Making Money Grow on Trees: Forest Policy in Light of a Carbon Tax

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Abstract: This paper addresses one very specific aspect of reducing global climate change. The role carbon emissions play in global climate change and the need to reduce the volume of these emissions has had greater attention recently. Logically, if carbon emitters are taxed for their emissions under any sort of carbon tax framework, there should be no reason not to subsidize, or pay, for sequestering carbon. Since trees naturally sequester carbon, there is the possibility for them to fall under a carbon subsidy resulting in greater carbon sequestration in US forests. First, this paper considers what factors are necessary to include when trying to design a subsidy that would encourage additional carbon to be sequestered in US forests under a carbon tax framework. It does this by modeling tree growth and carbon sequestration in trees. Then, it tailors a monetary subsidy based on carbon price. Next, the paper models the current value of an acre of trees, including the market value of timber, non-timber recreational values, and growing costs. After calculating the rate of return for a given acre of trees at any given point in time, with and without the subsidy, the paper discusses the effect the subsidy has on the amount of trees grown per acre. Finally, it considers what effect the subsidy could have nationally on carbon sequestration. The paper addresses the Markey Bill specifically, critiquing various provisions of the bill. Then, the paper considers possible considerations and consequences of implementing the designed subsidy independently of any other legislation and some other possible ways to use trees to sequester carbon. Finally, the paper looks at the Obama administration's carbon reduction emissions targets to see how useful a policy of this type could be in the near future.

Introduction:

Greenhouse gases are thought to play an active role contributing to global climate change. With certain, specific subsidies, the United States could capture more carbon by simply growing the same trees that are already in the ground for a longer period of time. Specific subsidy policies would induce even profit maximizing firms to grow trees longer. As an example of just how effective a program of this type could be, consider a simple case with 1,000,000 acres of trees. If highly managed, 33,333 acres of these trees would be harvested in each vintage at 30 years of age. The 1,000,000 acres would hold a total 42.6 million tons of carbon. With a subsidy encouraging firms to grow trees longer, the same million acres of trees would harvest 22,222 acres in each vintage, grown longer to an optimal harvest age of 45 years. The 1,000,000 acres would hold a total of 56.8

million tons of carbon, a net increase of 14.2 million tons sequestered in the same trees. Increased stand ages will affect the volume of timber harvested. In the 1,000,000 tree example, total volume harvested would decrease by 1,978,200 cubic feet. This is a 21.4% decrease in the production of timber volume, decreasing the value of lumber harvested per year by $155 million. A subsidy like the type proposed in this paper will capture as a stock of carbon 33.47% more carbon in highly managed tree stands and at only modest resource cost.

The stock-versus-flow nature of carbon emissions and carbon sequestration is a sizable problem. The subsidy of trees allows for a substantial one-time gain. It is an increase in the stock of sequestration, not an increase in the flow of carbon sequestration. In order to get this substantial one-time increase in the stock of carbon sequestration, property rights for carbon must be created. In the case of forest policy, carbon property rights would probably require big transfer payments. This policy will create a pure gain—a windfall profit, for those who already own the newly created carbon property rights.

There are several possible ways to make this increase in the stock of sequestered carbon more resemble an increase in the flow of sequestered carbon. Of all these available options, planting more trees and extending certification to more forests under the subsidy would be two of them. Permanently storing the carbon in wood products after harvest, a process called pickling, would be a third. The following portions of this essay will try to demonstrate that a subsidy incorporating these policies could produce the significant intended effects in sequestered carbon and address ways to implement such a policy.

Problem Significance

Global climate change is an important issue facing humanity. Since the publication of the Stern Report (2007), it is clear that economics will play a role in any solution. Carbon dioxide emissions from human processes are thought to contribute to rising global temperatures. Roughly 20% of greenhouse gas emissions are due to deforestation (Worldbank). Failure to manage forests to retain and capture carbon is a part of the problem and better management of forests may provide a substantial method to reduce global greenhouse gases in the atmosphere. While it is hard to predict the future with any certainty, many estimates show that without a rapid reduction in emissions net of capture, a daunting task given the current emissions levels and large economies coming online world-wide, there could be catastrophic climate change in the next 50-100 years.

One proposed solution to climate change, a cap and trade system for carbon emissions, could affect forests. As trees grow, they naturally sequester carbon, reducing carbon dioxide levels in the atmosphere and providing a positive externality. Logically, the same tax rate per ton of carbon emissions might also provide a subsidy per ton of carbon for sequestration. While this seems readily understandable, inducing landowners to manage their forests for carbon sequestration will be a challenge. Regardless of the specific policy, carbon sequestration in forests appears to be one part of a strategy to reduce global warming. The issue is even more important internationally. Brazil and other countries offer large, challenging opportunities. In a different approach, the Nature Conservancy has recently launched a fund raising effort to plant a billion trees in the coastal forests of Brazil. A well-designed US forest policy may help other countries improve their policies as well.

The literature on the subject of global warming, carbon sequestration, and carbon taxes is both substantial and sophisticated. Silviculture, the cultivation of trees in general, is both an industry and a field of study. As a consequence much data exist on costs and processes involved. The literature offers many possible solutions for global warming; carbon taxes are often recommended as a plausible theoretical solution. Carbon sequestration, while it has its limits, can certainly aid in reducing carbon dioxide levels and abating global warming. However, there is still much discussion about what is the best way to address sequestration, and many problems with implementation of any proposed policy.

This is a current issue for national policy in the US. There are three bills that address the issue of offering incentives to increase carbon sequestration in line with a carbon tax philosophy. **S. 1766: Low Carbon Economy Act of 2007** (Leiberman-Warner act) is a short bill that addresses the issue by setting up a cap and trade market for carbon, one of the specific ways to implement a carbon tax. **S. 2191: America's Climate Security Act of 2007** (Leiberman-Warner 2) is a longer and more specific bill which again sets up a cap and trade system for carbon emissions and, more pertinent to this paper, creates a forest and agriculture sequestration program. The Markey bill, **HR 6186**, proposes some support for forests but does not suggest a full subsidy per ton of carbon captured. With these bills, some provisions are in line with the philosophy and planned model set forth below, others are possible alternatives to the system proposed, and still others are in opposition to this proposal. These bills are currently under debate, so this paper promises to add new information to this important current issue. The Markey bill proposes:

> "a global effort to reduce anthropogenic greenhouse gas emissions worldwide by 50 to 85 percent below 2000 levels by 2050; (5) the costs of policies to achieve such levels of reduction are 5 to 20 times lower than the costs of unchecked global warming, according to the Stern Review of the Economics of Climate Change" (p7).

Meeting such high goals in reduction will be a challenge and probably take a combination of programs to be successful. The Stern report makes it clear that the costs of undertaking such a program are much smaller, and hence preferable, to the costs of doing nothing. This essay offers a critique of the forestry provisions of these current bills.

Theoretical Framework:

We want to know how forests can be used effectively to sequester carbon as part of a policy to limit greenhouse gases and reduce global warming. Carbon cap and trade legislation, in which a limit on greenhouse gasses would be set with provision for companies to compete in a free market to buy permits to emit, is a frequently proposed measure. Logically, if there is a set price that must be paid per ton of carbon emitted because there is a negative value attached to carbon emission, there should also be a subsidy on carbon capture. This would encourage companies to be carbon neutral by reducing emissions and capturing carbon. Being carbon neutral, as opposed to having zero carbon emissions (where a company physically does not create any carbon emissions), allows for companies to produce carbon emissions as long as they buy carbon offsets as well. This means that carbon emitters could theoretically plant enough trees to absorb its excess carbon emissions. It is possible that a net of zero carbon emissions is not economically efficient. If that is the case and some net release is optimal it would be easy to design quotas to allow some carbon emissions. However, it is important to remember that trees will only increase the stock of carbon sequestered, making it much harder to deal with the flow and release of carbon emissions over long periods of time. The following model will explain how exactly such a subsidy would increase carbon capture through incentives to firms and simultaneously discourage release though reduced cutting. There are of course practical considerations in the implementation of such a policy for forests.

Before examining the specifics of the model, there is one more major theoretical issue to address: additivity. An important issue is whether to subsidize the stock of carbon or only the flow of newly captured carbon. If firms are only subsidized for new additions of carbon sequestration, for example, a subsidy for planting more trees, perverse incentives arise. Such a policy would encourage firms to cut trees and replant them for the subsidy, reducing the amount of carbon sequestration. Alternatively, there could be a subsidy for each ton of carbon held in forests regardless of when it was sequestered. However, this could be a very costly framework providing a large windfall to current owners of forests, making political support difficult.

The ultimate goal is both to increase carbon sequestration, by encouraging new tree growth through subsidies, and to discourage tree harvesting, either by stopping subsidy payments upon tree harvesting or possibly imposing a tax on the carbon released. We want to encourage firms to plant more trees to increase carbon sequestration and to grow them longer. How much will the subsidy affect the amount of carbon sequestered? How does this subsidy change the decision of when a profit-maximizing firm harvests a tree?

The goal of the model is most easily accomplished in parts. Taking carbon emissions cap and trade legislation as a given, how much should the government pay for the carbon sequestered in a given acre of trees grown and how much should it tax firms for the carbon released by cutting down a given acre of trees? Will an effective policy require both a subsidy and a tax, and if so what is the optimal mix? Here are the three major policy initiatives:

1) paying a subsidy for the quantity of carbon captured in a given year (one time payment);
2) paying a rental rate for the total quantity of carbon within a given tree for a given period of time (1 year); and
3) taxing the carbon released from cutting

In more general situations, appropriate policy could include both a subsidy and a tax. However, this generally requires costs for monitoring both the tax and subsidy. There do not seem to be any major differences in monitoring costs, so the optimum is likely to be either a tax on cutting or a subsidy for growing. Note that a tax per ton on cutting would require higher incentives to encourage additional planting. Because the ultimate goal is to increase trees planted, this option seems sub-optimal. A rental rate strategy seems best, that is let the subsidy pay for all of the carbon sequestered as long as it is sequestered. If the trees are cut, subsidy payments will stop, creating an incentive to keep trees growing longer.

