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Trading Forest Carbon:
A Panacea or Pipe Dream to Address Climate Change?

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"Examine each question in terms of what is ethically and aesthetically right, as well as what is economically expedient."

—Aldo Leopold, ***A Sand County Almanac***

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Introduction

Alarmed at increasing levels of carbon dioxide (CO_2) in the atmosphere, and persuaded that this contributes to climate change, policy makers are looking for ways to slow down or even reverse its accumulation. The leading approach is to limit the amount of emissions entering the atmosphere, primarily by curbing fossil fuel use. An alternative or perhaps complementary approach is to increase the amount of CO_2 that is removed from the atmosphere.

Since the earliest discussions of global warming, forestry has been considered as a possible way to reduce the buildup of carbon dioxide in the atmosphere (see e.g., Dyson 1976; Marland 1988). Trees and other vegetation naturally remove CO_2 from the air during photosynthesis and store—sequester—carbon in leaves, bark, branches, roots, and soils. In the United States alone, forest ecosystems are estimated to contain about 64 billion metric tons of carbon (Heath and Smith 2004). This is nearly 40 times the 2004 U.S. energy-related emissions of carbon dioxide.[1]

Similar to the Kyoto Protocol (KP), which went into effect in February 2005 without U.S. support, legislation recently introduced in the U.S.[2] proposes implementation of a market-based emissions trading scheme—a cap-and-trade program. Affected companies would be able to meet their emission goals (cap) through their own efforts to limit carbon emissions or through purchases of tradable emission allowances or credits, which are essentially permits to emit specific quantities of CO_2 and other greenhouse gases.[3] Tradable credits and allowances would be generated primarily by activities that reduce the amount of emissions that enter the atmosphere. Alternatively, credits could be generated from activities that remove CO_2 already in the atmosphere by growing additional forests to sequester carbon. Each metric ton of carbon sequestered in new forests and certain forestry practices could generate tradable credits (forest carbon credits) that companies could buy as a means of offsetting their emissions or sell to others desiring offsets to their own greenhouse gas emissions.

A policy to address climate change that promotes the planting of forests and sustainable forestry practices is politically and environmentally attractive. Proponents envision widespread planting of new forests in the United States (and internationally) that would sequester significant stores of carbon (see Stavins and Richards 2005) and generate an abundant supply of forest credits that could be used by companies to help offset their emissions as required by their emission caps. However, a viable market for forest carbon involves far more than simply planting and maintaining forests. Scientific and economic evidence identifies serious concerns in trying to meet carbon dioxide emission caps in part through markets for forest-sequestered carbon.

Understanding the Carbon Cycle

The carbon cycle is the movement of carbon, in various forms, among global pools or reservoirs. They include the atmosphere, the oceans, terrestrial biosphere (living and dead vegetation and organic soils), and the geosphere (mineral soils, sediments, and rock layers of the Earth's crust including fossil fuels). The amount of carbon on earth is fixed, but the amount of carbon in individual reservoirs varies over time. Some reservoirs—the oceans and parts of the terrestrial biosphere (living vegetation and some soils)—are considered carbon "sinks" because over time they tend to accumulate carbon.

Other reservoir are sources of carbon to the atmosphere; tending to release more carbon than they accumulate over time. One of the largest and most important sources of carbon is the combustion of fossil fuels (coal, oil, and natural gas) extracted from the geosphere. In 2004, U.S. carbon dioxide emissions from fossil fuel use were more than 5.6 billion metric tons (94 percent of total U.S. greenhouse gas emissions), and roughly 21 percent of global fossil fuel emissions (Marland, Boden, and Andres 2005). Other anthropogenic (caused by humans) activities that release carbon into the atmosphere include changes in land use, such as deforestation and soil disturbances, cement production, and poor forest management practices; all of which can add to atmospheric concentrations of CO_2.

There are a number of natural sources of carbon, including the decay of organic material, volcanic activity, and disturbances such as wildfire, insect infestation and disease that can rapidly release large stores of carbon (primarily in the form of CO_2) back into the atmosphere. When the quantity of carbon entering the atmosphere from various sources exceeds the amount removed by sinks, CO_2 levels increase. For at least the last two centuries, carbon dioxide concentrations in the atmosphere have been increasing.

The movement of carbon among various pools occurs at different time rates. Significant amounts of carbon are exchanged daily between the atmosphere and the terrestrial and oceanic pools through photosynthesis, decomposition, and simple diffusion. In contrast, the transfer of carbon between the atmosphere or terrestrial ecosystems to the geologic pools, through the formation of fossil fuels, for example, may take millions of years.

Because transfers of carbon between the "active" pool (the atmosphere, terrestrial, and upper ocean layers) and the "inactive" pool (fossil fuels, sedimentary deposits, and deep oceanic layers) are a very slow process, the total amount of carbon in the active pool remains relatively constant, but for one important exception. The extraction and combustion of fossil fuels rapidly releases carbon from an inactive to an active pool, the atmosphere.[4] Without equal transfers from the active pool back into the inactive or long-term storage pool, atmospheric concentrations increase. Currently about half of all carbon dioxide emitted by fossil-fuel combustion and tropical deforestation accumulates in the atmosphere. Oceans and the terrestrial biosphere absorb the rest (Rayner et al. 1999; Battle et al. 2000; Bousquet et al.1999; Prentice et al. 2001).

