Climate Change, Agriculture, Forests, and Biofuels

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Abstract

This paper reviews literature on the impacts of climate change and climate change policy on agriculture and forests. The review suggests that the range of results in the impact literature is widening rather than narrowing as more studies are added. To a large degree, however, the range of results appears to depend largely on uncertainty in the climate effects themselves. The climate change policy literature suggests that land use has a critical role to play if society decides to try to stabilize future climate at a low level of carbon dioxide in the atmosphere. This role includes converting substantial land from agriculture into forests, and these changes would also have large impacts on land rental rates. Compared to the large potential impacts of climate policy, the implications of biofuels for carbon emissions are relatively benign.

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Introduction

In the last 10 years, climate change has moved to the forefront of environmental policy discussions. The roots of this movement could be debated, but the effects have been dramatic. The US Senate moved from the unanimity of the 95-0 vote on the Byrd-Hagel Resolution (Sen. Resolution 98)[1] in 1997 to coming only 12 votes shy in 2008 of ending a filibuster on a bill that would unilaterally curb US greenhouse gas emissions by even more than the Kyoto Protocol. President-Elect Barack Obama has indicated on numerous occasions that he would sign greenhouse gas legislation designed to cap carbon dioxide emissions. Global treaty negotiations currently are underway to write a successor treaty to Kyoto Protocol, and they are expected to be complete within the next year. There is quite a lot going on in the climate-policy arena, and as argued in this paper, it is important for land-using sectors, such as agriculture and forestry, to consider the implications of these developments.

This paper addresses two important ways in which climate change, broadly stated, will affect the agriculture and forestry sectors. First, climate change and carbon fertilization will alter crop and forest productivity. The contributions of current climate conditions to output in the agricultural and forestry sectors are already widely recognized (e.g. Mendelsohn et al. 1994), and assessing how changes in climate conditions could affect output in each sector is an important task. Beyond changing output, climate change could have dramatic impacts upon the distribution of cropland and forestland around the world in the coming century.

[1] The Byrd-Hagel Resolution stated that the Senate would never ratify a treaty that committed the US to greenhouse gas targets but not the developing world

The task of understanding how climate change may affect crop and forest productivity has become even more relevant in recent years as scientists have come to recognize that there is not much we can do today, or even in the next 10-20 years, to prevent substantial climate change from occurring (Intergovernmental Panel on Climate Change, 2007a; Hansen et al., 2007). The climate system has inertia, and making changes to the system will take long-term, persistent climate policy (Nordhaus and Boyer, 2000). As a consequence, society will need to develop mechanisms to adapt to at least some climate-induced changes in the coming years.

Second, climate policy itself will affect the productivity of the land using sectors by changing input prices, including energy prices and land rents. For example, carbon taxes or carbon cap-and-trade programs developed unilaterally or in conjunction with other countries, will raise energy prices. Alternatively carbon offsets from carbon storage in forests or agricultural soils, or methane mitigation from rice paddies and ruminant agriculture, will affect land rents for forest and agriculture. Current studies examining the role of carbon offsets suggest that they can play a substantial role in future climate policy. Furthermore, if carbon offsets actually are included in national policy in the US or international policy, they will have important implications for how land is used in the future.

This paper examines the literature on these two issues in more detail. The next section contains a review of the literature and discussion about the impacts of climate change in the agricultural and forestry sectors. This literature already implies that fairly substantial shifts in land rental values will occur in both sectors in the near- and longer- term. Several important implications of these changes in land rental values are discussed. The paper then turns to address climate policy and its potential impacts on the forest and agriculture sector. The paper focuses on the role of carbon offsets and the implications of these offsets for land use and land rents. In the final section, the paper considers potential interactions between climate change, carbon offset policies, and the development of biofuels. In particular, the paper suggests that while biofuel policy can increase damages to the climate system, current estimates do not suggest that these impacts are all that large.