The next goal, after determining the amount of the forest subsidy or tax, is to model the firm's decision to cut down an acre of trees and see if there are any significant effects in decision-making. The model is designed to indicate how much extra sequestration occurs for a given subsidy level. The model can calculate the value of the subsidy needed to achieve a given amount of carbon sequestration or the quantity of carbon sequestered within an acre for a given subsidy level.

The subsidy is only concerned with the carbon sequestered in a given stand of trees. Because of this, the value of the subsidy itself, paid to tree owners, continues to increase until there is no longer added sequestration (tree age equals fifty years in the model). The subsidy value is then included in the current decision for harvesting a given stand of trees. As basic economics suggests, a stand of trees will grow until the rate of growth of a stand of trees slows to equal a given interest rate and then they will be harvested. As long as the trees grow faster than the rate of interest on competing investments, the firm will enjoy higher profits by continuing to grow its trees. While the subsidy is expected to have a positive effect on average stand age, it is plausible to believe that the optimal harvesting age will still be before the stand is saturated with carbon. There is nothing that forces a stand of trees to be grown to full sequestering capacity. The model should give an estimate of how much extra growth can be expected.

Model Framework:

Determining the amount of the forest subsidy for carbon is the first part of the model.

$$Su= ((C*G*P*T)*Sc) \qquad (1)$$

Where: Su is the subsidy per acre of trees.

C is the price of carbon per ton as given, here $20-$200/ton (a plausible range).

P is the pickling rate, or the proportion of carbon fully sequestered.

G is the parabolic estimate of the total basal growth[1] of the tree, from 0-50 years.

T is a parameter to give model output in trees per acre (this coefficient makes the empirical estimate for carbon sequestered per acre valid for the model).

Sc is the amount of carbon sequestered per acre of trees.

(NB: longer discussion of these variables follows)

The rental rate for all the carbon in a given acre of trees is given by

$$RR = C*(\sum_{i=1}^{n} G_i)*P*T*Sc \qquad (2)$$

Where $(\sum_{i=1}^{n} G_i)$ accounts for all the carbon that has been sequestered in an acre of trees for their entire life span, paying for all the carbon stored and not simply the new amount sequestered in a given year.

Van Kooten, et al., (1995) make the point that it is not the age of trees or the volume of the biomass that matters in carbon sequestration, but the rate of timber growth. So, the model will need to be based on the timber growth rate to accurately incorporate carbon sequestration. Tree growth rates start slow, increase rapidly, and then slow down again. In order to simulate this, a logarithmic curve may be best.

Figure 1 Tree Growth Rate and Size

[1] While there are many ways to model tree growth, basal growth rate has been used here to try to model the actual sequestration as best as possible. Basal growth is essentially the growth in the area in cross section of the tree's trunk measured six feet from the ground.

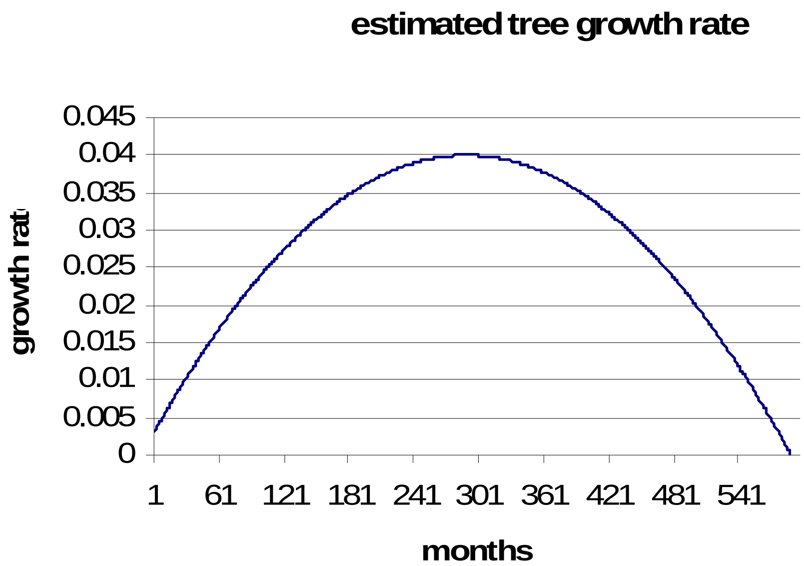
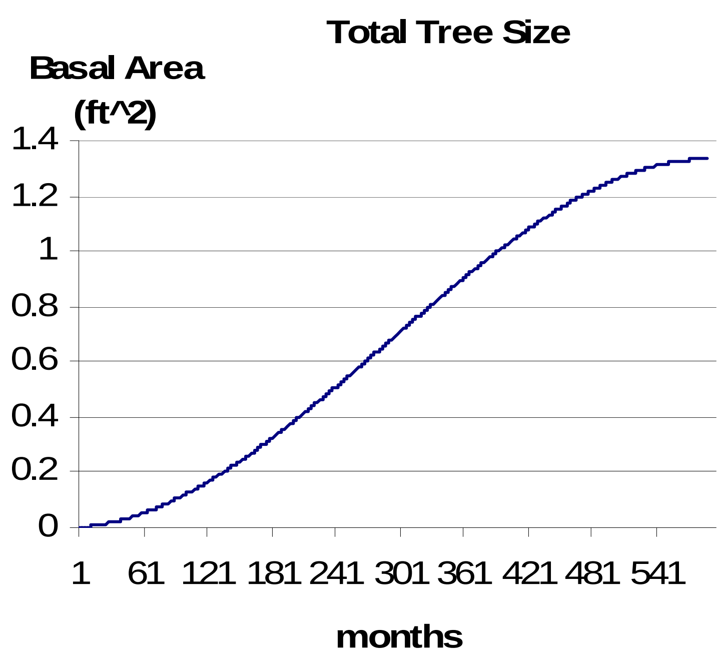


Figure 2 Total Tree Size by Month



However, overall approximate tree growth rates also coincide with a parabola because the height of the parabola at any given point in time can represent the rate of tree growth, increasing up to a maximum before slowing back down (Figure 1). Different species of trees grow at different rates, causing a noticeable difference in the rate of carbon sequestration. Were the government to adopt the overall plan proposed here for carbon sequestration subsidies, it would be best to have several different models designed by biologists or researchers at the Forest Service to better reflect the different rates of carbon growth by species and climate zone. With subsidies specific to each species of tree, the policy would induce a shift toward growing species that sequester more carbon. However, it is also useful to have one general model working, at least initially, with averages that give a picture of trends nation-wide. In his introduction, Boris Zeide (1993) notes that "probably no biologist believes that one equation would suit all growth processes. This seems to be a belief peculiar to biologists" (1). He goes on to counter with the example that physicists would not have multiple equations for different objects falling in a vacuum. While there are important differences in trees to consider while constructing a model, it is still plausible that a general model will yield some useful results for policy analysis.

The next step is to fit the parabola to model basal tree growth. The growth rate is the time derivative of the sigmoidal growth path, also pictured above (Figure 2). A concave down parabola is chosen in order to use the y-coordinate of the curve to model the amount of carbon sequestered in a given year. One point that needs to be set empirically is the age of the stand at which carbon is no longer being added, which in the model is the point when the y-value of the parabola equals zero. Since the parabola will cross the x-axis twice, the other point is set at $t = 0$ because logically the tree can neither grow nor sequester carbon when its age is below zero. Running and Gower (1991) state from their empirical estimates of carbon sequestered in trees, "At all sites, stem biomass was still accumulating at Year 50. The Missoula control stand showed a simulated NPP (net photosynthate production—the biological measurement of sequestration) of about 0.8 Mg ha^{-1} $year^{-1}$, but stem primary production was only 0.03 Mg ha^{-1} $year^{-1}$, because of maintenance respiration" (11). This number is sufficiently small that the model takes 50 years as the maximum limit for carbon sequestration; no new sequestration is modeled after tree stand age reaches 50 {when $x \geq 50$, $y=0$}. The other point when the y-value equals zero (there is no growth) is set for when the x-value is zero. This makes sense because the model anticipates that trees will not start sequestering carbon until they begin to grow (age equals zero), will then begin to sequester immediately as part of the growth process. Since it is growth rate of the tree and not total tree growth that matters, maintenance respiration will eventually overtake additional sequestration as the tree reaches its sequestration limit.

The final piece of the parabola that needs to be set is the vertex. Due to empirical estimates, the y-value of the vertex is set at 0.04. Teck and Hilt (1991) estimate potential individual tree basal area growth. The estimates reach a maximum slightly over 0.04 $feet^2$/year. Basal area is an estimate of area, a specifically measured cross section of a tree, so units are expected to be squared. While Teck and Hilt allow for the fact that disaggregated different species grow at different rates, an aggregated model is more useful for understanding consequences of the subsidy nation-wide. Teck and Hilt's study suggests 0.04 $feet^2$/year is a reasonable estimate and it is used here. Again, while tree growth is not exactly parabolic, corresponding growth rates are close enough to provide a reasonable estimate.