The Sequestration Role of Forests

Forests naturally sequester carbon during photosynthesis. Over time, carbon accumulates in trees, the forest floor, and especially soils. Between 1990 and 2004, existing U.S. forests, including harvested wood products (such as buildings, paper, furniture), accounted for an average annual net sequestration of roughly 171 million metric tons of carbon, offsetting approximately 11 percent of annual anthropogenic emissions of CO_2 (U.S. Environmental Protection Agency 2006).

Approximately 50 percent of the dry matter of trees is made up of carbon (Houghton et al. 1985; Koch 1989); thus as long as the tree is growing and accumulating biomass, it is accumulating carbon. However, the amount and rate of accumulation of carbon in forests varies widely depending on the species of tree, its age, geographic location, the climate, and other physical, chemical and biological factors. These are important factors when evaluating the efficacy of using forest-sequestered carbon markets to offset emissions.

Trees and other plants also release CO_2 back into the atmosphere through two forms of respiration. The first, autotrophic respiration, occurs within the tree and is essentially the opposite of photosynthesis. The breakdown of sugars (to produce energy, for example) consumes oxygen and releases carbon dioxide into the air. The second form of respiration, heterotrophic respiration, occurs during the decay and decomposition of organic material. As animals, fungi, and other organisms feed on leaves, roots, and branches, CO_2 is respired into the air. In the process, vital nutrients and the remaining carbon leach into the soil providing a fertile substrate for forest regeneration, growth, and subsequently the removal again of carbon dioxide from the air.

As a tree ages, or if damaged, carbon losses from respiration can exceed the amount of carbon removed from the air during photosynthesis, turning a tree (or forest) from a carbon sink into a carbon source. Once a tree dies, photosynthesis ceases and much of the remaining carbon fixed in bark, stems, leaves, and roots is released back into the air through decomposition. Typically, healthy forests, even old-growth forests (Carey et al. 2001; Harmon et al. 2004; Paw et al. 2004) are net sinks of carbon. Even as some trees inevitably die and decay, carbon sequestration by remaining and regenerating trees will often offset any losses of carbon. Conversely, forests that are affected by wildfire, disease, insect infestations, or poor forest management are typically carbon sources, potentially releasing significant stores of carbon into the atmosphere in the form of CO_2—the same carbon that had been accumulating over the life of the forest.

Nonetheless, forest carbon proponents argue that if an area of land can be converted to a forest or if increased carbon stores can be realized through improved management practices, then these actions provide a viable means of extracting additional carbon from the atmosphere. Moreover, important stimuli for such actions can be generated through the formation of forest carbon markets.

Emissions Trading & Forest Carbon

With the recognition that traditional command-and-control methods are not cost effective, policy analysts and policy makers are looking more to markets and incentive-based strategies to address environmental issues. Success stories are becoming widespread in the United States, from a program of tradable permits for sulfur dioxide (SO_2) emissions to reduce acid rain (1990 U.S. Acid Rain program), to a program of tradable individual fishing quotas to end overfishing (Leal, DeAlessi, and Baker 2006), to tradable water rights to preserve stream flows for fish, wildlife, and riparian habitat (Anderson and Snyder 1997; Scarborough and Lund 2007). Now, national, local, and state governments, corporations, organizations, and even private individuals and companies are looking to market incentives to address climate change.

Recently introduced legislation calls for a national limit (cap) on emissions and the adoption of an emissions trading scheme, referred to as a "cap-and-trade" program that is designed to help affected parties meet their reduced emissions goals more cost effectively. The proposals are similar to the Kyoto Protocol (KP) in that tradable carbon commodities can be generated through various emission reduction or offsetting activities, potentially increasing the flexibility by which regulated companies reduce their emissions.

Although the "cap" in a cap-and-trade program is imposed by government and therefore not a true market, the program does attempt to use a least-cost mitigation strategy by providing market-driven financial incentives for emission cuts. Once an overall cap is established, affected parties—primarily power companies and energy-intensive industrial sectors—are issued emission allowances by some government-appointed authority. The number of allowances issued to a particular party is typically based on its historic emissions, with each allowance representing a right or permit to emit one metric ton of greenhouse gases, measured in equivalents of CO_2,[5] during a certain time, typically one year. Only a limited number of allowances are issued annually to ensure that a reduced emissions level, the capped level, can be achieved (assuming all entities meet their goals).[6]

Affected parties can take advantage of the fact that not all companies face the same costs of reducing emissions by using the "trade" component in cap and trade. Those who can cut back at lower cost (perhaps by building a more efficient plant or cost-effective improvements to efficiency) can reduce their emissions beyond their requirements and then sell unneeded emission allowances to producers that face higher emission-reduction costs. Compared to a traditional command-and-control regulatory scheme, a cap-and-trade program can reduce costs to affected parties, while meeting the overall emission reduction goal (the cap).

Like the KP, the proposed legislation does not limit incentives to reduce emissions to only companies facing a cap. Entities not required to meet emission goals—smaller companies, organizations, municipalities, or even some individuals[7]—may, by certain emission-reducing or offsetting activities, generate tradable emission credits. These could then be sold to regulated companies to supplement the trading of emission allowances and further help them meet their emission caps.[8] Of course, the price for such credits has to be high enough so revenues received more than offset the costs of reducing emissions for non-regulated entities to undertake such actions.