Climate impacts on agriculture and forestry

The most comprehensive set of results assessing the impacts of climate change on agriculture are found in the recent report of the Intergovernmental Panel on Climate Change (Easterling et al., 2007). Across a range of global average temperature changes of 1-3 degrees centigrade, the study by Easterling et al. (2007) concludes that agricultural output will rise globally, with increases in the temperate zone output outpacing reductions in tropical zone output. Beyond 3 degrees centigrade, Easterling et al. (2007) suggest that yields could decline for most crops across the globe, and global output could decline.

Although the results in Easterling et al. (2007) suggest that climate change poses few risks for the global supply of food during this century, climate driven changes in productivity on the landscape could alter the returns to agriculture and consequently the way we use land. Perhaps the most influential analyses to date addressing potential effects of climate change on the productivity of the agricultural sector are the hedonic studies. Analysts using hedonic techniques have used the methods to explain current land values based on current climatic conditions. They then use the same models to predict the effects of changes in climate conditions.

The original study to do this, Mendelsohn et al. (1994), considered the U.S. only, and concluded that modest warming would generally benefit landowners in the U.S. There has been substantial debate about the approach used in this earlier study, and more recent studies confirm that the debate will continue. Schlenker et al. (2005; 2006) suggest that the model used in Mendelsohn et al. (1994) was mis-specified. Schlenker et al. (2005, 2006) find that climate change is likely to reduce land values in US agriculture. Deschenes and Greenstone (2006) also suggest that the model developed by Mendelsohn et al (1994) was mis-specified, however, with their alternative approach, they find that climate change likely will have positive effects on land values in the US.

Much of the hedonic literature thus far has examined impacts in the US, but some studies have been undertaken in tropical regions. In general, these studies suggest that climate change could have stronger negative effects on land values in tropical and sub-tropical regions where average temperatures are higher to begin with (Seo and Mendelsohn, 2007, 2008; Kurukulasuriya and Mendelsohn, 2007). The results from the hedonic studies in tropical countries correspond with agronomic studies reported in Easterling et al. (2007), which also imply that crop yields in tropical regions are susceptible to even modest warming.

An important issue left un-addressed by all of the hedonic studies is the effect of price changes. As landowners adapt to changing temperature and precipitation patterns, they will adjust the crops they grow, and prices are likely to change. Studies that have addressed potential changes in prices have found that they could have important consequences for measuring the overall impacts in the agricultural sector. One such study, by Reilly et al. (2003), used a large-scale agricultural simulation model of the United States, and found that climate change could cause a reduction in producer surplus. This loss of producer surplus resulted mainly from falling commodity prices caused by climate change, rather than from changes in crop yields.

Datasets to conduct hedonic analysis of the forestry sector have not yet been developed. As a consequence, studies in the forestry sector have, to date, largely utilized sectoral models of supply and demand to assess the impacts of climate change. Because timber is a stock resource, many forestry studies use dynamic optimization techniques that explicitly measure the intertemporal adjustment to climate change. Given that climate change will affect current species differently from future species on any particular site (e.g., it may reduce the growth of current species, but better adapted species may grow more rapidly), and given that it could take substantial time to convert the stock of existing species to the "optimal", climate adapted species, dynamic optimization techniques are not only preferred for forestry analysis, they are critical.

Take, for example, results from the United States. U.S. based studies suggest that the South and Pacific Northwest are the most vulnerable regions to climate change. These two regions currently produce most of the output in timber markets, but their current forest types are not optimally suited for a change in climate. Because it takes time to adapt forestland to new, better suited types, forestland owners in these two regions are projected to experience negative impacts as a result of climate change. Other regions, such as the Northern U.S. are less valuable initially, but they adapt to climate change by shifting to faster growing species. As a result of shifting ecological productivity from the Southern to the Northern U.S., Southern U.S. landowners are expected to lose welfare and Northern US landowners are expected to gain welfare as a result of climate change (Joyce et al., 1995; Sohngen and Mendelsohn, 1998, 1999).

