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Will Southern Agriculture Play a Role in a Carbon Market?

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ABSTRACT

While a carbon market offers substantial opportunities for US agriculture, regional differences in such a market are often ignored. This paper focuses on the advantages and challenges for agriculture in the South. The potential of two promising options are analyzed: conversion from cropland to forests and greater use of conservation tillage. It is argued that the right institutional arrangements can overcome three fundamental challenges to an efficient carbon market: transaction costs, risk, and perverse incentives. Some examples are given, such as the use of a farmer-owned organization and the provision of land use and carbon information by the government.

Key Words: *Carbon emission reduction (Q25), tradable permits, afforestation (Q23), conservation tillage (Q24), government policy (Q28), regional economics (R00)*

In 1997, the Kyoto Protocol to the United Nations Framework Convention on Climate Change called for developed nations to reduce six greenhouse gas (GHG) emissions, including carbon dioxide. The Protocol, if ratified, would require developed nations to reduce GHG emissions by 5 percent of 1990 levels by the year 2012. The United States has already agreed to reduce GHG emissions by 7 percent of 1990 levels by 2012. To achieve emission reductions, the Protocol (Article 17) permits countries to use market-based emission trades to fulfill their reduction commitments.

One of the Protocol's missions is to create a market for trading over one billion tons of carbon reductions per year (Totten). Many governments, large companies, and other agents, however, are not willing to wait for Protocol ratification; a neophyte carbon market is already emerging. Several major oil and electric utility companies, including Royal Dutch Shell and BP-Amoco, have already begun to trade greenhouse gas emissions, and legislation to reduce and cap CO_2 emissions is pending in the US and other countries (Environmental Defense Fund; Parker). "These firms are the first to see that fixing global warming could give rise to the world's next trillion-dollar industry: the greenhouse gas trade" (*The Economist*, p. 73). They are also being risk averse, taking the initiative in establishing early emission reduction credits prior to regulation, hoping that paying some now will mean paying less later (Romm).[1]

Carbon emission reductions can occur in two general ways: directly via reductions in emissions from firms (e.g., utilizing improved firm-level technology or finding alternatives

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[1] Taking action against global warming may also help a firm's image (i.e., by being socially responsible), which could translate into higher share values. Further, the reduction credits could increase in value if a carbon market emerges.

for the use of fossil fuels) and natural sources, such as forests, and indirectly by off-setting emissions with carbon units stored in natural sinks.[2] Carbon is stored naturally in many sources: oceans, fossil fuel deposits, the terrestrial system (rocks, soil, forests, wetlands, etc.), and the atmosphere (Sedjo, Sohngen, and Jagger). Currently, the Protocol only recognizes the use of forests as carbon sinks (Article 3.3), although the wording in Article 3.4 leaves open the possibility of accepting the use of agricultural soil sinks (Bruce *et al.*).

The US agricultural sector, which offers substantial carbon sequestration opportunities, could clearly profit from emission reduction efforts. This paper analyzes the potential of the two most promising options: (1) land conversion from crop production or pasture to forests (afforestation), and (2) greater use of conservation tillage.[3] Section 2 explores the carbon reduction potential of forests and agricultural soil, providing a well-documented review of current literature on these topics. Section 3 focuses on economic considerations and estimates. The discussion in Sections 2 and 3 raises the issue of regional differences in terms of carbon sequestration potential and costs.

It is generally believed that substantial amounts of marginal agricultural land and growing season conditions suitable for producing fast-growing southern pine varieties gives the South the best opportunities for carbon sequestration forest programs in the US (Alig, Adams, and McCarl; Sedjo and Solomon). The probable comparative advantage of the South in a carbon market is explored throughout these sections.[4] Other than regional disparities in soil, climate, and tree species, differences in other agricultural characteristics will necessitate a more regionally focused carbon market implementation strategy. The issues surrounding the implementation of a carbon market are discussed in more detail in Section 4. The discussion centers on three fundamental challenges to an efficient and equitable carbon market: transaction costs, risk, and perverse incentives. A carbon-trading scheme already in operation is used to illustrate how these challenges are surmountable with the right institutional arrangements.

Estimating the Carbon Sequestration Potential of Forests and Conservation Tillage

It is generally agreed that forests and agricultural soil offer the greatest potential for carbon sinks, but there is no consensus regarding the level of carbon that ultimately could be sequestered. Numerous scientific studies have been devoted to such estimates, but measurement estimates vary widely and are difficult to compare since assumptions, methods, and units of measurement usually differ. The first part of this section reviews the literature and attempts to find a range of consistent estimates regarding carbon sequestration rates and total carbon stored for both forests and soil. The lack of consistent measurement is often considered a major barrier to the formation of an efficient carbon market, a conclusion that is somewhat refuted in the latter half of this section. Complete accuracy may not be necessary.

Forests

The US forest sector maintains a net uptake of carbon (i.e., it stores more carbon than it releases), although the level of net uptake has

[2] Totten and others also note that it may be possible to de-carbonize fossil fuels to produce hydrogen instead of CO_2. Although this would clearly have great potential in carbon reduction, this paper only considers the more mainstream and viable carbon sequestration options.