In addition to tradable allowances and credits generated by activities that reduce the amount of greenhouse gases emitted, credits may be generated from activities that remove carbon dioxide already in the atmosphere, thus reducing the net amount of CO_2 in the air. This strategy could involve forests and forest management practices that could literally grow credits through carbon sequestration. Storing a ton of carbon in a new forest or through improved forestry techniques reduces the net amount of carbon in the atmosphere, in essence offsetting emissions from a power plant, industrial facility, or automobiles.

Although intuitively appealing, it turns out to be much more complicated than trading other carbon commodities that are created from actual emission reductions. Turning forest-stored carbon into a tradable commodity introduces complexities and potentially prohibitive costs stemming from implementation, measurement and monitoring, and long-term enforcement of carbon stores and contracts for tradable credits. Economists refer to these as transaction costs, which are essentially the costs of doing business, including the complexities of putting transactions together. As these costs increase, they inhibit the process of contracting and diminish the probability of a successful and effective market (Demsetz 1967; Tietenberg 2006, 41).

Commodities Differ

Of central importance to an effective emission cap-and-trade program is the accurate and cost-effective measuring, monitoring and enforcement of emissions, and changes in emissions, from regulated sources and, in the case of forestry, removals of carbon dioxide and changes in carbon storage. Since each commodity is to be backed by the amount of either avoided emissions (allowances or credits) or sequestered carbon (forest credits), inaccuracies in defining the commodity, or lack of enforcement in compliance, degrades the reliability and effectiveness of the program. Because each commodity, whether allowance, forest credit or other credit, is characteristically different, the transactions costs will determine its respective contribution, in practice, to reduce atmospheric CO_2 levels since the corresponding costs will be reflected in the commodity's price.

The measurement of point-source carbon emissions from power plants, production facilities, even residential use or transportation is relatively easy and therefore inexpensive (compared to forest credits), given the fact that this would be a multi-billion dollar market (Tietenberg 2006, 169). The amount of carbon dioxide that is emitted from the combustion of fossil fuels is closely correlated to the carbon content of the fuel. For example, combustion of each pound of bituminous coal from Montana results in emissions of 2.47 pounds of CO_2. Similarly, for every gallon of unleaded gasoline consumed, roughly 20 pounds of CO_2 is produced.[9] The U.S. Energy Information Administration (EIA) has compiled a detailed inventory of average carbon dioxide emissions from various fossil fuels based on their composition and source and annually tracks domestic fossil fuel use, thus simplifying the calculation of CO_2 emissions (see Hong and Slatick 1994).

Tracking changes in emissions from the adoption of new technologies, improved efficiencies, or fuel switching, could follow a similar accounting methodology—tracking changes in input fuel used to calculate emissions or changes in emissions. For example, if a power company currently using anthracite coal from Pennsylvania finds it cost effective to switch to natural gas for power generation, it could cut its emissions nearly in half—from 227.4 to 117.08 pounds of CO_2/million Btu (Hong and Slatick 1994) without affecting energy production. It would provide an opportunity to generate income from selling excess allowances or credits.

But forest carbon is different. A commodity backed by forest-stored carbon is subject to many of the same physical and biological influences that regulate the forest carbon cycle. Recall that sequestration rates vary spatially and temporally and no two forests (or even trees) exhibit the same rates of carbon accumulation. This complicates the measurement, monitoring, and long-term enforcement of carbon stores. Indeed disturbances to a forest could release carbon back into the air—the same carbon that companies may have used to offset emissions in the past—reducing and potentially eliminating any real reductions in net emissions and contributions to reducing atmospheric CO_2 levels.

Costs of Commodifying Forest Carbon

Growing a new forest has obvious costs—land, labor, seeds or saplings, machinery or equipment, and such. If the forest is to be managed for timber production, then there are costs for harvesting, thinning, and transportation. In addition, conversion of the land to forests forgoes some prior use, for example, agricultural production, rangeland, open space, or even wildlife habitat. A landowner's decision of whether or not to grow a forest is based on the expected costs and benefits. If the benefits—aesthetic values, watershed services, wildlife habitat, or timber revenues—exceed the expected costs, then one would expect to see a forest grown. When the costs exceed the benefits to alternative use of the land and other resources, there is no reason to invest. Similarly, the decision to grow a forest with the intention of generating tradable carbon credits will be made based on expected costs and benefits.

Forest carbon credits are not created by simply growing a forest or changing the way an existing forest is managed. Projects must be pre-approved, baselines established, and carbon stores or changes in carbon stocks must be determined before credits can be certified. Once the credits are created and certified, carbon stocks must be monitored for changes in carbon (additional sequestration or losses of carbon), and contracts enforced to ensure accurate accounting of carbon stores over time. Additional transaction costs involve completing and enforcing trades whether through a bilateral exchange, a broker, or central market. If such costs are significant, they "diminish the incentive to trade" (Tietenberg 2006, 41) and therefore diminish the incentive to grow new forests.