One unique contribution of forestry studies is to address the implications of the global nature of climate change when measuring welfare effects. Sohngen et al. (2001) show that while temperate and boreal regions gain productivity in the long run, tropical and sub-tropical regions actually become relatively more productive. Because timber rotation ages are shorter in tropical and sub-tropical regions than temperate and boreal regions, the tropics and sub-tropics can quickly take advantage of the gains from climate change. The tropics and sub-tropics consequently gain substantial market share as a result of climate change. As a result, even though productivity in temperate and boreal regions of the world tends to rise, producer surplus declines in those regions due to a loss of market share relative to other regions.

Overall, the current suite of agricultural and forestry studies imply that landowners in the U.S. and around the world could experience fairly substantial impacts from climate change (Table 1). And these impacts could occur relatively soon, e.g., within the next 20 to 40 years based on current climate modeling. There are a number of interesting implications of the results in table 1. First, given the large potential shifts in agricultural and forest productivity, there could be large regional shifts in the way that land is used. Although overall output in the agricultural sector may change only slightly, as current projected by Easterling et al. (2007), the land on which our agricultural output is grown could shift substantially as relative rents change.

Second, recent hedonic studies illustrate the important implications of the underlying climate changes. Schlenker et al (2005), for example, use predictions from a single large global climate model with several alternative economic scenarios. The actual climate changes predicted by the different scenarios differ substantially from one scenario to another, and not surprisingly, the economic implications differ substantially from one scenario to another. This result follows the literature on forestry, where modelers have long taken care to assess potential sensitivity across climate, ecological, and economic conditions (Sohngen and Mendelsohn, 1998).

The Implication of climate policies for agriculture and forestry

Given the pace of policy development in the climate change arena, climate policy may have more valuable impacts on the landscape in the near-term than climate change itself. There are two primary ways in which climate policy will affect land use. First, climate policy would affect energy prices. Second, climate policy may affect land use by providing incentives for carbon storage on the landscape, or reductions in externalities from methane or other outputs. For example, if climate policy provides incentives for carbon sequestration in forests, forestland rents will rise and the area of forestland will increase. This section of the paper focuses on this last component – the direct effect of climate policy on land use through incentives for land-based carbon offsets.

Historically, the potential for land-based carbon credits as a viable climate policy option has been driven by international climate negotiations. Land use options for mitigating climate change, for example, were originally introduced into the United Nations Framework Convention on Climate Change (UNFCCC) that was signed in Rio de Janeiro in 1992. These land-use options include forestry actions (afforestation, forest management, and reduced deforestation) as well as agricultural actions (conservation tillage and methane recovery from animal waste or other sources).

Between 1992 when the UNFCCC was signed, and agreement to the Kyoto Protocol to the Convention in 1997, fairly little was done by individual countries to mitigate carbon emissions with either energy reductions or land-based sequestration. During the run-up to the Kyoto Protocol and subsequent to that agreement, however, land-use options continued to play a substantive role. The Marrakesh Accords signed in 2002[2] established exactly which land-use options would be available to countries as they worked to meet their Kyoto Protocol emission limits. The Marrakesh Accords limited the credits to certain "sink" activities, and the accords limited the importation of land-based carbon credits from developing countries to developed countries. Specifically, only afforestation projects that passed through the Clean Development Mechanism (CDM) of the Kyoto Protocol could be imported into developed countries.

As a result of two factors— the stringent rules places on land-use activities from the Marrakesh Accords and removal of the United States' intention to accede to the Kyoto Protocol— forest and land-use "sink" activities have been undervalued over the past 10 years. The reasons for this are fairly clear. The rules created by the Marrakesh Accords substantially increased transactions costs for using the CDM, and the when the United States dropped from the Kyoto Protocol, the demand for sinks fell dramatically (Nordhaus, 2001).