However, this growth model is for a single tree, and the calculations are given in acres. So, this estimate must be multiplied by some factor to convert it to model total growth per acre. Multiplying the single tree growth model by the number of trees per acre accomplishes this. This estimate occurs in Baker et al. (1996), and the number of trees per acre before cutting is estimated at 166. Tree density is an important consideration. If the trees are planted too close together, the growth rate will slow and hence the amount of carbon sequestered will decline. However, if trees are spaced too far out, then more carbon could be sequestered on the given acre. The model here is for a generic southern pine forest. In implementing a national policy, similar models would be used for each type of forest with the potential to shift forest practice toward sequestering more carbon. The goal here is to describe an aggregate policy.

The next term is the pickling rate, or the proportion of carbon fully sequestered in the tree. This is included because after a tree is cut (or dies and begins to decay), much of the carbon stored, but by no means all of it, is released back into the atmosphere. If there were to be a tax on carbon emitted, it would be important to account for the amount that is not released. For the subsidy part of the model, the time when the trees are alive and actively sequestering carbon, the pickling rate is 100%, or 1. If the model is estimating the amount sequestered after cutting, 0.35 is used. This is because Heath et al. (1996) reports that on average "approximately 35% of the total C [carbon] removed is stored in products and landfills, 30% has returned to the atmosphere through decay or burning without energy production, and 35% has been burned for energy, partially offsetting fossil fuel use" (4). However, although some carbon emissions from landfills can be used to produce energy, as the methane is eventually burned and returned to the atmosphere as carbon emissions it does not count as sequestration. Since this model is only concerned with carbon released or sequestered and not offsetting carbon through energy production, the only percentage of carbon that counts as pickled is the amount sequestered in products and landfills: 0.35. Other ideas about pickling forest products appear in the discussion below.

Carbon price, C, is exogenous to the model. Under the given initial conditions with a legally enforced carbon cap, the government has set a limit on the amount of carbon emissions for the year and produced permits and sold them in a market, determining the price per ton of carbon. The government could also simply legislate a value per ton of carbon. The exact process in which the price of carbon is set is beyond the scope of this paper. The model allows this parameter to vary over time in order to show what would happen to the subsidy amount if the price rose over time, which is expected as efforts to curb carbon emissions are increased. Stern and others suggest the price of carbon might be near \$20 a ton in the near term and rise to \$200 a ton or more by the end of the century.

This product is then multiplied by a carbon sequestering per acre coefficient. Nowak et al. estimate this as percent of coverage in an acre (here assumed to be 100%) times a given coefficient. To estimate **annual** amount of carbon sequestered per acre in an area is empirically estimated at 0.00335 (Tons carbon*acre^{-1}*year^{-1}). The coefficient for total carbon sequestered is 0.4303, the value the subsidy is concerned with (Nowak and Crane, 2001). Because the growth parabola gives tree growth in basal area (the area in square feet of the trunk measured at a given height—6 feet—above the ground), which several studies argue promotes a better estimate for carbon sequestration, the basal area must be converted to a measurement of diameter in order for the carbon sequestration coefficient to be applicable. The subsidy for a single tree is graphed below.

Figure 3 Tree Value per Acre by Year with a $50 per Ton Carbon Subsidy

This model gives an increasing yearly rental rate for carbon per acre from trees aged 1-50. In order to see the total subsidy value for the trees planted on or after the year of legislation, one simply sums the rental rates for each specific year over the number of years the trees are growing. (Formally, we would integrate the function over the appropriate range.) But it is also important to know how much the carbon in tree stands planted before legislative implementation is worth. If trees are already at the maximum sequestration age of 50, one simply multiplies the number or years the subsidy is paid by the maximum subsidy value (in essence a rental rate). After the tree stand has reached the maximum age of 50, the subsidy would not increase unless carbon price were to change.

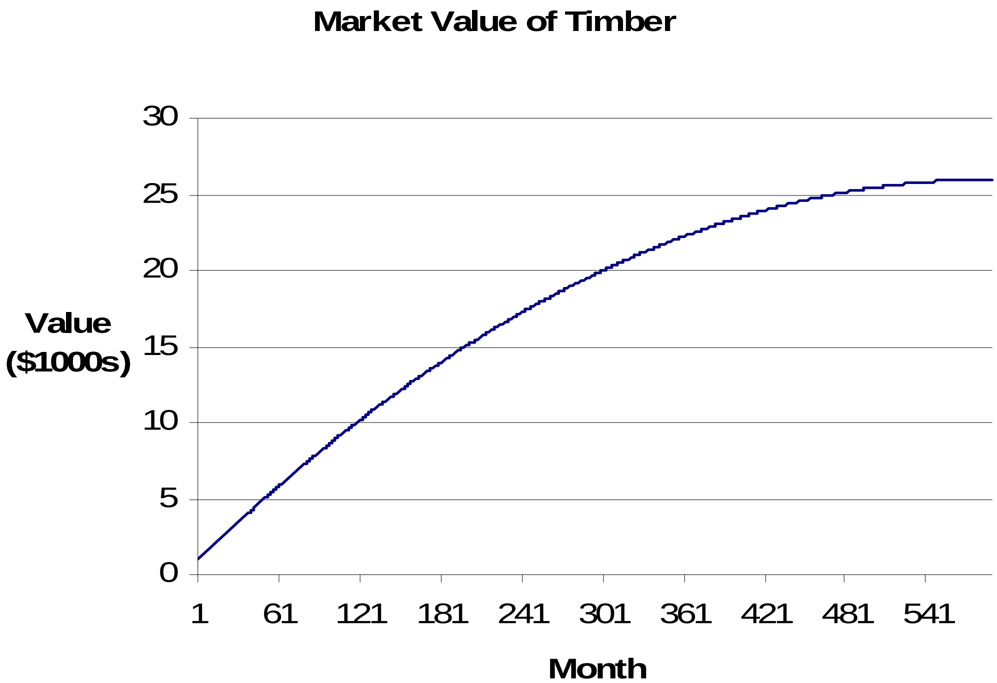
In order to see how a subsidy would affect the optimal growing point, a model for the value of an acre of trees at a given time is needed. The first step in this model is taking the value for timber at 50 years, the age at which the subsidy framework stops increasing the value of the subsidy, to have a comparable timeframe. Wilmott Forest Industries gives the harvest volumes from a forty year stand to be $259m^3$ of sawlogs and $24m^3$ of pulpwood, the two major types of harvest yields. The study also mentions that stand volume increases at an average of 4.67 to 8.5 cubic meters per acre per year. So, in order to approximate stand volumes at 50 years, ten years of growth at the lower bound average of 4.67 cubic meters a year was assumed. This value was picked for two reasons. First, one can assume that firms cut at whatever the optimal point is at a given interest rate, which would imply returns are low beyond that point in order to not make it economically profitable to cut a year or more later. Second, this slower growth rate matches the rate of the carbon sequestration. By no means would one expect the tree growth rate to be zero like carbon sequestration rate at 50 years, but one would expect it to slow greatly. This implies that over time the value of a carbon subsidy would decrease relative to the market value of the lumber, if only marginally. In order to properly assign how much of the estimated extra volume belongs to sawlogs and to pulpwood, the percentages of the overall volume at forty years was calculated and then the extra growth was split up into the same percentages and added to the existing volume: 91.5% of the volume are sawlogs, 8.5% is pulpwood.

After the total volume of harvest at fifty years is determined, the market value is needed. This is calculated by consulting world timber prices: southern pine sawlogs have a value of $59 per cubic meter and southern pulpwood prices are $27 per cubic meter. These prices are taken from RISI World Timber Price Quarterly, third quarter 2007. So, timber values are computed as:

$$TV = Q_{sawlog} * P_{sawlog} + P_{pulpwood} * Q_{pulpwood} \quad (3)$$

After a total market value has been calculated for a harvest at fifty years, an estimate is needed for the market value of the timber in a given acre of forest at any point in time. This is estimated by using a parabolic function with the maximum value set at the market value for timber at a fifty year stand age. While this may not capture the fluctuations in the market value of an acre of timber fully, it seems reasonable for a model. The estimated volume of a given acre of trees at fifty years of age, derived in the method discussed earlier, is 329.7 cubic feet of total wood volume, 301.7 cubic feet of which is sawlogs and 27.96 cubic feet is pulpwood. Simply multiplying the estimated volumes by the 2007 prices given above yields a value of $24,923.69 in sawlogs and $1056.90 in pulpwood, for a total value of $25,980.59 per acre of fifty-year old trees. Keeping these values in mind gives a standard to judge the relative value of a given subsidy.

Figure 4 Market Value of an Acre of Timber by Month



To this basic model for the market value for a given stand of trees, estimated non-timber market values are added to better incorporate the total worth. Trees offer a myriad of services, many of which are non-monetary benefits. These benefits include: soil stabilization, erosion control, air quality, climate regulation, biological diversity, recreation and tourism, non-timber commercial products, even a range of cultural values (even dog bathrooms, although the empirical study the values are pulled from does not estimate the monetary value of dog bathrooms). A general equilibrium model would take the value of these benefits as endogenous, but for this model estimates must be used to be able to reach a maximization point. Several studies have tried to estimate monetary values for these benefits in order to be more easily accounted for in an economic framework. The Wilderness Society has compiled an executive summary of these estimates of a total non-timber value of US forests to be 63.6 billion dollars, in 1994 US dollars. This is based on the empirically estimated value of $122.20 per acre per annum, again in 1994 US Dollars (these prices will be inflated to 2007 dollars later). So, the Recreational value equals