Planning & Implementation

Before carbon is sequestered in a new forest or through different management practice, there will be costs—potentially borne by taxpayers—for the creation of a carbon market and the development of methodologies for planning, measurement and monitoring, and enforcement related to a trading program.

More important is expectation. Landowners will estimate expected costs and revenues to determine the viability of forestry projects. If future revenues from carbon (or timber and carbon) are expected to exceed costs, then the forest will be planted or changes in forest management will be implemented. Estimating revenues from forest carbon credits in future periods will not be easy, however. Uncertainty in the future of emissions markets and forest credits further complicates revenue estimates.

Another complication is that not all lands are eligible to generate forest credits. For nations bound by the KP, only carbon stored in new forests and changes in forest management after 1990 are eligible for generating credits. Current U.S. proposals have adopted similar requirements (though not all proposals are the same and many of the details are forthcoming). Landowners will have to verify previous land use practices to ensure that lands would meet eligibility requirements. Under the KP, only lands that have been unforested for at least 50 years are eligible.

Only carbon that would not otherwise have accumulated will count toward the generation of credits. Therefore, carbon baselines must be established and only carbon that accumulates above the baseline could generate tradable credits. This is often referred to as "additionality."

Baselines require knowledge of past land use, an accurate measure of current carbon stores, knowledge of vegetation and soil capacities to sequester carbon over time, and accurate models and measurements to forecast changes in carbon. Each requirement translates into an added cost to the landowner.

Measurement & Monitoring

Before carbon credits can be traded, they must be certified by an approved third party or government-appointed authority. The certification process should ensure that forest credits represent actual amounts of sequestered carbon. The methodologies for certification in a U.S. mandatory program are still forthcoming; however, the U.S. Department of Energy's (DOE) voluntary greenhouse gas registry has developed preliminary guidelines for reporting, measuring, and monitoring carbon sequestration projects (U.S. Department of Energy 2007). Using national forest carbon stocks data, lists of average changes in carbon categorized by region, forest type, previous land use, and, in some cases, productivity class and management intensity, have been developed. Using such "look-up tables," landowners have a starting point to identify current carbon stores and forecast changes in carbon for their region and forest type. However, given the spatial and temporal differences in sequestration rates and carbon stores, the look-up tables alone are insufficient to determine specific carbon stocks and accurately predict changes in carbon.

Repeated site-specific physical measurements to track annual changes in carbon stocks can yield precise measurements, but the costs would be prohibitive. Rather, the use of region-wide estimates, combined with field measurements and carbon modeling techniques, is a more likely strategy, although the costs may still be too high for small forestry projects. Comparatively, a more cost-effective, but less accurate, way to measure and monitor changes in carbon stores is to use remote sensing (satellite or aircraft imagery) with carbon-budget modeling. This can be effective in determining changes in land use and forest coverage, but it is less useful in measuring actual changes in carbon stocks, especially when credits are generated from changes in existing management practices.

One strategy to increase carbon stores in existing managed forests is to increase harvest rotation lengths. If a forest is logged less frequently, more carbon will accumulate over time and less carbon will be lost from harvesting disturbances (Plantinga and Birdsey 1994; Krankina, Harmon, and Winjum 1996). Moreover, older trees typically produce more saw log timber. Carbon can remain locked up in timber products for decades or centuries before entering a landfill where little or no carbon is lost (Skog and Nicholson 1998).

Accounting for enhanced carbon storage in existing forests is not simple. Like new forest projects, baseline carbon amounts and forecasts must be determined before measuring additional carbon storage resulting from new management practices, which in many cases may be undeterminable.[10] Forests managed for profits from timber production alone present their own challenge. Because existing levels of carbon reflect current practices, where managers are trying to maximize timber growth to maximize yields and hence returns (indirectly maximizing carbon intake from the atmosphere), additional carbon gains will be limited thus reducing any additional revenue from saleable credits while timber managers incur the costs of certification and enforcement over time.

Accurate measurement of and accounting for changes in carbon stores are not only important for the certification and verification of carbon credits, but would help stabilize market prices for carbon credits. Inaccurate accounting or forecasting of forest carbon stores could disrupt the market for credits, evidenced by the recent market crash in Europe that resulted from a lack of transparency, poor forecasting of emissions, and over allocation of allowances.[11] Investors will naturally shy from such chaotic markets.

It is still unclear what degree of accuracy would be required for certification of credits. Ultimately, measurement and monitoring costs and whether new forest growth will have an impact on atmospheric CO_2 levels, will depend on the standards set by the EIA, U. S. Department of Agriculture (USDA), Environmental Protection Agency (EPA), or other agencies.

Non-permanence & Enforcement

A concern about growing forests to store carbon is the risk of the carbon being re-released into the atmosphere. Unlike reductions in source emissions—which never get emitted at all—carbon stored in a forest is always at risk of natural or deliberate disturbances that can quickly release carbon back into the atmosphere, reversing any benefits from sequestration.