[3] Although agriculture could also participate in a carbon market through other means, such as the production of biomass crops or carbon sequestration in crops, we do not consider these options since their potential currently seems more limited than land conversion and soil conservation (Dumanski *et al.*).

[4] The South, as used in this paper, refers to the following 13 states: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

been declining since 1990 (EPA).[5] In 1996, the forest sector was responsible for a net uptake of 208.6 million metric tons (MMT)[6] of carbon equivalent (EPA). It is estimated that approximately 52.5 billion MT of carbon are stored in US forests (Birdsey, 1992). Forest ecosystems sequester carbon through trees (living trees, standing dead trees, roots, stems, branches, and foliage), understory vegetation (shrubs and bushes), the forest floor (wood debris, tree litter, and humus) and the soil.[7] The net sequestration estimates of the forest sector also account for the carbon stored in wood products and landfill wood, which is appropriate given that the final end-use of harvested timber is an important variable in carbon sequestration estimates. For example, lumber that is used for houses, especially if it is from older trees, can sequester carbon for a long period (Heath *et al.* and Sedjo and Solomon). Unfortunately, the inclusion (or omission) of this variable further complicates comparisons of carbon sequestration estimates.

In the average US forest, trees and tree roots only account for about 31 percent of all forest carbon; 59 percent of all forest carbon is stored in the soil (Birdsey, 1992). Trees continually store additional carbon until they reach maturity, at which point their carbon stores remain relatively static. Since younger trees sequester carbon at a much faster rate than mature trees, carbon accumulation rates will be higher for newly planted and harvested forests than for preserved forests (Huntington). The relationship between forest age and total carbon stores is the opposite: younger, harvested forests have less total carbon stored than older, less-disturbed forests. In addition to forest age, tree species and climate also affect total carbon storage levels and sequestration rates. For example, the rate of carbon accumulation in live trees increases with the rate of volume growth, a trait more dominant in some tree species than others (Birdsey, 1992). Furthermore, cooler, wetter climates result in greater soil carbon sequestration rates. Climate also partially dictates forest type (e.g., hardwood species are pervasive in northern states).

The connection between climate and carbon sequestration results in regional differences in carbon storage estimates. Of the total carbon stored in US forests (excluding Alaska), the greatest proportion (about 21 percent) is contained in southern forests (Birdsey, 1992), a result directly tied to the South's vast forestland (discussed in more detail below). In terms of carbon stored per forest acre, the South does not fair as well. On average, the South stores about 120,000 pounds of carbon per acre, compared to an average of 165,000 pounds per acre in northern states and a 158,000 pounds-per-acre national average (Birdsey, 1992). The northern states have substantially more carbon stored on the forest floor and in the soil because of the climate and somewhat more carbon stored in trees because the region's forests are older and less disturbed. However, most of the nation's fast growing and young tree plantations are in the South, giving the region the greatest potential for rapid increases in forest carbon stock (Alig, Adams and McCarl).

The carbon sequestration potential of converting agricultural land into forests has been widely studied. The total potential carbon sequestration of any converted agricultural land is simply calculated by multiplying the expected forest carbon sequestration rate by the amount of land converted. Clearly, deviations in either variable will result in different carbon sequestration estimates. McCarl and Schneider's comparison of 14 afforestation carbon sequestration studies shows the results of such deviations. The carbon sequestration rates ranged from 0 to 73 MMT annually and 0 to 2,900 MMT total. Comparing estimates across studies is difficult since they are contingent upon numerous assumptions and constraints. For example, according to Lal *et al.* an average rate of carbon accumulation in afforested

[5] Forests are a net sink for carbon in the US because there is little net deforestation (Lal *et al.*).

[6] Comparisons across studies are difficult given that each study uses either metric tons, American (short) tons, or British (long) tons and often does not specify which unit is in use. Units for this publication reflect those used in the cited source.

[7] For an excellent description of the functioning of forest ecosystems as carbon sinks see Sedjo, Sohngen, and Jagger.

agricultural land is 550,000 pounds of carbon per acre per year. However, this rate assumes new forests and no timber harvests and is an average across the nation. Any changes in assumptions regarding tree species, timber harvesting, land condition, previous land use, and climate will affect the sequestration rate. Further, some studies include total forest ecosystem carbon estimates (i.e., carbon stored in soil, understory vegetation, etc.) while others only account for the carbon stored in trees.

Conservation Tillage

Although currently most agricultural soils in the US are no longer significant sources of CO_2 emissions, recent estimates show agricultural soil as a net emitter of carbon: 5.9 MMT of carbon equivalent were emitted in 1996 (Bruce *et al.*; EPA; and Lal *et al.*). Historically, land converted to crop production, as well as intensive tillage practices, resulted in significant carbon emissions (Lal *et al.*). Thus, it is estimated that US croplands have the potential to reduce US CO_2 emissions by 15 percent through soil carbon sequestration (Lal *et al.*). Current accounts estimate 15,600 MMT of soil organic carbon (SOC) stocks in US agricultural soil (Lal *et al.*) Soil carbon sequestration can be accomplished through the increased use of best management practices (BMPs), such as conservation tillage (no till and minimum till), reduction in pesticides and fertilizers, nutrient management, and precision farming. Farmers can also plant buffer strips and other cover crops that would add to the carbon sequestration potential of the soil.