$$RV = t*122.20 \quad (4)$$

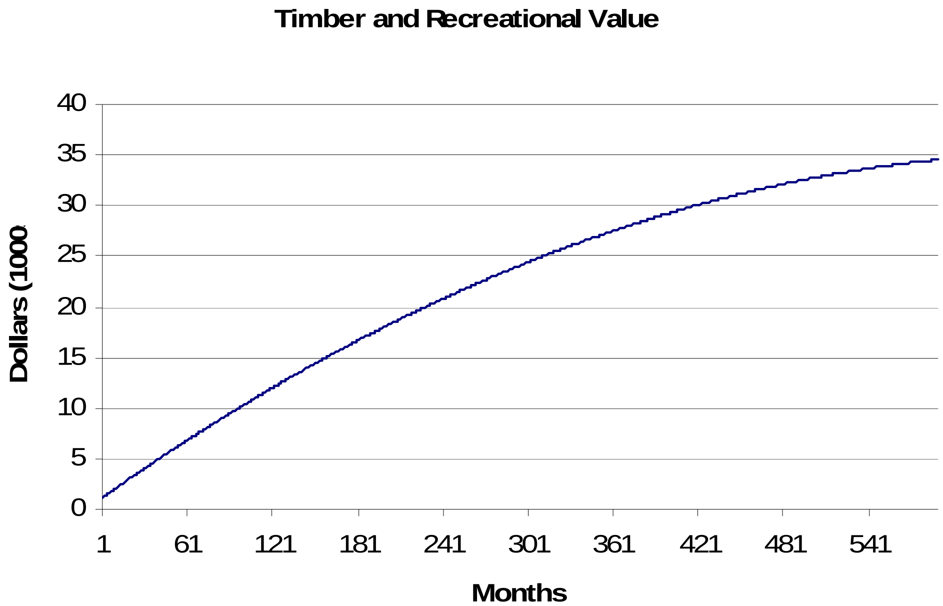
Where t is the number of years the stand has been growing. Non-timber values of forests are additional justifications for subsidies for forests. A forest subsidy above the carbon price might be appropriate. Here we use the carbon price.

The costs of a tree are then also incorporated into the model in order to have a more robust estimate of the value of an acre of trees at a given point in time. Cost is defined as:

$$\text{Cost} = \text{fixed planting costs} + \sum_{t=1}^{n} (\text{annual costs})_t \qquad (5)$$

For t = the number of years the trees have been commercially grown.

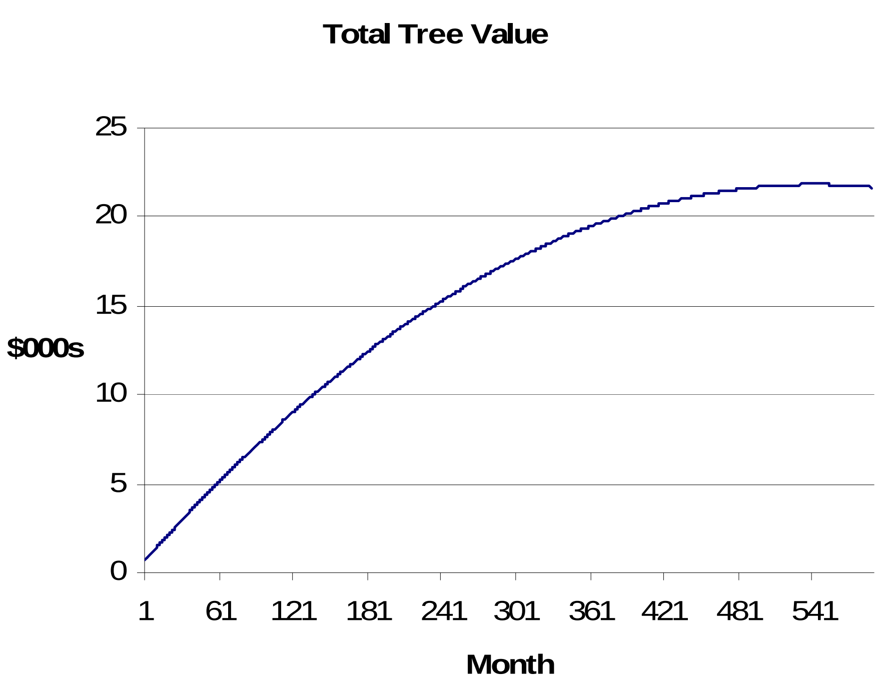
Figure 5 Value of Timber and Recreation in an Acre of Forest by the Age of the Trees



The study *Costs and Cost Trends for Forestry Practices in the South* (1999) enumerates the costs associated with growing trees commercially, and those estimates are used to approximate the cost of growing a tree. There are three input costs that only occur once during planting: site preparation for planting, the purchasing of the seedlings to plant, and the physical planting of the seedlings. These costs are estimated at $136.06, $20.90, and $40.40, per acre, in year 2000 dollars. After these one-time startup costs have been accounted for, the remaining seven factors are yearly expenditures. These factors are: chemical treatment (herbicide), prescribed burning as a method of stand management, fertilizer, fire protection, timber cruising (or stand sampling), timber marking (a method of thinning), and pre-commercial thinning. The reported costs per acre per year are: $62.12, $17.70, $43.80, $0.69, $3.45, $25.70, and $82.67, respectively. To calculate the total cost of growing trees of a given age, the model sums the fixed planting costs and then takes the value of the sum of the yearly costs times the number of years the stand has been growing.

Before adding the subsidy to this model for the value of the carbon in an acre of trees, two other factors must be taken into account. First, all the prices taken as empirical estimates from the literature must be converted into a common, and current, dollar level. This has been done by using the inflation calculator from the Bureau of Labor Statistics. All prices are put into 2007 dollars. The year 2007 has been picked over 2009 because of how the estimates are derived. The Bureau of Labor Statistics takes the average of all the months in a given year except for the current year, in which the estimate for the most recent month is used. An annual average is most likely closer to the real level than a fluctuating monthly estimate. The conversion factors for the other prices given in empirical estimates are: $1 in 1994 is equal to $1.40 in 2007; $1 in 2000 is equal to $1.20 in 2007.

Figure 6 Total Value of an Acre of Trees (before the subsidy)



The second factor is picking an appropriate discount rate. There is much debate over what is an appropriate discount rate, especially for intergenerational environmental issues. There are very few markets that give interest rates for time periods longer than thirty years. But for long estimates, it is crucial to attempt to get as close an estimate as possible because a very small difference in the interest rate can become a huge discrepancy over a period of, say 200 years. So, two estimates will be used. The first is the conservative estimate of a 4% discount rate. This has been the average rate of returns for government bonds and is used for many estimates currently (Newell and Pizer, 2004). The second case takes the work from Newell and Pizer (2004) into account, which tries to find better estimates for discount rates for long periods of time for environmental issues, where mathematically the discount rate converges to the lowest average of the numbers. Because of this, a discount rate of 2% is alternatively considered, because it is the historical lower limit of the market rate.

A third possible discount rate would be the cost of capital to the firm. If we are modeling the behavior of for-profit firms, then the relevant interest rate is the cost of capital to the firm, probably something like 10 percent. The model can be compared to current stand ages to make sure that it is a fairly accurate model. Current stand rotations for pine, the tree the model is based on, are 25 years. The model then is already a fairly close approximation at 2%, especially considering the fact that the model also includes non-timber values and explicit growing costs. Current stand ages at harvest in commercial forests also support the idea that the interest rate chosen here is replicating the behavior of firms. However, at a 10 percent interest rate, the subsidy creates a bigger percentage effect. Using a lower interest rate is then both more conservative and seems to more closely model the real world.

The value for market prices of timber, non-timber values, and growing costs can be taken as the total value estimate for a given acre of trees before the subsidy is added. Once the already-constructed subsidy term is included, the total equation for estimating the value of a given acre of trees with the values substituted is:

Value(t)= Timbermodel(t) + Rec*t - Plantcost - Annualcost*t+Subsidy(t) (6)

Where:

Rec is the empirically estimated non-timber value of an acre of trees in a given year

Plantcost is the sum of all one-time growing costs associated per acre of trees

Annual cost is the sum of annual costs of growing a given acre of trees in a year

Timbermodel is the model estimating the market value of an acre of timber at t

Subsidy is the integrated model calculating the volume of carbon per acre

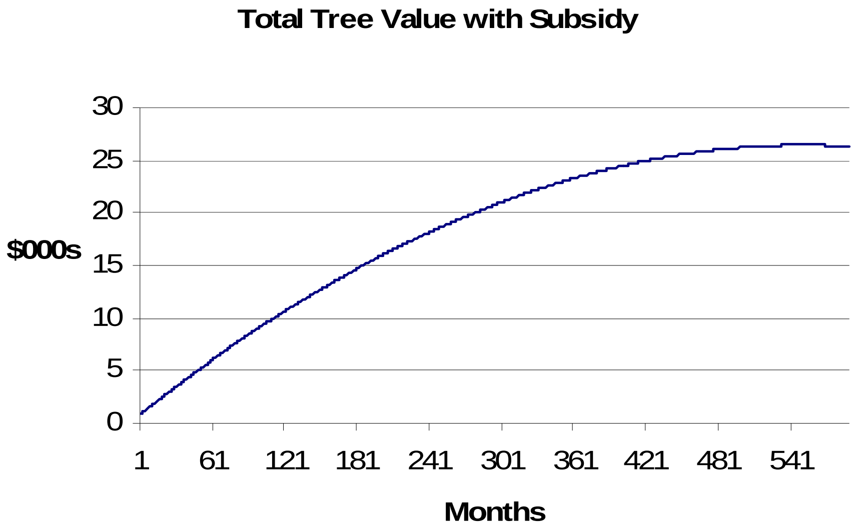
When all these steps have been completed and the proper empirical coefficients have been inserted, the full equation takes the form:

Total value of an acre of trees with the subsidy =

$$10.3922\, t \cdot (100 - t) + 171.08t - 261.91 - 475.4t + \left(\int_0^t .0032t - \left(\frac{1}{25^3} \right) t^2 \right) \cdot 71.43 p \qquad (7)$$

where t is the age of the tree in years and p is the given value of a ton of carbon.

