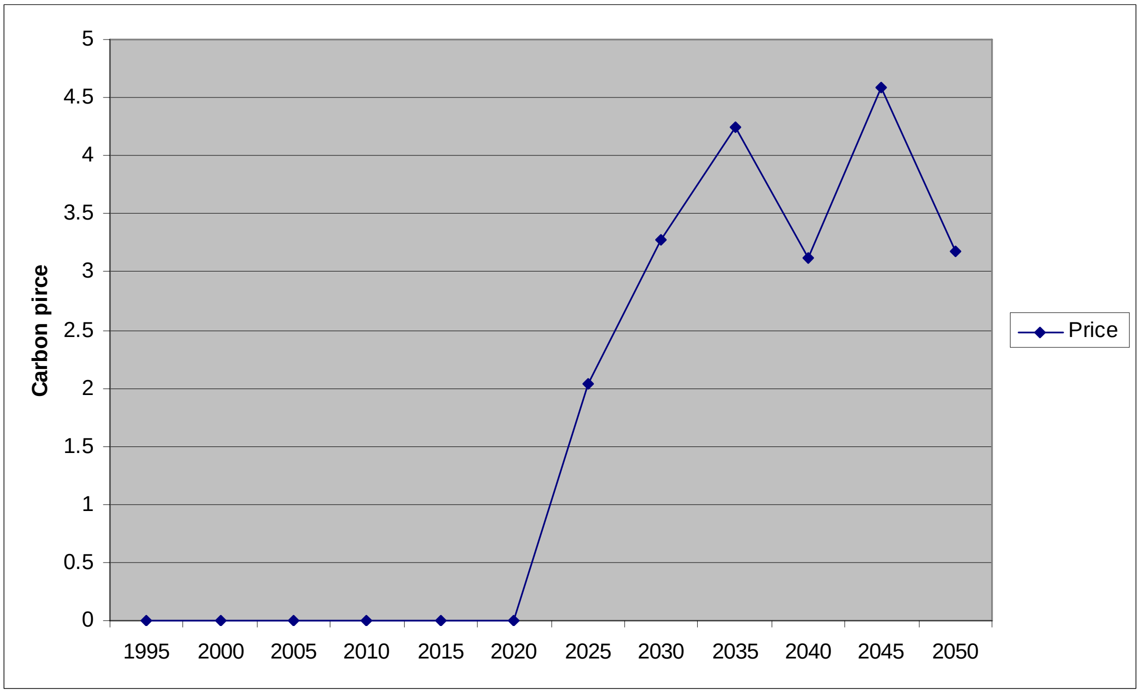

Figure 5.5 Forecasting endogenous carbon price in SGMGAMS

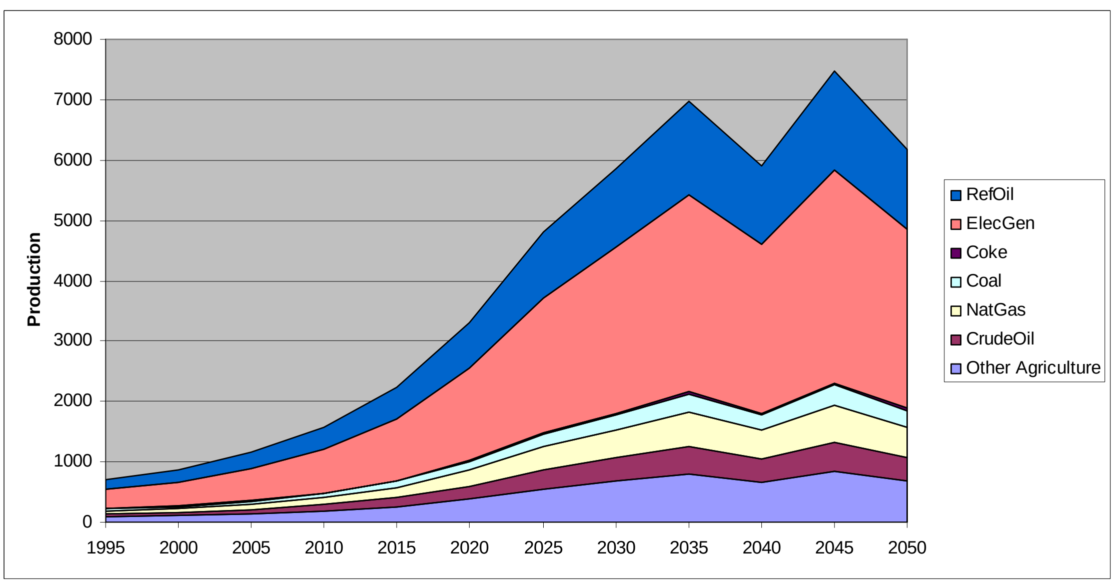

Figure 5.6 Production changes in various SGM sectors in response to carbon emissions