Each year wildfires scorch millions of acres of forests in the United States, releasing an estimated 33 to189 million metric tons of carbon dioxide annually (Leenhouts 1998), roughly 0.6 to 3.2 percent of annual U.S. anthropogenic CO_2 emissions in 2004. Insect infestations and diseases kill entire forests, halting sequestration and increasing losses of carbon from decomposition while increasing susceptibility to wildfire. Additional losses occur when forests are cleared for development or timber harvesting.[12]

Those entering the business of carbon sequestration will understand these facts—that at some point a disturbance may not only destroy the value of the credit but may negate any past contribution to reducing atmospheric CO_2 levels. Monitoring and protection from disturbances, and enforcement to ensure against possible catastrophic losses of carbon, will increase the costs of producing and transacting carbon credits as well as the risks of purchasing and holding these credits over time (assuming the buyer is held liable for losses).

The problem of non-permanence, and the need for perpetual monitoring, measuring and enforcement against losses, has led to proposals for temporary and renewable forest carbon credits. Limiting carbon contracts to 5, 10, or even 20 years (potentially renewable) would reduce the risk of unaccounted carbon losses. However, this assumes that at the end of the contract period, the credits are replaced with other offsets to ensure that any future unaccounted losses of carbon from the original credits do not result in a net loss of carbon back into the air. Often overlooked are the cost consequences of retiring or replacing short-term credits. In nations bound by the KP, the purchaser is liable for replacing credits at expiration. Unless there is some assurance that the carbon from the original credit will remain permanently sequestered, replacement credits will have to sequester or permanently offset at least as much carbon as the retired credit. Alternatively, if the original project continues to sequester or store adequate carbon, the purchaser may be able to renew the temporary credit. Whether renewed or replaced with new credits or permanent offsets this represents an added cost to the buyer and ultimately all credits would have to be replaced (at a potentially higher price).[13]

The Chicago Climate Exchange (CCX), which permits the use of carbon-forestry projects in a voluntary trading program, maintains different methodologies for addressing permanence. Landowners must "commit to long-term permanent maintenance of forest carbon stocks" by establishing conservation easements, transferring ownership to a conservation entity, or other means deemed acceptable by the CCX Offsets and Forestry committees.[14] Only carbon sequestered during the 2003-2010 period is eligible for credits. Losses of carbon beyond that period are unenforced.[15]

Permanent protection of forest lands can decrease the risks of non-permanence, but comes at an added cost to the landowner. Forest lands that are set aside by conservation easements or land trusts are restricted in perpetuity against certain land use activities—typically commercial development or other activities as specified (Parker 2003).[16] If the length of a national emissions trading program is uncertain, or the demand for forest credits diminishes, landowners would lose rights to their land indefinitely in exchange for limited carbon revenues.

Another strategy to reduce the risks of non-permanence is to issue credits based only on a portion of the total carbon sequestered. For example, restricting saleable credits to 80 percent of the total sequestered carbon would provide some insurance against potential losses from disturbance and measurement errors. On the CCX, 20 percent of all forest credits generated (20 percent of carbon sequestered) must be held in a carbon reserve pool as protection against losses. At the end of the program (2010) the remaining credits are returned to the project owner less any losses. This strategy provides added assurance against carbon losses but would come at a cost to forest owners, who would still incur the associated costs of growing more trees but receive revenues from only a portion of their forest.

It is unclear how permanence will be addressed in recently proposed legislation. Details are forthcoming or would likely be the responsibility of the EIA, USDA, and/or the EPA. The Department of Energy's guidelines for voluntary reporting of GHG emissions contains methodologies for calculating and reporting losses of carbon due to natural or human disturbances, but it does not address permanence in the context of issuance, monitoring and enforcement of tradable forest credits. Without replacement of forest credits with permanent offsets, monitoring, and enforcement of carbon stores would have to continue indefinitely—an unrealistic and prohibitively costly endeavor.

Leakage

Certain sink projects in the United States might have little or no net effect on offsetting emissions because of "leakage." Leakage is an unanticipated increase in emissions in one place because of the implementation of an emission-reduction or offsetting project in another. For example, conversion of agricultural lands to forests for carbon sequestration would remove those lands from farm production. Without a decline in demand for goods that were produced from those farm lands, existing marginal forests elsewhere, which are not eligible for credits, may be removed to restore agricultural production. In this case, increased removal of CO_2 in one area was partially or fully offset by increased carbon losses in another. Similarly, by increasing harvest rotation lengths (to increase carbon stores), there is a decrease in the supply of timber. To meet an unchanged demand for timber products, harvesting frequencies may increase elsewhere—likely overseas[17]—offsetting any sequestration benefits.

Accounting for leakage would require precise domestic and international monitoring of changes in land use. Unless everyone could be held responsible for emission contributions, it is unclear who would be liable for offsetting any emissions resulting from leakage. Increased forestation in the United States or nations bound by the KP could lead to increased deforestation and harvesting rates in unregulated nations.

Where to Grow Trees

Some researchers have concluded that large-scale forestry projects in the United States have the potential to sequester roughly one-third of annual domestic emissions, approximately 500 million metric tons of carbon (see e.g., Stavins and Richards 2005). However, estimates are based on the assumption that sufficient lands are available and capable of growing forests that can sustain high sequestration rates. Studies often assume that sequestration rates are geographically and temporally uniform, when in fact forests around the country vary widely in their capacity to sequester carbon. This is true even within a given forest (Watson et al. 2000).