Figure 7 Total Value of an Acre of Trees with the Carbon Subsidy Included

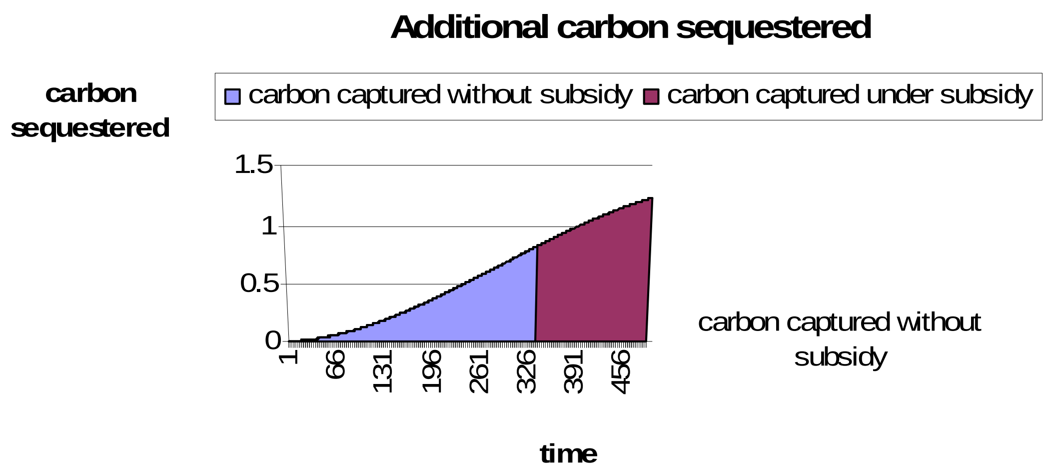


The parabolic estimate created earlier simulates tree *growth*. Total amount of carbon sequestered in the tree at any given time is the main interest; this can easily be found by integrating the tree growth model and then adding this term to the portion of the model that estimates total value before the subsidy (Figure 7). In order to find the optimization point, basic capital theory is necessary. Following the above steps creates a model estimating the total value of an acre of trees in a given year. The derivative of the previous equation, which is needed for calculating the rate of return, is given as:

$$734.9 - 20.78t + \left(.0032t - \left(\frac{1}{25^3} \right) t^2 \right) \cdot 71.43p \qquad (8)$$

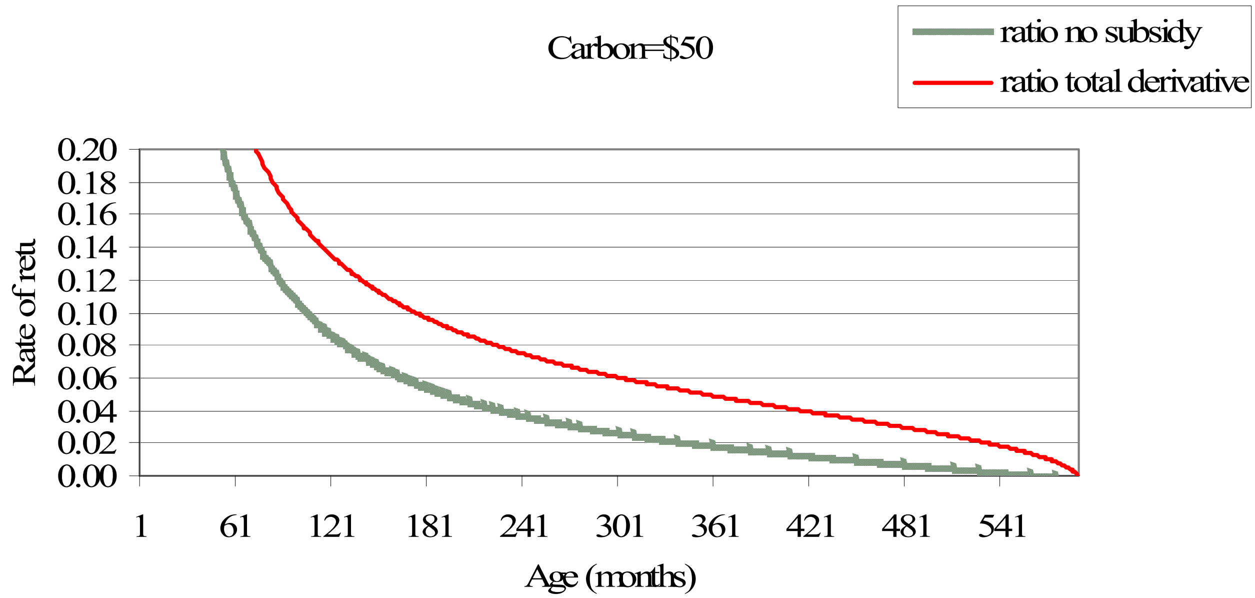
Taking the ratio of the derivative to the total value will give the rate of return in a given point in time for the value of the lumber in the tree. This can then be graphed and compared to a given discount rate to see when the optimal cut point is. Again, the discount rates used will be 2% and 4%. Taking the derivative with respect to t will give the gain in lumber value by year (and the derivative of the tree model is the previously created tree growth portion of the model). This optimization will be compared to the graph of the value of the tree without a subsidy to see how the subsidy affects the cut point.

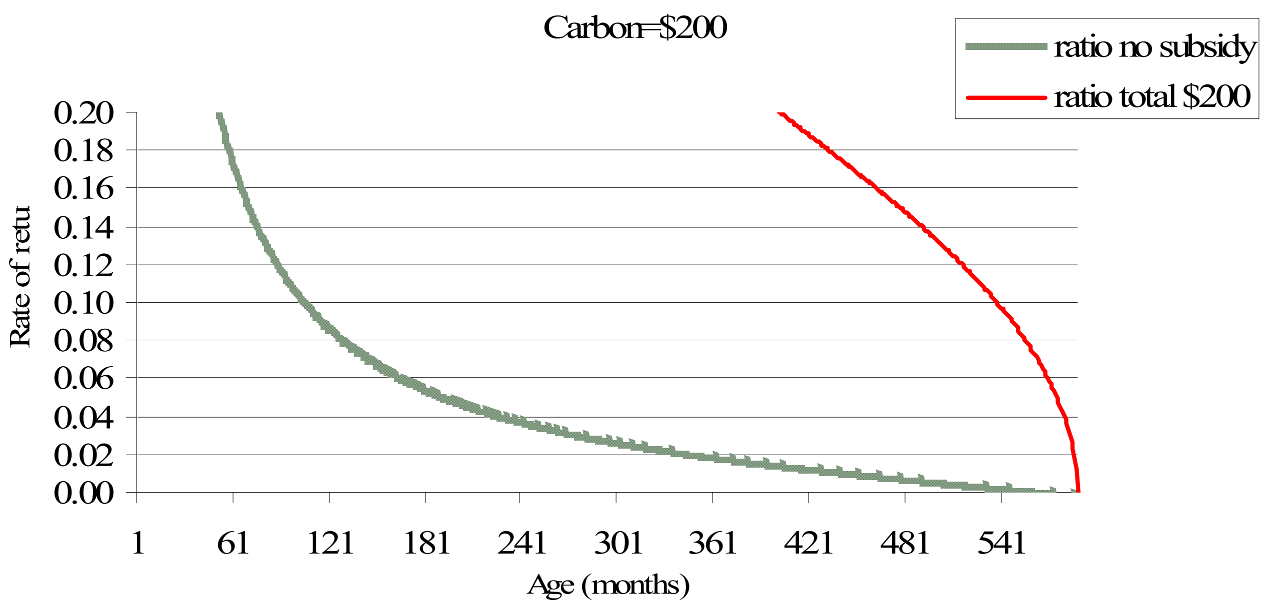
Figure 8 Carbon Sequestered as a Result of a $20 per Ton Subsidy



Below are the graphs for the ratios for the ratio of derivative to total value of the tree, by month, with and without the subsidy included, for a carbon price of both $50 and $200 per ton. These values have been picked because they seem to be about the minimum for an effective price and the projected upper limit for a carbon price for the next century.

Figure 9 Rate of Return on an Acre of Trees, with and without Subsidy





The x-axis of each graph is the age of the tree, in months. Using the capital theory described above, each line is the ratio of the derivative to the overall value of the tree (the incremental rate of return). The gray line represents the rate of return of the tree without the subsidy for any given month from zero to fifty years of age. The solid line is the ratio of the derivative to the total value of the tree with the subsidy included. The y-axis is the rate of return. The scale is set to display a relevant range of rates of return. To find the optimized tree age, a rate of return is drawn from the market (as previously discussed, the two rates used here are 2% and 4%) and then the month when the market rate equals the rate of return for the tree is located. The time that elapses between when an acre of trees would be cut with and without the subsidy is represented by the horizontal distance between the two graphs.

Model Results

It is evident that the subsidy makes a greater difference in stand age the higher is the price of carbon. Capital theory says that this ratio gives the decision point to cut for a given rate of return. The time, in months, between when a firm would cut without a subsidy and when a firm would cut with one can be used to determine how much more carbon is sequestered with the subsidy. The subsidy amount is equal to the value of the carbon in a tree at a price of carbon per ton, taken either from a market or legislation, for the volume at the new optimization point. The subsidy is the value that must be added in order to change the optimization point. For example, at a carbon price of $50 per ton, the new optimal age for a tree stand at an interest rate of 2% is 45.33 years. The value of the carbon in an acre of trees that age is $4596.06. The subsidy is the value of the carbon in the trees, shifting the optimization point to the new age. This could arguably be paid out in a lump sum of that value, but greater incentives would most likely be created if the subsidy paid for the value of the carbon in the trees is paid yearly, resembling a rental rate. Were a lump sum payment to be designed, discounting would be needed to ensure the total subsidy remained the same. At a carbon price of $200 a ton the optimal age with an interest rate of 2% is 49.833 years. The value of the carbon of an acre of trees in this scenario is $18,613.68. At a 4% interest rate, the optimal age is 49.333 years and the value of the carbon in the trees, taken as the monetary value of the subsidy, is $18,608.84.