There has been strong pressure in recent years to re-invent the role of sinks. At the 11th Conference of the Parties (COP) in Montreal in 2005, negotiators agreed to re-consider whether reductions in deforestation and forest degradation could be counted as emission reductions. By the time of the 13th COP In Bali in 2007, negotiators agreed to the "Bali Road Map" which placed land-use sinks at the heart of international negotiations. The idea that reductions in deforestation and forest degradation could benefit the atmosphere had firmly taken root in the international policy community.

From an economic perspective, "sinks" and other land-use options are an important part of the policy mix. By increasing the number of options available to reduce net carbon emissions,

[2] The Marrakesh Accords are a set of rules related to implementing the Kyoto Protocol. They were agreed upon by the parties to the Protocol at the 7th Conference of Parties (COP) to the UNFCCC held at Marrakesh in late 2001.

land use sinks can reduce overall costs to society as long as at least some of them are lower cost. According to a review of sink options by Richards and Stokes (2004), a substantial amount of carbon can be sequestered in forests for carbon prices well within the range expected with stringent carbon policies over the next half century. Sohngen and Mendelsohn (2003) examine the potential of sinks within the context of "efficient" climate policy suggested by Nordhaus and Boyer (2000). They find that with moderate or high damages from climate change, forest sinks could efficiently contribute approximately 30% of "net" emission reductions over the coming century.

The efficient approach of course, leads to substantially less stringent climate policy than is currently being proposed either by U.S. climate legislation before congress, or by international negotiators taking part in the UNFCCC process. Policy-makers in the climate arena have increasingly been focusing on "stabilization" policy. Stabilization policy targets specific concentrations of carbon dioxide in the atmosphere and sets annual emissions limits to ensure that the concentration is not exceeded. Rather than addressing benefit cost goals, economists analyzing stabilization policy instead consider how to design carbon policies that are cost-effective. [3]

The stringency of stabilization policy depends on the target level of CO_2 concentrations in the future. A recent economic analysis of stabilization policy by three well-known energy models (Clarke et al., 2007) suggests just how economically stringent different levels of stabilization may be. The business-as-usual for the three energy models used in Clarke et al (2007) show CO_2 concentrations rising from 380 parts per million (ppm) today to 700 to 900

[3] Of course, stabilization policy may in fact be "efficient" in that the benefits of avoiding climate change are not yet fully known. Stern (2006) suggests that these benefits could in fact be very large.

ppm by 2100. Commonly discussed stabilization targets are 750 ppm, 650 ppm, 550 ppm, and 450 ppm.[4]

Under the two most stringent of the stabilization policies (450 and 550 ppm) analyzed in Clarke et al. (2007), carbon prices in 2020 are projected to be as low as $8 per tonne carbon under one model to $259 per tonne carbon under another model. By 2050, carbon prices could be as high as $842 per tonne carbon under the most stringent scenario. All of the models in the analysis by Clarke et al (2007) suggest that biomass energy will play an important role in abatement of greenhouse gases after 2030, but Clarke et al. do not consider other land-use sinks, such as reductions in deforestation.

According to Tavoni et al. (2007) and Kindermann et al. (2008), ignoring land-use sequestration options could bias the cost estimates upwards, and potentially substantially. For example, Kindermann et al. (2008), presents marginal abatement cost curves for reducing deforestation in 2010, 2020, and 2030. Their marginal cost curve for reductions in deforestation in 2020 is compared to the marginal cost curve for carbon abatement for the entire energy sector for Clarke et al. (2007) in Figure 1. Reductions in deforestation have less overall potential, of course, but the scale of reductions in deforestation in 2020 is large compared to the energy sector.