Differences in topography, aridness, soil fertility, and other factors have to be taken into account when considering nationwide prospects for reforestation. Because of the large demand for agricultural products in the United States, it is unlikely that the nation's most productive agricultural lands would be replaced by new forests. Tree planting would more likely occur on marginal croplands and pasture lands in the eastern half of the nation and perhaps parts of the Pacific Coast region. Low precipitation and poor soil chemistry limit tree growth in much of the Great Plains and the Southwest, while current forest cover in parts of the Rocky Mountain region is close to its natural range, a fact that limits possibilities for new growth.

A study by Parks and Hardie (1995) used land productivity, soil, and climate data to identify the total U.S. cropland and pastureland that would be capable of supporting either hardwood or softwood forests without having to convert the lands most suited for cultivation. The researchers concluded that out of the 500 million acres of non-federal U.S. cropland and pastureland, only 116 million acres would be suitable for conversion to forests for carbon sequestration. Of these lands, only 22 to 23 million acres of land (an area roughly the size of Maine) could be cost-effectively converted to forest; the value of the remaining lands was higher in their current crop and pasture uses.

Another problem is that the available land might not be that productive at sequestering carbon. Regional estimates and site-specific results give a better idea of the upper bounds of sequestration possibilities in U.S. forests.

The Intergovernmental Panel on Climate Change reports global sequestration estimates for major climate regions (Watson et al. 2000). Forests in tropical regions maintain the highest sequestration rates with rates of 1.6 to 3.2 metric tons of carbon per acre per year (MtC/acre/yr). Temperate regions, which would include much of the Eastern United States, follow with rates of sequestration estimated to be between 0.6 and 1.8 MtC/acre/yr. The lowest sequestration rates are in high-latitude or high-elevation forests, where rates range from approximately 0.2 to 0.5 MtC/acre/yr. Noble and Scholes (2001) estimate that as a whole, developed nations, on average, have the capacity to sequester between 0.16 and 1.82 MtC/acre/yr through new forest growth.

Focusing in the United States, lodgepole pine forests in southwestern Wyoming reach maximum sequestration rates from 0.5 to 0.65 MtC/acre/yr between ages 40 and 60 in even-aged stands of forest (Pearson, Knight, and Fahey 1987). A comparatively productive loblolly pine plantation in the Delta states region of the United States reaches its maximum sequestration rate (over 4 MtC/acre/yr) within the first few decades, then declines rapidly thereafter; thus averaging about 1.9 MtC/acre/yr over 75 years (Richards, Moulton, and Birdsey 1993). According to the U.S. Department of Energy (2007), the highest sustained carbon accumulation rates occur with new forest growth on high productivity sites in the western portions of the Pacific Northwest where rates can average 2.91 MtC/acre/yr over a 125-year period. Sequestration rates for existing forests are much lower. On average, forest carbon accumulation rates on existing forests are estimated to range from 0.0 to 0.36 MtC/acre/yr in the central Rockies and the Southwest and from 0.64 to 0.91 MtC/acre/yr in the Pacific Northwest and the Southeast (Birdsey 1992), with much variation among and within states. Sequestration rates can vary widely from year to year due to changes in precipitation and temperature. Overall, plantation forestry in the Southeast and the Pacific Northwest produce the most productive forests for carbon sequestration; however, current extensive use of these lands for forestry, agriculture, and urban purposes limits availability of land for new forests.

These figures suggest that the lands likely to be available for new forests are unlikely to support high sequestration rates, so that the amount of land needed to offset significant emissions would be enormous and unrealistic. For example, if rates average 1 MtC/acre/yr, as would be expected from a loblolly-shortleaf pine stand in the southeast (40 year rotations) (U.S. Department of Energy 2007), a 30 percent offset of current U.S.

emissions would require nearly 500 million acres of new forests.[18] This is 22 percent of U.S. land area, roughly five times the size of California.

Assuming that all 116 million acres of land suitable for forest growth (based on Parks and Hardie's estimation) were planted and resulted in a modest 1 MtC/acre/yr sequestered, the new forests would offset approximately 7.5 percent of annual emissions. If we make the unrealistic assumption that the entire nation can be covered in trees (not including current urban use lands), just over 80 percent of annual emissions could be offset by forest sequestration assuming an average, highly favorable sequestration rate of 1.2 MtC/acre/yr. However, this assumption is ridiculous since planting trees in inhospitable areas such as the desert southwest would be impossible without massive government subsidies to maintain them.

Another important element to consider is time. Keep in mind that there would be a delay before any sequestration benefits were realized. Sequestration rates are typically high in young forests, but total carbon storage remains relatively low in the first 5 to 30 years (depending on species, climate, and location) compared to older forests; therefore limiting the number of credits that can be generated in the short term.

Investment Risks

Both the KP and the CCX trading market have specified termination dates—2012 and 2010, respectively. The status of policy to address climate change beyond Kyoto or the CCX is unclear. Therefore, the decision to plant massive new forests, which could cost tens of billion of dollars annually,[19] and may not generate many credits until after 2010 or 2012, would be an incredible gamble without some assurance that a new (or extension of existing) mandated emission targets would still be in existence to maintain demand for forest credits.