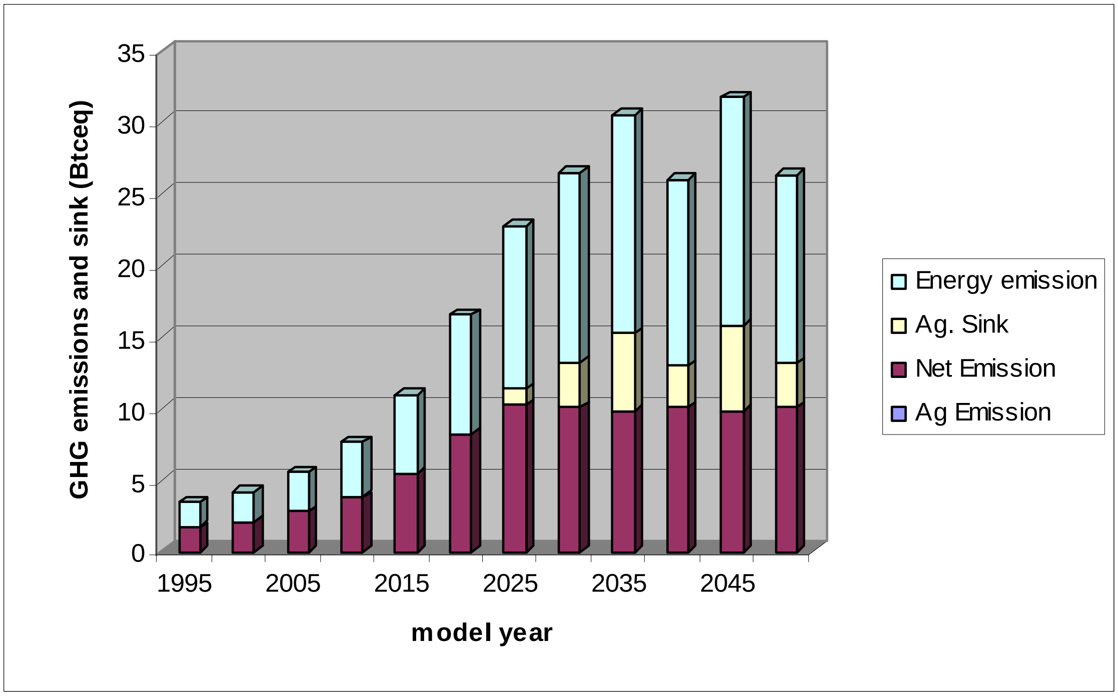

Figure 5.7 GHG emissions and sink from agricultural and energy sector

5.2 Incorporating Saturation and Volatility Characteristics

Saturation and volatility for agricultural soil carbon sequestration are an important consideration in this research. Agricultural soils and forest ecosystems can't sequester carbon forever; the amount of this sequestration in AF sector is eventually limited by biophysical factors. West and Post (2002) analyzed experiments to estimate the time period and change of annual sequestration rate after tillage decrease and showed that soil carbon accumulation occurs for periods of 15 to 20 years. FASOMGHG results generally show that saturation will be reached after 30 years of sequestration programs and the net emissions increase from agricultural sector in comparison with the BAU scenario.

Lee (2002) modified the FASOMGHG to simulate a without-saturation scenario in agricultural soil carbon sequestration by assuming the cropland can sustainably absorb or emit CO_2 once they are in some specific tillage management and found agricultural soil is a much more important carbon sink if we disregard future saturation on cropland.

In this section, we ignore cropland sequestration saturation in the CGE model; we make an assumption that cropland can continue to sustainably absorb CO_2 through out the model years without ever saturating as has been done in some CGE models (Sands and McCarl for example). We employ this strategy by using the initial period response functions throughout the model time horizon. To use FASOMGHG to simulate the without–saturation scenario, we use a response function based on the initial period solution of FASOMGHG for the without saturation scenario and one from subsequent periods where saturation is observed for the with saturation scenario. For with

–saturation scenarios, we estimated response function using the whole dataset, which is generated from FASOMGHG for model year 2000-2070.we then integrated this response function into SGMGAMS to simulated the with –saturation scenarios.

The response functions for the with-saturation scenario include the time trend since the sequestration depends on time since land conversion. To be specific, the response function we used for the with-saturation scenario is shown in Table 5.3:

Table 5.3 GHG Response Function for With-saturation Scenario

Dependent Variables	Intercept	Carbon Price	Fuel Price	Agriculture Demand	Exports	Trend
GHG Accounts:						
Total CO_2 emissions	*-1.499*	*-0.006*	*0.012*	*0.01**	*-0.006**	*0.165*
Total CH_4 emissions	*-1.769*	*-0.014*	*-0.023*	*0.103*	*0.050*	*0.186*
Total N_2O emissions	*-1.610*	*-0.005*	*0.018*	*0.019**	*-0.011**	*0.176*
Total CO_2 sinks	0.325	0.001	0.100	0.159	0.024	0.004

The response functions for the without-saturation scenario use data from earlier model year (2000 to 2020). We estimated the response function as in Table 5.4 for GHG emissions and sink. The data we used for estimation is from model year 2015 in FASOMGHG..

Table 5.4 GHG Response Function for Without-saturation Scenario

Dependent Variables	Intercept	Carbon Price	Fuel Price	Agriculture Demand	Exports
GHG Accounts:					
Total CO2 emissions	-0.7155	4.21E-06	-1.13E-05	3.26E-05	2.41E-05
Total CH4 emissions	-0.82904	-3.71E-08	7.01E-08	1.33E-06	1.44E-06
Total N2Oemissions	-0.80065	1.98E-08	-3.74E-08	-7.09E-07	-7.66E-07
Total CO2 sinks	6.956	0.001	-0.019	0.037	-0.003

These response functions are integrated into SGMGAMS throughout the whole model period and results show that the agricultural soil can sequester one-tenth of total GHG emissions in the without-saturation situation.

These two simulations were run for a set of endogenous GHG price which was determined by the model to clear the GHG market. The different results are shown on Table 5.5 for projection period 2010-2050. The results show that the agricultural soil carbon sequestration potential is much higher and more relied on in the "without saturation" case through all the model periods. This overestimate can be 6 times larger if we ignore the saturation and volatility. AF Sequestration can produce considerable GHG mitigation in the near future for 10 to 30 years but saturation and practice change are important factor need to be included.