These values can be compared to the estimated value of the acre of trees at the age when they are cut. It makes more sense to compare it to the total value of the tree at that age, including both the non-timber values for that age and the costs of growing, rather than the simple estimated market value of the lumber because this is a more accurate estimate of the value. At an interest rate of 2% and carbon price of $50 per ton, the optimal age is 45.33 years. The total value of the trees at this age is $21,825.67. The value of the subsidy in this case is equivalent to 21% of the total value of an acre of trees. For a carbon subsidy of $200 a ton, the total value for the optimal age at a 2% interest rate is $21,685.25, making the value of the subsidy equivalent to 85.8% of the non-subsidized tree value. These numbers for the additional sequestration at a price of carbon equal to $50 and $200 a ton are reproduced in the table below:

Table 1 Value of Carbon Sequestered per Acre by Interest Rate

				added carbon value per acre	
Interest rate	years added	total tree volume	additional carbon sequestered	Carbon=$50	Carbon=$200
0.02	15.500	0.242	17.281	864.037	3456.148
0.04	15.667	0.394	28.138	1406.902	5627.606

So the subsidy is effective beginning at $20 per ton of carbon, and at a carbon price of $50 a ton it sequesters between 17.2 and 28.1 extra tons of carbon per acre over a growing period extended by 15 years depending on what interest rate is used. This extended growing period brings significant sequestration, with a 33.47% increase in carbon at the $50 subsidy level. The total worth of this carbon is totally dependent on the value of carbon, but again depending on the interest rate the total amount can be worth anywhere between $864 and $5627 per acre, a sizable incentive.

Forest Policy

But the true consequence of a subsidy of this nature becomes clearer in light of some national statistics. In 2007, the EPA reported 736.7 million acres of forest land in the US, a definition that mandates the area be a minimum of 1 acre, have 10% forest cover, and be “not currently developed for non-forest use” (Forestry 2007). Of this land, the Federal Government owns 249.1 million acres; the other 487.6 million acres are owned by a combination of companies, individuals, and other non-federal levels of government. More importantly, almost 490 million acres (2/3 of the total forest land area) are designated as “timberland,” or areas that can be harvested for “commercial wood products” (Forestry 2007). The nature of US forest land makes it hard to readily plug into the previously created model, but some interesting choices still arise in different hypothetical situations.

It is important to remember that the designed subsidy is dependent on the trees being a part of highly managed stands—stands that use optimal land, pre-commercial thinning, and optimal density. In order to decide how much of the total forest land can be included under considerations for national forest policy, we must determine which different types of forest owners manage their stands closely enough to qualify under the subsidy. For reasons that will be more fully developed later, it seems reasonable that the commercially owned private forests and public timberland meet the criterion of being highly managed enough to be included in subsidy legislation.

The results from the model are heavily dependent on the age of the tree, or at least the average age of the stand, but this information would be a general estimate at best for such a large area. Consider first the scenario in which the subsidy of $50 per ton of carbon is in place and extends the optimal harvest age out in all the acres of timberland, where the decision-making ostensibly takes place. Assuming the subsidy altered the optimal harvest date for the entire area, at a discount rate of 2% an additional 8467.5 million metric tons of carbon are sequestered in the stand for N years. This extra carbon sequestered has a value of between 423.3 and 1693.5 billion dollars. At a 4% discount rate 13,787.6 million metric tons of carbon sequestered.

Another interesting scenario is to consider the total volume of carbon sequestered in US forests assuming all the stands were at the maximum sequestration age of 50 years that this model uses. This is an unrealistic assumption for the entire age of forests in the United States, as is the assumption of 100% tree cover for a given acre (the definition only mandates 10%). Still, with these assumptions in place the total volume of carbon sequestered in forests is 70.16 billion metric tons of carbon. Granted, this value overestimates the amount of carbon actually sequestered in forests, but still gives an idea of the magnitude a subsidy of this nature could have for both US forest policy and US carbon policy. The results from the model do show that subsidies on the amount of carbon sequestered can be effective. Subsidies increase stand age and overall amount of carbon sequestered in existing forests. The amount of carbon sequestered and the dollar value of the carbon are both substantial under this subsidy framework, suggesting it would be effective but expensive to put such legislation in place.

Implications of the Model:

The previous section developed a model to estimate the amount of carbon sequestered in trees and then calculated the value, first of the carbon sequestered in trees, and then the overall value of a plot of land to examine the changes, if any, that occur for a firm's planting decision. But a more important question to address is the role a subsidy of this type could play in a national policy for carbon sequestration. An excellent place to start is by examining this subsidy's relation to current legislation. The Markey bill, HR 6186, was introduced in the 110th Congress of the United States. While nothing came of it in that session, it is an important enough bill that it will most likely be reintroduced in the 111th Congress. The Markey bill incorporates wide-reaching reforms for environmental policy. One part of the bill stipulates:

> "qualifying offset projects within the United States that achieve greenhouse gas emission reductions below, or increases in biological sequestration above, the project baseline ensure that such offset credits represent real, verifiable, additional, permanent, and enforceable reductions in greenhouse gas emissions or increases in biological sequestration;" (69)

The proposed subsidy could qualify as a potential offset project. It is important that the word permanent be clearly defined in the bill. In one sense, because trees are not planted and then grown in perpetuity under the proposed model for carbon subsidies, they could be excluded from the legislation. However, with a subsidy for capture there is an appreciable increase in the amount of carbon sequestered in a given acre of trees and even with producers still harvesting lumber, the increase in sequestered carbon is maintained perpetually in these managed forest stands. There is a 33.47% percent increase in sequestration for a given plot of land just by adding a subsidy of $50 a ton because of how it changes the age of the stand and the decision point for cutting. Because of this, it is important to ensure that this subsidy is acceptable under this legislation.

The Markey bill does address the use of trees specifically. It calls to be increased, "biological sequestration of carbon through afforestation or reforestation of acreage in the United States that was not forested as of June 3, 2008" (70). This is a troubling demand. Afforestation and reforestation are viable options to increase biological sequestration, but the model clearly shows that they should not be the only two options for biological sequestration considered. The bill defines additionality (and additional) as: "the extent to which reductions in greenhouse gas emissions or increases in sequestration are incremental to business as-usual, measured as the difference between— ''(A) the baseline; and ''(B) net greenhouse gas emissions or sequestration resulting from an offset project"(14). This definition allows for incremental sequestration from business as usual levels. It therefore is inconsistent to allow some offsetting programs to incorporate additionality but only consider biological sequestration through planting new trees. Again, the amount of additional carbon sequestered in an acre with the subsidy is significant, beginning at 33.47%. Depending on the costs of purchasing land that is not currently forested, either cropland or some other source of available land, and planting new trees on it, it is quite possible that afforestation and reforestation are not lowest cost ways to achieve the same target amount of sequestration. It makes more sense to allow for additionality in sequestration across the board in order to make the biggest impact on carbon emission levels. Allowing for additionality with forest policy specifically would allow programs such as the designed subsidy to take effect.

The Markey bill also puts some thought into what monitoring measures must be implemented to check on the sequestration. Generally, the bill calls for development of standardized tools for monitoring and quantification. The model already is a standardized tool for quantification. The bill specifies that ‘‘the type or scope of audits, including—(A) reporting and recordkeeping; and (B) site review or visitation; (C) the rights and privileges of an audited party; and (D) the establishment of an appeal process” (81). These are important things to consider; however, under a carbon subsidy for trees. The monitoring can be specified much more explicitly and brings up some important considerations. Forest fires, volcanoes, disease, and global climate change can diminish carbon sequestration in a forest and the monitoring would need to account for these problems as they arise for a specific stand. Once proper coefficients for how these problems affect carbon sequestration are determined, they would be easy to incorporate into the model.

Since there is a subsidy paid to producers, it is in their interest to certify their forest lands in whatever way is required to receive the subsidy. This increases the chance of success of setting up a registry system similar to income taxes, where the company files a form. In order for the model to be as correct as possible, it seems reasonable that the Forestry Service could use its research and team of biologists to refine the model to make it species-type specific. Then, after registering initially, a special survey team would come out to the forest stand and measure both the acreage and the type of tree. Annually the firm would only have to report acreage and tree type in the stand. These numbers would then be plugged into the refined model to calculate the appropriate subsidy. Since there is not much carbon sequestered in the trees the first few years a stand grows, it is reasonable to begin paying the subsidy at an age greater than zero. Once subsidy payments did start, at 3 years for example, they would again be for the total amount of carbon in trees. Delaying subsidy payments for the first few years allows the trees to be established and also helps reduce some of the monitoring costs.

While this seems like an efficient way to collect all the yearly information from firms about forest stands to calculate the subsidy, it also presents a moral hazard for firms to try to cheat. Several easily implemented monitoring measures could reduce these incentives to cheat. The first and most effective would be satellite image monitoring. There are plenty of government-owned imaging satellites that, if they are not already surveying the area, could easily be doing so. This could be overlaid on a base image to automatically check and make sure unreported cutting did not occur. This would also need to be paired with on-the-ground spot checks. This could be a relatively small team, but it would be important to have random spot checks in a further attempt to keep producers honest. Making the owners post signs about being part of the carbon subsidy program could also aid in reducing the moral hazard. Much like warning people about not hunting through posted signs, if there were a description explaining that the owner was getting paid for growing the trees and had a number to call to report any problems, it might help the neighbors keep the grower accountable for growing the trees.