Irrespective of the uncertainties surrounding future emission caps and markets, investors are likely to face declining revenue streams from forest credits. Growing demand for cleaner energy sources and new technologies is driving innovation and development of increasingly cost-effective means to reduce point-source emissions. Furthermore, these are permanent reductions in emissions, unlike forest credits that carry the risk of being re-released into the air. As the cost of reducing actual emissions from the source declines, there will be less demand for forest carbon credits and less incentive to maintain forests for carbon. Declining forest carbon values (and thus forest credit prices) reduces the value of having a forest that is generating credits. Unless restricted to do so, newly forested lands would be expected to revert to their previous uses (non-forested), releasing some of the stored carbon back into the atmosphere. Perpetual restrictions on land use would reduce this risk; however, future price declines increase the investment risk to prospective forest growers.

Forestry credits for sale on the CCX are generated from sequestration that has already occurred, meaning credits cannot be certified and sold until the carbon has been sequestered. An alternative that would reduce the delay in payments for credits (waiting for the forest to grow and sequester carbon) would be to permit the issuance of credits based on future expected sequestered carbon. Although this strategy may reduce the initial investment risk to landowners, they will still incur the ongoing costs of monitoring and measurement of carbon stores and any future costs of additional credits to cover unexpected losses of carbon.

One of the largest barriers to companies or landowners wanting to participate in the CCX forestry credits program is the requirement to protect new forests in perpetuity, restricting future changes to land use. Without a long-term commitment to limiting emissions and maintaining a viable market for offsets, landowners face the substantial risk of tying up their land in perpetuity for potentially only a few years of carbon revenues. Moreover, if a mandatory program required landowners to cover any carbon losses that occur in the future, they would face the additional costs of purchasing credits on the market or growing new forests.

One potential (but economically self-defeating) strategy to reduce investment risk and entice the production of forest credits would be to offer landowners subsidies or tax credits—a cost which would ultimately be borne by taxpayers. Unfortunately, this form of federal support is unlikely to go away even in the future when the cost of permanent offsets declines relative to forest credits. This scenario is not inconceivable, but begs the question of why create a forest carbon market in the first place.

Conclusion

As pressure mounts for the United States to address rising CO_2 levels, we appear to be moving toward a national mandatory program to limit emissions. The most widely proposed strategies promote the use of a cap-and-trade program and, like the KP, include provisions for the creation of forest carbon commodities with the intention of increasing flexibility and supposedly decrease the costs to regulated parties.

The use of forests to address climate change is understandably appealing, from both a political and environmental perspective. Forests provide a long list of social, economic, and environmental amenities and have the capacity to remove and store significant amounts of carbon from the atmosphere over time.

Unfortunately, tradable forest credits are not created by simply planting trees or altering management practices in existing forests. Commodification of forest carbon would require accurate measurement, monitoring, and long-term enforcement of carbon stores not only to account for changes (including losses) in carbon stores but to ensure that actual reductions in net emissions will occur. To landowners, and potentially taxpayers, this process introduces significant costs. As these costs increase, they reduce the incentive to grow new forests and diminish the likelihood of a viable market. Relaxing certification, monitoring, and measurement standards would cut forest credit production and transaction costs, but it would come at the risk of compromising accuracy and overall effectiveness in actually offsetting emissions. Moreover, without strict enforcement there would be greater opportunities for landowners to exaggerate sequestration amounts and not report disturbances.

If these costs are overlooked, policy makers' projected total costs of reducing emissions in the United States will be grossly underestimated. If the supply of forest credits is below expectations, companies will have to meet their emission caps through the purchase of alternative and potentially more expensive offsets or allowances, increasing the overall costs of the program and decreasing the contributions of forestry to address rising CO_2 levels.

In the end, given the costs and uncertainties of commodifying forest carbon, future risks of carbon losses, and the unlikely event that forestry will play a significant role in a national emissions reduction program, one has to ask: Is it really worth it?

Notes

1. Often in discussions of carbon storage, units are reported in metric tons of carbon, while emissions are generally reported in units of carbon dioxide. Because of the chemical makeup of plants, it makes little sense to report carbon storage amounts in units of carbon dioxide; however basic comparisons with emissions are possible by converting units of carbon to its CO_2 equivalence. The average atomic weight of an atom of carbon (C) is 12 and oxygen is 16 (O) giving a molecule of CO_2 a weight of 44 (one atom of C and two atoms of O). The weight of carbon is therefore roughly 12/44 of a molecule of CO_2. Similarly there is one metric ton of carbon in every 3.67 metric tons of CO_2. In 2004, U.S. emissions of CO_2 were 5,988 million metric tons, which equates to roughly 1,632 million metric tons of carbon (approximately 40 times the 64 billion metric tons of carbon currently stored in forest ecosystems.
2. See e.g.: Senators John McCain (R-AZ) and Joe Lieberman (D-CT) (The Climate Stewardship and Innovation Act of 2005); Wayne Gilchrest (RBMD) and John W. Olver (DBMA) (Gilchrest-Olver Climate Stewardship Act); Jeff Bingaman (D-NM) (Climate and Economy Insurance Act of 2005); and Sen. Dianne Feinstein (D-CA) (Strong Economy and Climate Protection Act of 2006).
3. Greenhouse gases are both natural and anthropogenic gases that absorb and emit radiation, trapping heat in the atmosphere. This process is often referred to as the greenhouse effect—allowing light energy to enter and exit while trapping heat energy. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. In addition, there are a number of entirely human-made greenhouse gases in the