The size of the agricultural sequestration sink is positively related to carbon price in both the with-saturation and without-saturation scenario. In the with-saturation case, although the size of the agricultural sink is relatively small compared to the whole economy, it still has an effect on the carbon price and the net emissions. In the without-saturation scenarios, the agricultural sink generally increases when the carbon price increases, the agricultural sink can sequester almost one-fifth of the total CO2 emissions when carbon price is low and decrease to one-tenth of the total CO2 emissions when carbon price increase. The agricultural soil sequestration appears highly competitive at low carbon price. As we expected, agricultural cropland carbon sequestration is an important carbon sink and Agricultural and forestry can provide more time for long run solution for GHG emissions.

Table 5.5. Report on Agricultural Emissions and Sink in BTCEq for With and Without-situation Scenario

Without saturation:

Model Year	GHG	Price	Ag Emit	Net Emit	Ag. sink	Energy
1995	CO2	0.0000	0.0005	0.6009	1.1357	1.7361
2000	CO2	0.0000	0.0005	0.9458	1.1429	2.0882
2005	CO2	0.0000	0.0005	1.6553	1.1431	2.7979
2010	CO2	0.0000	0.0005	2.6845	1.1479	3.832
2015	CO2	0.0000	0.0005	4.3459	1.1491	5.4945
2020	CO2	0.0000	0.0005	7.0958	1.1516	8.2469
2025	CO2	1.9120	0.0005	10.2616	1.155	11.4161
2030	CO2	8.6498	0.0005	10.2774	1.1542	11.4311
2035	CO2	5.3105	0.0005	10.2702	1.1292	11.3989
2040	CO2	10.5151	0.0005	10.2858	1.1318	11.4171
2045	CO2	16.4214	0.0005	10.2688	1.1551	11.4235
2050	CO2	19.8000	0.0005	10.2686	1.1617	11.4298

With saturation:

Model Year	GHG	Price	Ag Emit	Net Emit	Ag. sink	Energy
1995	CO2	0.0000	0.0002	1.7309	0.0054	1.7361
2000	CO2	0.0000	0.0002	2.0828	0.0057	2.0882
2005	CO2	0.0000	0.0002	2.7924	0.0057	2.7979
2010	CO2	0.0000	0.0002	3.8263	0.0059	3.832
2015	CO2	0.0000	0.0002	5.4887	0.0061	5.4945
2020	CO2	0.0000	0.0002	8.2409	0.0062	8.2469
2025	CO2	7.9647	0.0002	10.397	0.0064	10.4031
2030	CO2	2.8473	0.0002	10.3851	0.0059	10.3907
2035	CO2	11.2966	0.0002	10.4072	0.0056	10.4126
2040	CO2	19.7220	0.0003	10.4391	0.006	10.4448
2045	CO2	10.1794	0.0002	10.4027	0.0055	10.408
2050	CO2	9.0454	0.0002	10.3982	0.0052	10.4032

CHAPTER VI

SUMMARY AND CONCLUSIONS

This dissertation integrates AF response into a CGE model to examine the optimal dynamic portfolio of mitigation strategies in the US AF sectors. It attempts to fill a need for a method and analysis that integrates AF considerations into an economy wide , integrated assessment. Need for such an analysis is inherent in the following statement "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).

We utilized an AF sector dynamic model, FASOMGHG, to simulate the effects of mitigation alternative by using different prices. The FASOMGHG results show that the AF sectors offer significant potential for GHG mitigation. In turn to include those results into the CGE a family of response functions were estimated, which encapsulates the AF responses. In turn the response functions are integrated into the CGE model – SGMGAMS- and an economy-wide integrated assessment study was carries out on the role of US AF activities in global climate change mitigation.

The response functions estimated forecast FASOMGHG agricultural market characteristics, land use, allocation and valuation, and welfare implications under alternative GHG and commodity prices. They take into account the role of various strategies as current and lagged offset prices offset prices increase and also shift in demand and energy prices. In general, the regressions had good structural fits according to the goodness-of-fit statistic (R squared) and all the efficient are significant by the P-Value.

The functions shows AF sinks increase as the carbon price rises. Biofuels and forests are significant contributors to the emissions and sequestration response. The results also indicate that AF consumer welfare is negatively correlated with mitigation efforts while environmental indicators and producer welfare are positively correlated. Carbon price and fuel price has less effect on the GHG emissions and sinks in the first periods than the second periods because of saturations. No considerations for sequestration limits because of saturation will overestimate aggregate mitigation potentials as larger as 6 times

The CGE based integrated assessment shows that AF mitigation increases as the carbon price increases> In the earlier model period, while the carbon price is zero as determined by SGMGAMS, AF mitigation through emissions and sinks are quite small compared to the energy sector, as carbon price increases over time, AF sinks contribute about 25% off the net emissions.

The findings of this dissertation support the assertion that that AF carbon sequestration can help to reduce the costs of greenhouse gas emission mitigation and buy more time for the development of new technologies related to energy emissions.

Greenhouse gas emission mitigations are sensitive to saturation. This research finds that ignorance of saturation and volatility characteristic can overestimate by as large as 6 times AF mitigation potentials.

This dissertation enriches the literature on the response functions of AF in climate change and their effects.

6.1 Limitations

We assume U.S. is the only country with mitigation strategies, since we only analyze the forest, agricultural and general economy activity in the US, and thus ignore the leakage effects for other countries assuming conditions in the rest of the world will remain the same.

We only include Agricultural Soil sequestration saturation in this research and ignore the forest sequestration saturation, because the forest saturations can take as long as 80 years while our model years in SGMGAMS is only 50 years.

6.2 Future Research

We can extend this approach in several ways:

- Inclusion of transaction costs. Transaction costs can be the important factor in mitigation alternative, they are not negligible in most cases especially when the mitigation activity is hard to monitor or there are more parties involved.
- Further investigation of the role of AF sequestration in the world. SGM has been applied to include a lot of other countries and leakage effects are important in studying GHG emissions, further research under the whole world framework is desired.
- Inclusion of forest sequestration saturation.