The results in Figure 1 imply that including forestry sinks in energy sector models could drive down carbon prices, and consequently, costs of climate mitigation. Tavoni et al. (2007) directly address the question: "what impact would the inclusion of sinks in climate policy have on carbon prices and overall abatement costs." They combine an energy model that optimally chooses energy abatement alternatives with a dynamic optimization of land use, and use the

[4] Some important atmospheric scientists suggest that even 450 ppm may be too much (see Hansen et al., 2007).

resulting model to assess a 550 ppm stabilization policy. They find that including the sequestration from the land use sector, and specifically reductions in deforestation in the near-term, can reduce carbon prices by around 40% over the century (Figure 2). As a result of the reduction in carbon prices in their model, Tavoni et al (2007) project that consumption losses decline by $3.0 trillion compared to the same stabilization scenario without considering carbon sequestration in forests and land use. Given that the present value costs of the forestry program are $1.1 trillion, the benefit-cost ratio of introducing land-based offset credits is 3 to 1.

The study by Tavoni et al. (2007), however, implies rather dramatic changes in land-use. Their results indicate that an additional 500 million hectares of land will be forested in 2050 compared to the baseline, and around 1.0 billion additional hectares will be in forests by the end of the century. Given that their baseline projects a 400 million hectare loss in forestland over the century, the net change in forests relative to today is 600 million hectares. Clearly, any program that adds 600 million hectares to forests over the century will have important implications for agriculture. The study by Tavoni et al. (2007) does not explicitly model competition for land across agricultural, forest, and biofuel uses, and thus may over-estimate the potential.

Is 600 million additional hectares in forestland even remotely plausible? One useful way to assess this is to consider the value of the carbon embodied on the landscape. Falk and Mendelsohn (1993) show that the price of carbon is equal to the marginal abatement cost for carbon, which is in turn equal to the present value of future marginal damages. Thus,

$$(1) \qquad MC_t^{forest} = MC_t^{energy} = MC_t^{n} = \mu_t = P_t^C$$

Where μ_t is the shadow value of a tonne of carbon in the atmosphere, and P^C_t is the market price of carbon. If 1 tonne of carbon released from a tree into the atmosphere causes damage worth P^C_t, then 1 tonne of carbon stored in a tree for one year is worth $r*P^C_t$, where r is the interest rate. This is simply the rental value of storing carbon for one year (R^C_t):

(2) $R^C_t = (P^C_t) \text{ x } (r)$

Given equations (1) and (2), it is fairly straightforward to value standing carbon in forests. For example, suppose that carbon prices are \$12 per tonne CO_2, or \$44 per tonne C. This price is the ceiling price that Congress established in discussions in 2008 over potential cap and trade legislation. It is also well within the bounds of carbon prices described in stabilization scenarios in Clarke et al. (2007). For the United States, the average carbon in a hectare of forests is 59.1 tonnes C. If carbon prices are \$44 per tonne carbon (C), and the interest rate is arbitrarily chosen as 5%, then the annual rent on one tonne of carbon stored for one year in forests is \$2.20 per tonne C per year. With 59.1 tonnes C per hectare, the annual rental value on the carbon for an entire hectare is \$130 per hectare per year. Annual rent of \$130 per hectare per year would not motivate all landowners to shift land from agriculture into forests, but it is high enough to have an effect on marginal landholders.

Climate Change and Policy Interactions with Biofuels.

What distinguishes climate change policy from biofuel policy is the time horizon of analysis. Economic analyses of climate change are clearly interested in long-run issues, whereas economic analyses of biofuels tend to be focused on near-term questions. For example, most of the studies discussed above have 100 year or longer time horizons because it is difficult to talk about climate change without considering impacts in the long-term. Most analyses of biofuels, however, focus on impacts within the next 1 to 10 years.

One of the short-run implications of biofuel policy for climate change is that biofuel policy may cause additional emissions of carbon dioxide today. Because carbon emissions cause damages over a long time frame, it is important to at least account for the scale of these potential damages. This is basically the argument of Searchinger et al. (2008), who suggest that the biofuel mandate in the US would cause approximately 1.0 billion tonnes of additional C emissions in the next 10 years.[5] Damages from current carbon emissions are estimated to be \$3 - \$14 per tonne CO_2 (Yohe et al., 2007), so the results in Searchinger et al. (2008) suggest that biofuel policies could cause additional climate damages in the range of \$3 - \$14 billion.