atmosphere, including sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

4. Melting permafrost layers may also contribute to atmospheric CO_2 levels (Zimov, Schuur, and Chapin 2006) and could be considered an inactive to active pool transfer. However carbon losses will be at least partially offset by increasing vegetation growth and advancing treelines which will increase sequestration amounts, countering losses.
5. Carbon dioxide equivalent or CO_2e is the international standard measure for greenhouse gasses (GHG). Each GHG contributes differently to the greenhouse effect, often stated as global warming potential (GWP). Each GHG is assigned a GWP value relative to the number of CO_2 molecules that would have the same warming effect. For example, one million tonnes of methane, a far more potent greenhouse gas than carbon dioxide, is measured as 23 million tonnes of CO_2 equivalent, or 23 $MtCO_2e$.
6. Nations bound by the Kyoto Protocol typically impose penalties (in excess of the market price of emission allowances) for companies that exceed their emissions cap. Companies affected by proposed U.S. legislation that exceeded its cap would also face penalties, but vary with the proposed legislation. Typically companies would be imposed a fee of three times the current market price for each excess metric ton of GHG emissions.
7. In order to be eligible to sell emission credits, entities will have to meet certain criteria. For example, entities must have annual emissions in excess of some specified level (to be determined), limiting participation to moderately sized companies that are not large enough or produce enough emissions to be regulated by the emissions cap. In the case of forestry projects, land holdings will have to own and maintain a certain acreage (e.g., in excess of 500 acres).
8. Emission credits could be generated by, for example, switching to alternative fuels, technological improvements, the capture and use of landfill gas, and improving energy efficiencies. Unlike forestry credits these credits are created from actual point source emission reductions and are permanent.

9. Gasoline is approximately 87 percent carbon and 13 percent hydrogen (there are trace amounts of other compounds as well). Each gallon weighs roughly six pounds, therefore there is roughly 5.2 pounds of carbon (87%) per gallon. When combusted the carbon and hydrogen atoms separate and combine with oxygen (O_2) in the air to form CO_2 and water (H_20), respectively. Carbon has an atomic mass of 12 and each atom of oxygen has a mass of 16 giving one molecule of CO_2 a mass of 44. To calculate the amount of CO_2 produced, simply multiply the weight of the carbon by 44/12 or roughly 3.7.
10. Timber managers try to maximize yields of merchantable timber, which is often very similar (although unintentional) to maximizing carbon sequestration. Additional carbon storage from minor changes in how the forest is managed may be impossible to determine with certainty.
11. In April 2006, prices for emission allowances plummeted over 50% in only a few days after five EU nations reported actual emissions lower than anticipated. Emission allowances are issued based on historic and forecasted emissions. When actual emissions fell below the forecasted level, it created a surplus of tradable allowances causing the price to fall.
12. Although wood in the form of a forest product will continue to store carbon (potentially indefinitely), the mechanical disturbance of soil layers and higher forest floor temperatures from loss of canopy cover can increase erosion and heterotrophic respiration (Lytle and Cronan 1998; Schlesinger and Andrews 2000). Decay or burning of logging slash and unsaleable wood also release carbon back into the atmosphere.
13. Government issued allowances and permanent emission reduction credits are expected to sell at premium compared to forest credits.
14. CCX® Forestry Carbon Emission Offsets. Available online at: www.chicagoclimatex.com/news/publications/pdf/CCX_Forest_Offsets.pdf.
15. Kellee James, Economist, the Chicago Climate Exchange. Telephone conversation, 26 July, 2006.
16. Under certain circumstances timber harvesting may be permitted; however this would decrease the revenues from carbon credits due to

the associated losses of carbon. In many cases conservation easements provide tax incentives for landowners thus providing an added financial incentive and potentially offsetting some of the costs incurred from certifying forest credits.

17. Deforestation practices in developing nations may actually result in greater losses of carbon compared to land conversion in the United States or other industrialized nations due to readily available markets for timber, technologies that may minimize disturbance, and certain environmental standards. In this case the net result would lead to an increase in global emissions even though a U.S. company is able to meet their emission reduction goal.
18. For a sense of scale, the combustion of fossil fuels in the United States produced nearly 1.5 billion metric tons of carbon in 2004 (U.S. Environmental Protection Agency 2006).
19. Normalizing data from eleven previous studies, Stavins and Richards (2005) estimated the marginal cost of growing forests in the United States to range from approximately $33–$119 per metric ton of carbon, sequestering between 300 and 500 million metric tons annually (roughly 18–31% of 2004 emissions of CO_2). Current prices for carbon credits on the Chicago Climate Exchange are roughly $14.00 per metric ton of carbon. Total cost in present terms using a five percent discount rate would translate into a one-time cost of over $171 billion to well over half a trillion dollars (inflation adjusted). These estimates are for the cost of acquiring land and growing forests and do not include the costs associated with a carbon trading program as discussed in this publication. Moreover, their results should be interpreted with some caution. Often the findings of the underlying studies are based on the assumption that sufficient lands in the United States are available and capable of growing forests that can consistently sustain high annual sequestration rates.

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