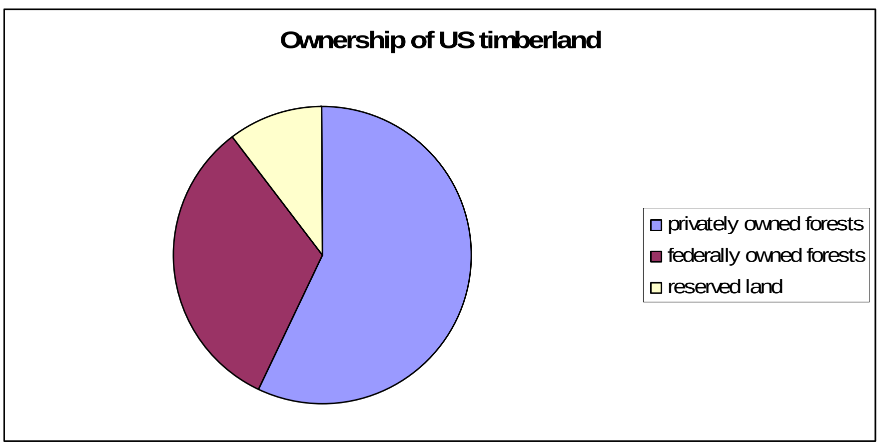
It would also be important to have large penalties in place as further incentive for firms not to cheat. Removing current subsidies, large monetary fines, and banning firms from participating in subsidy programs again could all be combined to create effective incentives for firms. As a final way to keep firms accountable, sawmills could start reporting who they buy their lumber from and how much lumber was purchased as an easy measure to crosscheck the accuracy of self reporting.

There is one part of the Markey bill that is in fairly direct opposition to the proposed tree subsidy and other parts of the bill. It proposes that “Offset credits shall be issued under this subtitle only for reductions in emissions or increases in biological sequestration that occur after the date of promulgation of regulations under section 741(a)” (82). In contrast, the proposed carbon subsidy is better conceptualized as a rental rate on all of the carbon in a forest. All this requires is the age of the stand, the size of the stand, and the type of tree for the model to give the appropriate carbon capture. If only increases in biological sequestration are only accepted after the date of regulations, these restrictions add enough complexity to make it only so newly planted trees are accounted for in the subsidy. While it is a valid argument that subsidizing the entire amount of carbon in a stand of trees will cost the taxpayer more, a subsidy of all the carbon would most likely create better incentives for firms and will be more successful in sequestration, a topic fully explained below. Such policy also creates a kink in the supply of carbon offsets. There is not sufficient reason to limit the carbon subsidy to only the carbon that is sequestered after the onset of legislation.

Policy implications:

The Markey bill is a step towards legislation addressing the problem of global climate change. Under a Markey bill framework, a subsidy such as the one proposed here can contribute to overall carbon sequestration. However, there are some issues that would have to be reconciled between the two in order for the subsidy to work optimally under Markey legislation. An interesting alternative question to propose is how effective would the subsidy be in inducing carbon sequestration if it were the only program in place. Even though trees sequester carbon in the same manner whether they are currently being managed by Federal government, State government, a private firm, or are newly planted trees, different policies are more appropriate depending on the situation. Profit-maximizing firms may respond differently to incentives than government agencies due to their individual concerns. If this is true, then it makes sense to make sure each of the three major categories is being sent the right signals. For all scenarios, specific acreage estimates come from *Forest Resources of the United States, 2002* (Smith et all, 2002) in order to get a clearer picture of the scale, both monetarily and in terms of carbon sequestration, that such a national subsidy would entail.

Figure 10 Ownership of US Forests



Consider first the trees that are currently managed by private firms. There are an estimated 429,761,000 total acres of private forest land in the United States. Of this, only 66,380,000 or 15.4% is owned by the forest industry. Such a low percentage of forest industry ownership has two possible implications. First, there is a possibility that the non-forest industry owners are harvesting at sub-optimal stand ages. This allows for the possibility of even greater gains in carbon sequestration if the subsidy encouraged better optimization of stand age (or lesser, if the non-forest industry owners are not currently harvesting at all). However, all calculations will assume that all acres were previously managed in a way that maximized stand age with the market value. Using the estimate from the model, at a 2% interest rate there are 32.1 billion tons of carbon already contained in privately owned forests. With a subsidy of $50 per ton, the total amount of carbon sequestered in private forests increases to 39.5 billion tons, a net increase of 7.4 billion tons. This is a little more than one year's current emissions. The total value of all subsidies the government would have to pay out, at a carbon price of $50 a ton, would amount to $ 371.3 billion, not including any monitoring costs.

The total value of the subsidy to private owners is quite high, but there are several considerations that make the amount more acceptable in society's eyes. First, it is important to remember that the overall goal is to capture an important external cost and integrate it into the market so companies are paying for the environmental degradation they cause. Also, the subsidy is one part of an overall carbon tax. Companies will have already bought carbon emissions permits by the ton, either through a cap and trade system or some other regulatory construct. There are many possible options for the government to spend the income from a price on carbon. Using the money to fund research and development for more energy and carbon efficient technologies or returned in the form of rebates to make sure a tax on carbon is not a regressive tax are two possible ideas. Some of the government income created from this overall tax could be used to pay out the subsidy. The subsidy on existing forests grown to current levels is a transfer to owners of existing forests, a budgetary outlay for government but not a cost in forgone production to the economy. There is no resource cost to a transfer, no reduction in GDP. In national income accounting, the transfers to forest owners would be like social security payments. In the case for privately owned forests, the subsidy would be traditional, with money changing hands as a transfer payment.

The process of carbon sequestration is the same whether the acres of forest are owned publicly or privately, but the value of the carbon has very different implications. There are an estimated 319.2 million acres of publicly-owned forests, of which 246.4 million acres—77.2%, is federally owned. While states do own significant acres of forest, it is reasonable to assume that with federal legislation in place that they would behave in the same manner as federally managed forest stands. Thus, all publicly owned acres will be treated the same here. There is an important difference between federally managed and privately managed stands. There are 77 million acres of "reserved" land, or land that has been set aside permanently that cannot be harvested. This has two major implications for trying to calculate how much extra carbon could be sequestered under such a subsidy. First, unlike the other acres of timberland that are currently being managed, the reserved land by definition cannot be harvested and thus should be estimated as holding the maximum amount of carbon. Since these acres already hold the maximum amount of carbon, they will not be affected by the subsidy. Thus, an estimated 7.2 billion tons of carbon are permanently sequestered in these reserved forest lands; while it important to consider the amount of carbon stored through these means, the amount holds little sway over the rest of policy formation. This leaves 242 million acres of public timberland that can be affected by the carbon subsidy. Using the base case of a 2% interest rate and a carbon price of $50 a ton, a tree subsidy would sequester an extra 4.2 billion tons of carbon, at a value of $ 209.2 billion.

But, unlike with privately owned land, there is no reason for the government to make such large transfer payments from itself. This increased value should manifest itself in different ways. The subsidy makes it so the trees on a given acre of federal timberland are worth more. Private firms who want to engage in contracts with public agencies would have to pay 100% of the increase in price value in order to be able to harvest. This extra revenue could easily be set aside to help alleviate the large amounts of money being paid out to private companies through the same subsidies. The National Forest Management Act of 1976 states that "the public interest is served by the Forest Service," and since carbon sequestration is one way to serve the national interest, the carbon sequestration subsidy is a reasonable issue for the Forest Service to address (1). The current legislation on what timber can be harvested and how harvesting can occur addresses many different aspects of the harvest process. Some of the most relevant parts of the legislation deal with where the timber can be harvested: harvesting cannot cause irreversible damage to the land, the lands must be able to be restocked within a five-year period, and nearby water sources must be considered and protected. Also, legislation forbids harvesting simply because a region will give the greatest dollar return or quantity of timber (1976 5-6). Another important aspect of the National Forest Management Act of 1976 is the limitations that are placed on timber removal: "The Secretary of Agriculture shall limit the sale of timber from each national forest to a quantity equal to or less than a quantity which can be removed from such a forest annually in perpetuity on a sustained-yield basis" (8). Both parts of this legislation are important because they show that there is already something that resembles an optimal management system in place for national forests. The restrictions on land push for harvests with the lowest overall marginal cost, giving a higher utility. Also, the sustainable limits show that the Forest Service is actively managing its forests, and not passively or randomly deciding when and how much to cut.

There is also very specific policy in place for selling the right to harvest specific tracts of land. Areas have to be displayed on maps and be available for all interested parties. The bidding methods by law must “insure open and fair competition” and “insure that the Federal Government receive not less than the appraised value” (10). This means that in open competition the bid must reach at least the value of the forest. Because the subsidy adds the value of the carbon to the timber, the starting price for bids would increase by the value of the carbon sequestered. This accomplishes the goal of the subsidy with respect to nationally-owned forests specifically. The legislation in place makes the Forest Service manage their stands actively enough to plausibly fit into the assumptions of the subsidy framework. The increased price of the timber under the subsidy, which the Forest Service would charge as the low point for bids, would almost certainly affect the harvest decision for private firms buying public trees. Finally, the increased revenue to the government could be used to help offset the value of the transfer payments paid out to private firms. A combination of all these legislative articles makes it so publicly owned stands seem highly managed to qualify for consideration under the designed subsidy.