Clearly, if Searchinger et al (2008) are correct, these additional damages reduce (or eliminate) any efficiencies associated with a US biofuel policy. However, it's also useful to put the estimates in context of climate policy. Tavoni et al. (2007) for instance, calculate that the cumulative abatement in all sectors by 2100 must be on the order of 700 billion tonnes C, with forestry contributing around 170 billion of those tonnes. The additional 1.0 billion tonnes of C emissions that Searchinger et al. (2008) suggest will occur as a result of biofuel policy represent only about 2-3 months worth of energy abatement activities, and 1 – 2 years worth of the forest carbon sequestration recommended in Tavoni et al. (2007). Climate policy is simply on a

[5] Searchinger et al. (2008) claim that the 56 billion liter mandate by 2016 would lead to an additional 10.8 million hectares of cropland globally, and that on average, converting those hectares would cause 351 tonnes CO_2 emissions per hectare (or around 95 tonnes C per hectare).

different scale, and it requires persistent policy action across an entire century, as well as reductions in net carbon emissions well beyond the effects caused by biofuel policy.

Conclusion

This paper begins by reviewing the literature on potential climate impacts in the agricultural and forestry sectors. The literature review suggests that the forestry sector is largely expected to benefit from climate change, while impacts in the agricultural sector are more unknown. There is not much concern that global food supply is at risk as a result of climate change, but agricultural studies now suggest that the impacts of climate change on net returns within that sector are highly uncertain. Most of the uncertainty seems to revolve around variation in the results from climate models used to project regional impacts. Regardless, forestry and agricultural studies now suggest that net returns, and consequently land rents, could shift dramatically within the next half century, causing large changes in future patterns of land use.

The second section of the paper reviews literature that analyzes the implications of climate policy for land use. Land use has become increasingly important in climate policy as policy-makers consider options for containing costs from large emission reductions. Land-based carbon offsets are widely considered to be a cost-effective component that can help reduce the overall costs of meeting stringent climate stabilization targets by 30-40%. If climate policy moves forward with clear guidelines for including land-based carbon credits, however, there could be large changes in land use in the future.

Finally the paper considers some of the links between climate policy and biofuel policy. Both policies will affect how land is used, but a simple analysis shows that the climate implications of US based biofuel policy, while important, are relatively small when compared to the abatement required over a century to stabilization carbon dioxide concentrations. The additional 1.0 billion tonnes of C emissions resulting from the US biofuel mandate represents about 3 months worth of the reduction in energy emissions required to meet a stabilization target of 550 ppm.

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Table 1: Range of percentage changes in land rents resulting from climate change projected by various climate change studies in agriculture and forestry.

	2020-2040	2070-2100
Agriculture		
Temperate Zone (1990s)[1]	-5.7% to +1.2%	--
Temperate Zone (2000s)[2]	-25% to +29%	-69% to +4%
Tropical Zone (2000s)[3]	-16% to +63%	-62% to + 68%
Forestry		
Temperate Zone[4]	-4% to +12%	+2% to +30%
Tropical Zone [4]	+5 to +20%	+14% to +50%