REFERENCES

Aber J., R.P. Neilson, S. McNulty, J. M. Lenihan, D. Bachelet, and R.J. Drapek. 2001. "Forest Processes and Global Environmental Change: Predicting the Effects of Individual and Multiple Stressors." *BioScience* 51:735-751.

Adams D.M., R.J. Alig, B.A. McCarl, and B.C. Murray 2005. FASOMGHG Conceptual Structure, and Specification: Documentation. Texas A&M University, (http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/1212FASOMGHG_doc.pdf)

Adams, R., B.A. McCarl, D. Dudek, and J. Glyer. 1988. "Implications of Global Climate Change for Western Agriculture." *Western J. Agric. Econ.* 12(2):348-356.

Adams, R., C. Rosenzweig, R. Peart, J. Ritchie, R. McCar, J. Glyer, R. Curry, J. Jones, K. Boote, and L. Allen, Jr. 1990. "Global Climate Change and US Agriculture." *Nature* 345(17):219-223.

Adkins, L., and R. Garbaccio. 1999. "A Bibliography of CGE Models Applied to Environmental Issues." Working Paper, US Environmental Protection Agency, Washington, DC.

Alig, R.J., D.M. Adams, and B.A. McCarl. 1998. "Impacts of Incorporating Land Exchanges Between Forestry and Agriculture in Sector Models." *Journal of Agricultural and Applied Economics* 30(2): 389-401.

___. 2002. "Projecting Impacts of Global Climate Change on the US Forest and Agriculture Sectors and Carbon Budgets." *Forest Ecology and Management* 169**:**3-14

Alig, R.J., D.M. Adams, B.A. McCarl, J.M. Callaway, and S.M. Winnett. 1997. "Assessing Effects of Mitigation Strategies for Global Climate Change with an Intertemporal Model of the US Forest and Agriculture Sectors." *Environmental and Resource Economics* 9**:**259-274.

Antle, J.M., S. Capalbo, S. Mooney, T.E. Elliott, and K. Paustian. "Spatial Heterogeneity, Contract Design, and the Efficiency of Carbon Sequestration Policies for Agriculture." Accessed October 2002. Available at http://www.climate.montana. edu/pdf/JEEM.pdf.

Antle, J.M., and B.A. McCarl. 2002/2003. “The Economics of Carbon Sequestration in Agricultural Soils.” *The International Yearbook of Environmental and Resource Economics* 278-311.

Antle, J.M., and S. Mooney. 2002. “Designing Efficient Policies for Agricultural Soil Carbon Sequestration”, In J. Kimble, ed. *Agriculture Practices and Policies for Carbon Sequestration in Soil*, pp. 323–336, CRC Press LLC, Boca Raton, FL.

Arthur, L. 1988. “The Greenhouse Effect and the Canadian Prairies,” in Johnston, G., Freshwater, D., and Favero, P., (eds.), *Natural Resource and Environmental Policy Issues*, Boulder, CO: Westview Press, Inc.

Babcock, B.A., P.G. Lakshminarayan, J.J. Wu, and D. Zilberman. 1996. “The Economics of a Public Fund for Environmental Amenities: A Study of CRP Contracts.” *American Journal of Agricultural Economics* 78: 961-971

Babiker, Mustafa H. 2001. “Subglobal Climate-Change Actions and Carbon Leakage: The Implications of International Capital Flows.” *Energy Economics* 23**:**121-139.

Bairam, E. 1991. “Elasticity of Substitution, Technical Progress and Returns to Scale in Branches of Soviet Industry: A New CES Production Function Approach.” *Journal of Applied Econometrics* 6:91-96.

Barker, T. 1999. “Achieving a 10 Percent Cut in Europe’s Carbon Dioxide Emissions Using Additional Excise Duties: Coordinated, Uncoordinated and Unilateral Action Using the Econometric Model E3ME.” *Economic Systems Research* 11(4):401-421.

Bernstein, P. M., W. D. Montgomery, and T. F. Rutherford. 1999. “Global Impacts of the Kyoto Agreement: Results from the MS-MRT Model.” *Resource and Energy Economics* 21:375-413.

Binkley, C., M. Apps, and L. Nilsson. 1997. “Sequestering Carbon in Natural Forests.” *Critical Reviews in Environmental Science and Technology* 27: 23-46.

Binkley, C., D. Brand, Z Harkin, G. Bull, N. Ravindranath, M. Obersteins, S. Nilsson, Y. Yamagata, and M. Krott. 2002. “Carbon Sink by the Forest Sector: Options and Needs for Implementation.” *Forest Policy and Economics* 4(1): 65-77.

Birdsey, R. 1992. “Carbon Storage in Trees and Forests.” *Forests and Global Change. Volume I: Opportunities for Increase Forest Cover*. Washington, DC: American Forestry Association.

Boscolo, M., J. Buongiorno, and T. Panayotou. 1997. "Simulating Options for Carbon Sequestration Through Improved Management of a Lowland Tropical Rainforest." *Environment and Development Economics* 2(3): 241-263.

Burtraw, D., A. Krupnick, K. Palmer, A. Paul, M. Toma, and C. Bloyd. 2003. "Ancillary Benefits of Reduced Air Pollution in the US from Moderate Greenhouse Gas Mitigation Policies in the Electricity Sector." *Journal of Environmental Economics and Management*. 45: 650-673.

Capros, P., G. Georgakoroulos, S.Zografakis, S. Proost, D. van Regemorter, K. Conrad, T. Schmidt, and Y. Smeers. 1996. "Double Dividend Analysis: First Results of a General Equilibrium Model(GEM-E3)Linking the EU-12 Countries." *Environmental Fiscal Reform and Unemployment*, Dordrecht: Kluwer, 93-227.