As stated in the introduction, a subsidy like the type proposed would decrease the volume of timber harvested initially by 21.4%. This occurs because as the optimal stand age increases, the size of each vintage of trees decreases. With the 15 year increase in stand age resulting from the subsidy, the size of each vintage for any given amount of land decreases by 33%. While growing the trees longer increases the volume of timber products at harvest, it is not enough to compensate for the larger loss in volume from harvesting 33% fewer acres. While the timber market would reach the original equilibrium as tree stands reached the new optimal age, this would initially create a negative supply shock. This would be a real resource cost, as sawlogs and pulpwood, which are used to make products like lumber and paper, would increase in price as demand outstripped supply. While a decrease in the products produced would cause a decrease in the amount of carbon pickled in final products, because the trees would still be growing, holding 100% of the carbon sequestered, this would not offset any gains in carbon sequestration. Final timber product prices would be expected to rise across the board.

A final policy implication to consider is the fact that land prices are not explicit in the model. Land price trends are important to consider in a broader context. With global population pressure, climate-driven drought, and rising sea levels, the price of land may very well rise in the future. With land prices higher because of a higher demand for land, getting more carbon sequestration from existing forests is even more valuable as a way to sequester carbon. Rising land prices would make it even more costly to plant new trees in an effort to sequester more carbon as the Markey bill proposes. At the same time, rising land prices would increase the opportunity cost of keeping forests on land they already occupy. It would be important to make sure the subsidy incorporated the effects of rising land prices, which could be great increases indeed, on the value of an acre of trees to ensure that the proper incentives to grow trees longer still existed.

Forest Sequestration in light of overall carbon emissions reduction targets

For all the positive effects a carbon subsidy of trees could produce both within the framework of the Markey bill and operating independently and possibly more effectively, it is important to evaluate the subsidy in terms of reaching overall carbon subsidy goals. Near his inauguration, President Obama's transition team announced "strong targets that set us on a course to reduce emissions to their 1990 levels by 2020 and reduce them an additional 80 percent by 2050" (Broder 1). For reference, the 1990 level of carbon dioxide emissions was 5.02 billion metric tons of carbon dioxide. Below is a summary table of the estimated possible sequestration under such a subsidy.

Table 2 Carbon sequestered in US forests

Billions of Tons of Carbon sequestered in US forests

			total tons at steady state with each level of subsidy				
		stock 2007	$20	$50	$100	$150	$200
	Existing Land:						
	Industry	4.84	5.78	6.10	6.16	6.17	6.18
.02 Interest Rate	Informal	26.50	31.62	33.40	33.75	33.80	33.82
	Public	23.28	27.78	29.34	29.64	29.68	29.70
	Total	54.62	65.18	68.84	69.55	69.65	69.70
	Industry	3.65	4.57	5.52	6.01	6.11	6.18
.04 Interest Rate	Informal	20.00	25.02	30.22	32.91	33.44	33.81
	Public	17.56	21.98	26.54	28.90	29.37	29.70
	Total	41.21	51.57	62.29	67.82	68.93	69.68

It is hard to know where carbon emissions will peak before beginning to decrease in order to reach the goal of being equal to the 1990 level of carbon emissions by 2015, but a low end estimate would be to take the 2007 level emissions as the high mark to calculate how much reduction would be required. The 2007 estimate of 6,021.8 million metric tons of carbon means that 100.4 million metric tons would need to be sequestered per year to hold 1990 levels constant until 2020. The fact that the necessary sequestration is a flow whereas the sequestration gained from trees is a one time gain makes it harder to compare overall effects. For the 2020 case, a total of 11.004 billion tons need to be sequestered. This amount of sequestration is attainable at subsidy levels as low as $20 a ton of carbon. The subsidy creates enough additional sequestration to cover this needed amount without doing anything more than using the subsidy to make firm decision-making more accurately reflect the full cost of their decisions. However to achieve the same amount with forests under the Markey bill, this amount would have to be sequestered in 11 years with only new planting. This means that 335,907,580 acres would have to be planted in order to reach 1990 levels by 2020, an enormous amount of land.

Reaching the sequestration goal for 2050 is more challenging. An 80% reduction of 1990 level emissions means that by 2050 the US should only be emitting 1004.28 million metric tons per year. It is hard to compare the stock of carbon stored in forests to the annual flow of such a high level of emissions. However, it is reasonable to assume over time emissions reductions would occur to allow the US to really only be emitting 1004.38 million metric tons by 2050. In order to better approximate how much carbon dioxide would actually have to be sequestered by 2050, a linear estimate is used. This estimate takes the 2007 emissions level as the high point, and then from 2009 linearly decreases emissions levels over the next 41 years to reach the target emission level in 2050. This is a simplification of what will most likely occur in reality, but should give a general idea of the actual amount of sequestration required. Taking a linear estimate of the reduction in emissions and then integrating over the 48 year period gives the total amount of emissions over the period: 148,066 million metric tons. The total increase in sequestered carbon in all forests public and private at the $50 subsidy level is 14,220 million metric tons of carbon, or 9.6% of the estimated total amount of sequestration required. At the $200 subsidy level, the extra amount of sequestered carbon increases to 15,020 million metric tons, 10.1% of the estimated total amount of sequestration required. This puts the discrepancy between a stock of carbon sequestration and the yearly flow of carbon emissions into better focus, but still makes sizable headway towards meeting the 2050 goals. Combined with new technologies to reduce emissions, the nine to ten percent of total needed sequestration that can come from trees lends strength to the argument that trees should be at least a part of any plan to address carbon emissions.

Large windfall profits go to firms or individuals that currently own tree stands that are managed enough to fall under the proposed subsidy. Windfall profits are acceptable as they are an important consequence of property rights. Once the value of carbon was created, owning acres of forests would be no different than an individual or firm owning the mineral rights to a piece of land that had oil. However, these windfall property rights affect policy formation. If the American public was unwilling to pay such high carbon rental rates to companies, legislation could mandate that the forest service buy a given amount of acreage every year. The more land the US owns that qualifies for the subsidy, the higher the revenues will be from the increased price that would have to be paid by private firms to harvest.

Similarly, in a cap and trade arena, it would also be possible for the large subsidy owed to private forest owners to be paid by emitters as well as the government. A cap and trade market would be for tons of carbon emitted by producers, an annual flow. The forest subsidy described here is for each ton of carbon sequestered, a stock value. The nature of these stock and flow variables means there must be some way to relate these two values to each other. It is conceivable that the carbon sequestered in trees could be turned into credits that are then sold in the cap and trade market to increase the total amount of carbon sequestered. The market needs to be designed so that emitters must buy more sequestration in order to offset additional carbon emissions. Instead of the government paying the subsidy from revenue collected elsewhere, the government could simply certify the amount of carbon currently sequestered (or future carbon sequestration credits) and then these certification requirements could be sold in the cap and trade market to carbon emitters. That way the emitters pay the cost of their carbon emissions directly and in full and these who own the trees sequestering the carbon still receive the proper subsidy to encourage the additional growth to take place. Under this system the government would only have to pay the monitoring costs.

But there are other ways that the government could use trees to sequester carbon that might be more cost effective. One thing the government could do is offer free trees for individuals to plant. Subsidizing the costs by giving the seedlings away should create incentives for trees to be planted but do so in a lower cost than paying rental rates on sequestered carbon. Consider the scenario where the US government gives away 1,000,000,000 seedlings. It is reasonable that with individuals planting a few trees on the plots of land they own overcrowding will not be a problem, so optimal density will be achieved. At 166 trees an acre, the 1,000,000,000 trees would be the equivalent of 6.02 million acres of trees planted. There is the additional consideration that as these trees will not be harvested to become timber products it is reasonable to assume they grow to reach full maturity at 50 years. Upon cutting though, these trees probably have much lower pickling rates than managed forests. Six million acres of saturated carbon sequestration would be the equivalent of 560.56 billion tons of carbon sequestered, a sizable sum. Mayor Bloomberg proposed to plant one million trees in New York City, an example of the possibility of government-led mass tree plants.

A final consideration for the proposed carbon subsidy is if it is possible to turn the stock of sequestered carbon into some sort of flow of sequestration in order to better keep up with the flow of carbon emissions. It seems that a more advanced model could indeed turn the amount of carbon sequestered in trees through the subsidy into a flow. The model currently only considers the carbon currently held in growing trees. Since managed trees are planted and harvested in a manner that the total stock is constant over time, the incentive to grow the trees longer will increase the amount of sequestered carbon up until the stock of trees reaches equilibrium again. However, including amount of carbon pickled in harvested wood would turn the amount of carbon sequestered into a flow variable. In addition to the one time addition to the stock of carbon sequestered in the acres of trees each vintage of harvested trees would have some percentage of carbon pickled in various products. Accounting for this amount of pickled carbon would turn the amount of carbon sequestered under the subsidy into a flow variable. This would require empirical estimates of pickling rates of various common products and market research on how much of each product is made for a given vintage of harvested wood. A subsidized program to buy wood for permanent burial, one form of pickling, would increase the price of timber and increase carbon sequestration in the forest as the trees grow and create a flow of carbon being permanently captured. However, it is reasonable to believe that the opportunity cost of the resources necessary to bury wood permanently in an act of sequestration would outweigh the projected gains, rendering it a non-viable option. While these estimates are within the scope of reason to calculate, they are beyond the scope of this paper. Further study in this area could perhaps turn the proposed subsidy into a more sustainable policy.

Carbon emissions are a large part of the problem of global climate change. It will take a concerted effort to solve such a daunting problem. However, a subsidy for the amount of carbon sequestered in trees naturally could affect the optimal harvest point greatly for public and private firms alike, leading to impressive gains in carbon sequestration. The aggregate model may not be accurate enough to form real policy, but the Forest Service could easily retool a model such as the one developed above to account for individual species. The volumes of carbon sequestration attainable through existing trees and the monetary value that could be attached to the carbon are sufficient reason to try to incorporate a subsidy such as this into any of the current bills addressing climate change and the part the United States will play in addressing the issue.

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