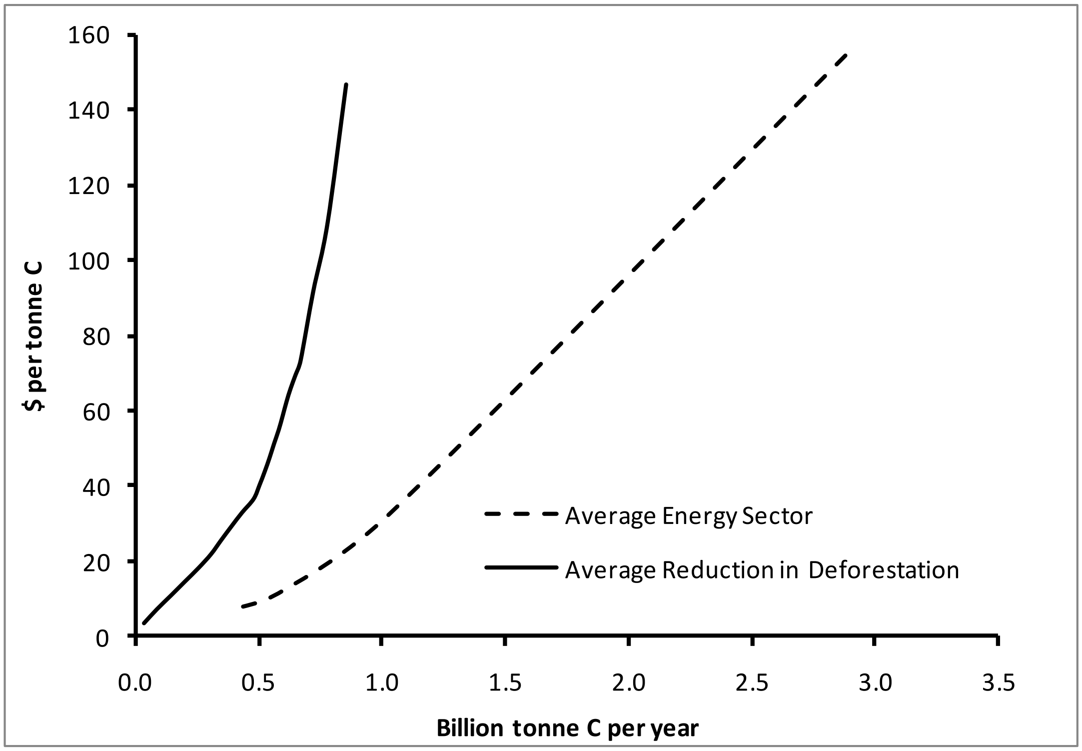
[1] Mendelsohn et al (1994); [2] Schlenker et al. (2005, 2006); Deschenes and Greenstone (2006); [3] Seo and Mendelsohn, 2007, 2008; Kurukulasuriya and Mendelsohn, 2007; [4] Sohngen et al. (2001), Perez-Garcia et al. (2002).

Table 2: Average aboveground carbon in forestland, implied annual carbon rent for a carbon price of \$12/tonne CO_2 (\$44/t C), and average present value of carbon (r= 5%)

	Average Aboveground Carbon[1]	Annual Carbon Rent	Present Value of Carbon Rent
	t C/ha	\$/ha/yr	\$/ha/yr
United States	59.1	\$130.05	\$2,601
Canada	31.0	\$68.36	\$1,367
South America	119.4	\$262.90	\$5,258
Central America	93.0	\$204.72	\$4,094
European Union	31.4	\$69.05	\$1,381
Russia	42.8	\$94.34	\$1,887
China	47.7	\$104.99	\$2,100
India	65.7	\$144.68	\$2,894
Oceania	26.0	\$57.36	\$1,147
SE Asia	131.8	\$290.22	\$5,804
Central America	35.2	\$77.54	\$1,551
Japan	37.9	\$83.43	\$1,669
Africa	99.9	\$220.02	\$4,400

[1] Estimates from model in Sohngen and Mendelsohn (2007).

Figure 1: Marginal abatement cost functions in 2020.



Notes: Average energy sector results are the average world abatement of carbon dioxide from the three energy models used in Clarke et al. (2007). The marginal abatement cost function for the average reduction in deforestation is the average result from the three models used in Kindermann et al. (2008).

Figure 2: Carbon prices for a 550 ppm stabilization scenario with energy only options and with energy options plus sequestration. Figure reproduced from Tavoni et al. (2007).