Conrad. K. 2002/2003. "Computable General Equilibrium Models in Environmental and Resource Economics" *The International Yearbook of Environmental and Resource Economics* pp.66-115.

Conrad. K., and T. Schmidt. 1998a. "National Economic Impacts of an EU Environmental Policy-An AGE Analysis," In S. Proost and J. Braden eds, *Climate Change Transport and Environmental Policy*, Cheltenham, UK: Edward Elgar pp. 48-77.

Conrad, K., and T. Schmidt. 1998b. "The International Policy Dimension of Sustainability-the Effect of Policy Harmonization within the EU using the GEM-E3 Model", In J. van den Bergh and M.W. Hofkers eds, *Theory and Implementation of Economics Models for Sustainable Development*, Dordrecht: Kluwer pp.287-316.

Creedy, J., and A. Wurzbacher. 2001. "The Economic Value of a Forest Catchment with Timber, Water and Carbon Sequestration Benefits". *Ecological Economics* 38:71-83.

Dale, V.H., L.A. Joyce, S. Mcnulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J.Hanson, L.C. Irland, A.E. Lugo, C.J. Peterson, D.Simberloff, F.J. Swanson, B.J. Stocks, and B. M. Wotton. 2001. "Climate Change and Forest Disturbances." *Bioscience* 51**:**723–734.

Devarajan, S., D. Go, J. Lewis, S. Robinson, and P. Sinko. 1997. "Simple General Equilibrium Modeling." In J. Francois and K. Reinert, eds, *Applied Methods for Trade Policy Analysis: A Handbook*, Cambridge, UK. Cambridge University Press pp. 156-158.

Dixon, P., B. Parmenter, J. Sutton, and D. Vincent. 1982. *ORANI: A Multisectoral Model for the Australian Economy.* Amsterdam: North-Holland.

Ellerman, A., and A. Decaux. 1998. *Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves*. Report No. 40, MIT Joint Program on the Science and Policy of Climate Change, Cambridge, MA.

Environmental Protection Agency (EPA). 2001. Climate Change Review [Online Available]: http://yosemite.epa.gov/OAR/globalwarming.nsf/UniqueKey Lookup/SHSU5BNM7H/$File/bush_ccpol_061101.pdf

Environmental Protection Agency (EPA). 2006. *Inventory of US Greenhouse Gas Emissions and Sinks 1990 – 2004*, Washington D.C.

Feng, H, C. Kling, and J. Zhao. 2000. "*Implementing Carbon Reductions with Agricultural and Forest Sinks*". Working paper, Iowa State University, Ames.

Fleming, R.A. and R.M. Adams. 1997. "The Importance of Site-Specific Information in the Design of Policies to Control Pollution" *Journal of Environmental Economics Manage.* 33:347–358.

Gasiorek, M., A. Smith, and A. Venables.1992. "Trade and Welfare – A General Equilibrium Model." In L. Winters, ed. *Trade Flows and Trade Policy after 1992*. Cambridge, MA: Cambridge University Press.35-61.

Ginsburgh, V., and J. Waelbroeck.1981. *Activity Analysis and General Equilibrium Modelling*. Amsterdam: North-Holland.

Gillig, D., B.A. McCarl and R.D. Sands. 2004. "Integrating Agricultural and Forestry GHG Mitigation Response into General Economy Frameworks: Developing a Family of Response Functions." *Mitigation and Adaptation Strategies for Global Change* 9(3):241-259.

Golombek, R., and M.Hoel. 2004. "Unilateral Emission Reductions and Cross-country Technology Spillovers" Advances in Economic Analysis and Policy, 4(2):1318-1318

Gregg Marland and Tom Boden (Oak Ridge National Laboratory). January 2002 National Fossil Fuel CO2 Emissions [online] Available at http://cdiac.esd.ornl.gov/trends/emis/top98.tot

Hansen A.J., R.P. Neilson, V.H. Dale, C.H. Flather, L.R.Iverson, D.J.Currie, S.Shafer, R.Cook, and P.J.Bartlein. 2001. “Global Change in Forests: Responses of Species, Communities, and Biomes.” *BioScience* 51: 765–779.

Harrison, G., T. Rutherford, and D. Tarr. 1996. “Increased Competition and Completion of the Market in the European Union: Static and Steady State Effects.” *Journal of Economic Integration* 11(3): 332-365.

Helfand, G.E. and B. W. House. 1995. “Regulating Nonpoint Source Pollution Under Heterogeneous Conditions.” *American Journal of Agricultural Economics* 77**:**1024–1032.

Howarth, R.B.1997. “Sustainability as Opportunity”, *Land Economics*, **73**(4), 569-79

Huang, C., and G. Kronrad. 2001. “The Cost of Sequestering Carbon on Private Forest Lands.” *Forest Policy and Economics* 2(2):133-142.

IPCC (1996c). 1996. *Climate Change 1995: Economic and Social Dimensions of Climate Change - Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 458s.

IPCC. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group 2 to the Third Assessment report of the Intergovernmental Panel on Climate Change*. McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (Eds.). Cambridge University Press. New York, USA. 1032 pp.

IPCC. 2007. *Climate Change 2007: The Physical Science Basis: Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press. New York, USA. IPCC, 18 pp.

Irland L.C., D.M. Adams, R.J. Alig, C.J. Betz, C.C. Chen, M. Hutchins B.A. McCarl, K. Skog and B.L. Sohngen. 2001. “Assessing Socioeconomic Impacts of Climate Change on US Forests, Wood-product Markets, and Forest Recreation.” *BioScience* 51:753–764.

Johansen, L. A. *1960*. *Multisectoral Study of Economic Growth*. Amsterdam: North-Holland.

Joyce, L., and R. Birdsey. technical editors. 2000. *The Impact of Climate Change on America's Forests: A Technical Document Supporting the 2000 USDA Forest Service RPA Assessment*. USDA Forest Service RMRS-GTR-59, Fort Collins, CO, pp. 1-133.

Kane, S., Reilly, J. and Tobey, J. 1992. "An Empirical Study of the Economic Effects of Climate Change on World Agriculture." *Climatic Change* 21:17-35.

Kim, M-K., B.A. McCarl, and B.C. Murray. 2005. "Permanence Discounting for Land-Based Carbon Sequestration." Presented at USDA meeting on carbon sequestration, Baltimore, MD.

Kirschbaum, M. 2000. "Forest Growth and Species Distribution in a Changing Climate." *Tree Physiology* 20**:** 5-6, 309-322.

Kokoski, M. and V. Smith. 1987. "A General Equilibrium Analysis of Partial-Equilibrium Welfare Measures, The Case of Climate Change." *American Economics Review* 77:331-341.

Lee, H.C. 2002. "*The Dynamic Role for Carbon Sequestration by the US Agricultural and Forest Sectors in Greenhouse Gas Emission Mitigation.*" PhD Dissertation, Department of Agricultural Economics, Texas A&M University, College Station.

Ley, E., and R. Sedjo. 1997. "Optimal Subsidies for Carbon: Cost-Effectiveness and Distributional Considerations." *Critical Reviews in Environmental Science and Technology* 27:177-184.

Lind, R.C. and R.E.Schuler. 1998. "Equity and Discounting in Climate-Change Decisions." *Economics and Policy Issues in Climate Change* 59-96.

Lindner, M., P. Lasch, W. Cramer, and T. Smith. 1996 "Application of a Forest Succession Model to a Continentality Gradient Through Central Europe." *Climate Change* 34(2):191-199.

Manne, A.S., and R.G. Richaels. 1992. *Buying Greenhouse Insurance-The Economic Costs of CO_2 Emission Limits*, Cambridge, MA: MIT Press.

McCarl, B.A. 2005 "Chapters on Permanence, Leakage, Uncertainty and Additionality in GHG Projects." In G.A. Smith ed. Terrestrial GHG Quantification and Accounting. Book being developed by Environmental Defense, Boston, MA.

McCarl B.A., and U.A. Schneider. 2001. "The Cost of Greenhouse Gas Mitigation in US Agriculture and Forestry", *Science*, 294:2481-82.

____. 2000. "Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective". *Review of Agricultural Economics* 22:134-159.

____. 1999. "Curbing Greenhouse Gases: Agriculture's Role." *Choices* First Quarter:9-12.

McCarl, B.A., D.M. Adams, R.J. Alig, and J.T. Chmelik. 2000. "Analysis of Biomass Fueled Electrical Power Plants: Implications in the Agricultural and Forestry Sectors." *Annals of Operations Research* 94:37-55.

McCarl, B.A., M.K.Kim, H.C.Lee, B.C.Murray, S.D. Sands, and U.A.Schneider. 2007. "Insights from Agricultural and Forestry GHG Offset Studies that Might Influence IAM Modeling." In Schlesinger M, Kheshgi H, Smith J, de al Chesnaye F, Reilly JM, Wilson T, Kolstad C. eds *Integrated Assessment of Human Induced Climate Change.* Cambridge, UK: Cambridge University Press.

McCarthy JJ, O.F.Canziani, N.A.Leary, D.J.Dokken, and K.S.White. (eds) 2001*.Climate change 2001: impacts, adaptation, and vulnerability.* United Nations Intergovernmental Panel on Climate Change. Available at: www.grida.no/climate/ipcc_tar/wg2/001.htm

Mendelsohn, R., W.Nordhaus, and D.Shaw. 1994. 'The Impact of Global Warming on Agriculture: A Ricardian Analysis." *American Economics Review* 84:753-771.

____.1996. "Climate Impacts on Aggregate Farm Values: Accounting for Adaptation." *Agricultural and Forest Meteorology* 80:55-67.

____.2003. "Assessing the Market Damages from Climate Change." *Global Climate Change: The Science, Economics, and Politics.* UK: Edward Elgar Publishing, pp. 92-113.

Newell, R.G., and R.N. Stavins. 2000. "Climate Change and Forest Sinks: Factors Affecting the Costs of Carbon Sequestration." *Journal of Environmental Economics and Management* pp. 211-235.

Nordhaus, W. D. 1991. "To Slow or Not to Slow: The Economics of the Greenhouse Effect." *The Economic Journal* 101: 920-937.

_____.1992. *The DICE Model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming.* Cowles Foundation Discussion Paper No.1009, New Haven, CT. Yale University.

_____.1994. "Rolling the 'DICE': An Optimal Transition Path for Controlling Greenhouse Gases." *Resource and Energy Economic*s 15:27-50.

Norton, B.G. and M.A.Toman. 1997. "Sustainability: Ecological and Economic Perspectives." *Land Economics* 73(4):553-68.

Oliveira-Martins, J., J-M. Burniaux, and J.P. Martin. 1992. *Trade and the Effectiveness of Unilateral CO2-Abatement Policies: Evidence from GREEN*, OECD Economic Studies 19, Paris, pp. 123-140.

Okogu, B., and F. Birol. 1994. "Valuing Carbon Sequestration Services of Developing Countries' Forests." *Development Policy Review* 12(4):355-368.

Parks, P. J., and I.W. Hardie. 1995. "Least-Cost Forest Carbon Reserves: Cost-Effective Subsidies To Convert Marginal Agricultural Land To Forests" *Land Economics* 71(1):122-36.

Parton, W.J., D.S. Schimel., D.S.Ojima, and C.V. Cole.1994. "A General Model for Soil Organic Matter Dynamics: Sensitivity to Litter Chemistry, Texture and Management." In R.B. Brant and R.W. Arnold Eds. *Quantitative Modeling of Soil Forming Process*, SSSA Special Publication 39. Madison, WI: Soil Science Society of America, pp.147-67.

Paustian, K., E.T. Elliott, G.A Peterson, and K. Killian. 1996. "Modeling Climate, CO_2 and Management Impacts on Soil Carbon in Semi-Arid Agro Ecosystems." *Plant and Soil* 187:351-65.

Pautsch, G. R., L. A. Kurkalova, B. Babcock, and C. L. Kling. 2001. "The Efficiency of Sequestering Carbon in Agricultural Soils." *Contemporary Economic Policy* 19(2):123-34.

Pezzey, J. 1992. "Sustainability: An Interdisciplinary Guide" *Environmental Values* 1(4):321-62.

____.1992. "Analysis of Unilateral CO2 Control in the European Community and OECD," *The Energy Journal* 13(3):159-171.

____.1997. “Sustainability Constraints Versus ‘Optimality’ Versus Intertemporal Concern, and Axioms Versus Data.” *Land Economics* 73(4):448-66.

Pezzey, J., and M.A. Toman. 2002/2003. “Progress and Problems in the Economics of Sustainability.” *The International Yearbook of Environmental and Resource Economics* pp. 165-232.

Pew Center. 2006. *Analysis of President Bush's Climate Change Plan*. [Online]. Available at http://www.pewclimate.org/policy_center/analyses/ response_bushpolicy.cfm

Pfaff, A., S. Kerr, R. Hughes, S. Liu, G. Sanchez-Azofeifa, D. Schimel, J. Tosi, and V. Watson. 2000. “The Kyoto Protocol and Payments for Tropical Forest: An Interdisciplinary Method of Estimating Carbon-offset Supply and Increasing the Feasibility of a Carbon Market under the CDM.” *Ecological Economics* 35(2):203-221.

Plantinga, A. 1997. “The Cost of Carbon Sequestration in Forests: A Positive Analysis.” *Critical Reviews in Environmental Science and Technology* 27:269-278.

Pohjola, J. 1996. “Integrating Forests as Carbon Sinks in a CGE Framework: A Preliminary Analysis for Finland.” Paper presented at the Meeting of the European Association of Environment and Resource Economists, Lisbon, Portugal.

____. 1999. “Economywide Effects of Reducing CO_2 Emissions: A Comparison Between Net and Gross Emissions.” *Journal of Forest Economics* 5(1): 139-168.

Reddy, S., and C. Price. 1999. “Carbon Sequestration and Conservation of Tropical Forests under Uncertainties.” *Journal of Agricultural Economics* 50(1):17-35.

Reilly, J., R. Print, J. Harwich, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melville, P. Stone, A. Solomon, and C. Wang. 1999. “Multi-gas Assessment of the Kyoto Protocol.” *Nature* 401:549-555.

Reilly, J.M., J. Hrubovcak, J. Graham, D.G. Abler, R. Darwin, S.E. Hollinger, R.C. Izaurralde, S. Jagtap, J.W. Jones, J. Kimble, B.A. McCarl, L.O. Mearns, D.S. Ojima, E.A. Paul, K. Paustian, S.J. Riha, N.J. Rosenberg, C. Rosenzweig, and F. Tubiello. 2002. *Changing Climate and Changing Agriculture: Report of the Agricultural Sector Assessment Team*. US National Assessment, prepared as part of USGCRP National Assessment of Climate Variability, Cambridge, UK: Cambridge University Press.

Reilly, J.M., F. Tubiello, B.A. McCarl, D.G. Abler, R. Darwin, K. Fuglie, S.E. Hollinger, R.C. Izaurralde, S. Jagtap, J.W. Jones, L.O. Mearns, D.S. Ojima, E.A. Paul, K. Paustian, S.J. Riha, N.J. Rosenberg, and C. Rosenzweig. "2002 US Agriculture and Climate Change: New Results" *Climatic Change* 57:43-69.

Sampson, R., and R. Sedjo. 1997. "Economics of Carbon Sequestration in Forestry: An Overview." *Critical Reviews in Environmental Science and Technology* 27:1-8.

Sands, R and B.A. McCarl. 2003 "Assessment of Terrestrial Carbon Sequestration Options within a Market for Greenhouse Gas Emissions." Paper Presented at Second Conference on Carbon Sequestration, Alexandria, VA.

Sands, R, J.A. Edmonds, and C.N. MacCracken. 2000. *SGM 2000: Model Description and Theory.* Working paper, Pacific Northwest National Laboratory, Richland, Washington.

Sands, R.D., and A.A. Fawcett. 2005. *The Second Generation Model: Data, Parameters, and Implementation*. Working paper, Pacific Northwest National Laboratory, Richland, Washington.

Scarf. H. 1967. "The Approximation of Fixed Points of a Continuous Mapping." *SIAM Journal of Applied Mathematics* 15(5):328-343.

Sedjo, R., and W. Libby. 2001. "From Foraging to Cropping: The Transition to Plantation Forestry, and Implications for Wood Supply and Demand." *Unasylva* 52:24-32, 204.

Sedjo, R., J. Wisniewski, A. Sample, and J. Kinsman. 1995. "The Economics of Managing Carbon via Forestry: Assessment of Existing Studies." *Environmental and Resource Economics* 6(2):139-165.

Shoven, J., and J. Whalley. 1992. *Applying General Equilibrium*. Cambridge, UK: Cambridge University Press.

Sohngen, B., R. Mendelsohn, R. Sedjo. 1999. "Forest Management, Conservation, and Global Timber Markets." *American Journal of Agricultural Economics* 81:1-13.

Sohngen, B., and R. Mendelsohn. 2003. "An Optimal Control Model of Forest Carbon Sequestration." *American Journal of Agricultural Economics* 85(2):448 - 457.

Sohngen, B., and R. Mendelsohn. 2002. *Optimal Forest Carbon Sequestration*. Working paper, The Ohio State University, Columbus.

Sohngen, B., and R. Sedjo. 2000. "Potential Carbon Flux from Timber Harvests and Management in the Context of a Global Timber Market." *Climate Change* 44:1-2, 151-172.

Sohngen, J.F., and S. Tommy. 2000. "Skill and the Value of Life." Unpublished paper, Department of Economics and Finance, University of Wyoming, Laramie.

Springman, R.M. 2004. "The US Stance on Global Warming Part II" http://www.seas.upenn.edu/~springma/Papers/US%20Stance%20on%20Global%20Warming%20Part%20%20II.doc.

Stavins, R.N. 1998. "What Can We Learn from the Grand Policy Experiment? Lessons from SO_2 Allowance Trading." *Journal of Economic Perspect*ives 12(3):69-88.

___. 1999. "The Costs of Carbon Sequestration: A Revealed-Preference Approach." *American Economic Review* 89(4):994-1009.

Swisher, J. 1994. "Forestry and Biomass Energy Projects: Bottom-up Comparisons of CO_2 Storage and Costs." *Biomass and Bioenergy* 6(5):359-368.

___. 1997. "Incremental Costs of Carbon Storage in Forestry, Bioenergy and Land-Use." *Critical Reviews in Environmental Science and Technology* 27:335-350.

Tahvonen, O. 1995. "Net National Emissions, CO_2 Taxation and the Role of Forestry." *Resource and Energy Economics* 17:307-315.

Taylor, L. 1990. *Socially Relevant Policy Analysis: Structuralist Computable General Equilibrium Models for the Developing World*. Cambridge, USA: The MIT Press.

Tietenberg, T.H. 1990. "Economic Instruments for Environmental Regulation" *Oxford Review of Economic Pol*. 6(1):17-33.

Toman, M.A. 1994. "Economics and 'Sustainability': Balancing Trade-offs and Imperatives." *Land Economics* 70(4):399-413.

United Nations Statistics Division. Nov. 2006. [Online]. Available at http://data.un.org/unsd/ENVIRONMENT/air_greenhouse_emissions.htm

UNFCCC. Nov. 2006. [Online]. Available at http://www.volker-quaschning.de/datserv/kyoto/index_e.html

Van Kooten, G.C. 1990. “Climate Change Impacts of Forestry: Economic Issues.” *Canadian Journal of Agricultural Economics* 38 (4):701-710.

Van Kooten, G.C., C.S. Binkley, and G. Delcourt. 1995. “Effect of Carbon Taxes and Subsidies on Optimal Forest Rotation Age and Supply of Carbon Services.” *American Journal of Agricultural Economics* 77: 365-374.

Van Kooten, G.C., A. Grainger, and B. Solberg. 1997. “Conceptual Issues Related to Carbon Sequestration: Uncertainty and Time.” *Critical Reviews in Environmental Science and Technology* 27: 65-82.

Watson, R.T. 2000. *Report to the Sixth Conference of the Parties of the United Nations Framework Convention on Climate Change.* IPCC.

Watson, R.T., M. Filho, E. Sanhueza, and A. Janetos. 1992. *Greenhouse Gases: Sources and Sinks.* The Supplementary Report of the IPCC Scientific Assessment. Cambridge, MA: Cambridge University Press.

Watson, R. T., M.C. Zinyowera, R.H. Moss, and D.J. Dokken. 1997. *Summary for policy makers, The Regional Impacts of Climate Change: An Assessment of Vulnerability*. A special report of IPCC Working Group II, Intergovernmental panel on climate change.

Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken. 2000. *Land Use, Land-Use Change, and Forestry.* A special report of the IPCC, Cambridge, UK: Cambridge University Press.

Weart, S. 2003. *The Discovery of Global Warming.*” Cambridge, MA: Harvard University Press.

West, T., M. Post, J. Amthor and G. Marland. 2000. “Review of Task 2.1, National Carbon Sequestration Assessment.” Presentation at DOE center for Research on Enhancing Carbon Sequestration in Terrestrial Ecosystems (CSITE) Program Review, Oak Ridge National Laboratories, Oak Ridge, TN, November.

West, T.O. and W.M. Post. 2002. “Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis.” *Soil Science Society of America Journal* 66:1930-1946.

Weyant, J.P. and Hill, J. 1999. “The Costs of The Kyoto Protocol a Multi-Model Evaluation.” In J. Weyant ed. Special Issue of the *Energy Journal*.

White House. Global Climate Change Policy Book, February 2001. [Online]. Available at http://www.whitehouse.gov/news/releases/2002/02/climatechange.html.

Woodward, F., and S. Lee. 1995. "Global Scale Forest Function and Distribution." *Journal of Forestry* 68(4):317-325.

Wright, J., A. DiNicola, and E. Gaitan. 2000. "Latin American Forest Plantations: Opportunities for Carbon Sequestration Economic Development, and Financial Returns." *Journal of Forestry* 98(9):20-23.

Wu J.J., and W. G. Boggess. 1999. "The Optimal Allocation of Conservation Funds." *Journal of Environmental Economics and Management* 38:302–321.

Wu, J. 2000. "Slippage Effects of the Conservation Reserve Programs." *American Journal of Agricultural Economics* 82:979-992.

Wu, J., D. Zilberman, and B.A. Babcock. 2001. "Environmental and Distributional Effects of Conservation Targeting Strategies." *Journal of Environmental Economics and Management* 41:333-350.

Yohe, G.W., J.E. Neumann, P.B. Marshall, and H. Ameden. Forthcoming. "Wading Through the Greenhouse - The Shrinking Economic Cost of Greenhouse Induced Sea Level Rise in the United States." *Climatic Change*.

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