However important the other methods ultimately may be, current interest is focused on the potential of conservation tillage, which could result in significant soil carbon accumulation (Bruce *et al.*, Paustian *et al.*, Tweeten, Sohngen, and Hopkins). Lal *et al.* estimate that US cropland has the potential to sequester 75–208 MMT of carbon per year through better management (Lal *et al.*). While minimum tillage practices will reduce the amount of carbon released into the atmosphere, no-till will actually increase carbon sequestration (Kern and Johnson; Tweeten, Sohngen, and Hopkins). Paustian *et al.*'s summary of 27 studies, mostly in the US, found that on average no-till soil sequesters 3 tons per hectare per year and carbon accumulation rates range from −4 to +10 tons per hectare (Tweeten, Sohngen, and Jagger). The upward limit for carbon sequestration with improved soil management is estimated to be about 5 billion MT of carbon, a level that may take as long as a century to achieve (Bruce *et al.*).

As with forestry, carbon sequestration estimates for agricultural soil are not always consistent across studies (Barnwell *et al.*). The amount of carbon sequestered in agricultural soil is determined by the interaction of climate, soil properties, land-use, and agricultural management practices (EPA; Kern and Johnson; and Dick *et al.*). In addition to tillage practices, the types of crop being produced, the use of crop rotation and cover crops, erosion, drainage, and fertilization also impact net soil carbon sequestration (Dick *et al.*, Dumanski *et al.*, EPA). Temperate regions store the greatest soil carbon (Bruce *et al.*, EPA). As with trees, soils with carbon stores below their maximum carbon sequestration level (i.e., carbon-depleted or young soils) have the greatest potential to sequester additional carbon (Bruce *et al.*; Kern and Johnson). Differences in climate and agricultural management practices thus lead to regional disparities in soil carbon sequestration rates and totals.

Is Inconsistent Estimation a Barrier?

The previous discussion reveals that estimates of carbon sequestration rates and carbon sequestration totals for forests and agricultural soil vary widely. Carbon accumulation rates and levels of total carbon stored depend on climate, tree species, soil and tree age, and numerous other variables, making consistent national estimates impossible. Consistent national estimates (or averages) should not, however, at this point be considered a barrier to a carbon market. Carbon sequestration rates will have to be measured on a regional or perhaps much smaller scale to be accurate (thus, creating accurate inconsistencies). For example, to achieve a truly accurate estimate of soil carbon sequestration rates for a single farm, one might have to make several measurements to account for variations in soil, grade, crops, etc. Clearly, the measurement accuracy is diminished the more it is extrapolated to cover neighboring farms, even within a certain region. The science of estimation also contains some measurement error (i.e., measurement of carbon remains a challenge, subject to estimation and technological error), although some argue that measurement uncertainty is often overstated (Totten).

Regardless, measurement error may not be a barrier to an efficient carbon market, since insurance and contract mechanisms could be developed that would account for this error. For example, farmers within a fairly homogenous region could receive an average carbon sequestration rate per acre with the adoption of no-till. As long as market regulators accepted this average, with the knowledge that it represented a range of expected carbon sequestration rates, no further precise measurement would be needed. Markets can accept some uncertainty and still function efficiently.

What is known with certainty is that the US contains vast forest and agricultural soil resources that could become major carbon sinks: over 700 million acres of forest (over 400 million on private land) and 375 million acres of cropland (USDA 1997c; USDA 1997d). The South alone contains over 214 million acres of forest, 29 percent of the nation's total forestland (USDA 1997c). It is also clear that land-use patterns are dynamic. From 1982 to 1997, cropland decreased by 46 million acres (most of which was enrolled in CRP) and non-federal forestland increased by 800,000 acres, trends that mask annual shifts and regional variations in land-use (USDA 1997d). The EPA estimates average fluctuations in forestland acreage to be about 0.1 percent a year. Cropland acreage in the Southern Plains (Oklahoma and Texas) jumped 7.4 percent from 1996 to 1997, a leap more than three times greater than any other region (USDA 1997b). Land owners transfer land among competing uses depending on economic and environmental (e.g., crop rotations to sustain soil resources) incentives, thus supporting the feasibility of a carbon market dependent upon land-use changes. This may be especially true in the South, where approximately 20–30 million acres represent marginal agricultural land unsuitable for cultivation, but appropriate for forestland (NRCS; Alig, Adams, and McCarl).

Increased adoption of conservation tillage also seems likely, given past producer trends. In 1996, 36 percent of cropland was already under conservation tillage, 15 percent under no-till (USDA 1997a). In addition to environmental concerns and regulations, farmers have responded to potentially higher profits: yields may increase while production costs may decrease (Day *et al.,* USDA 1997a). Farm programs in 1985 and 1996 also required farmers to implement conservation practices before they could receive government payments. There is clearly potential, especially in the South, for further conservation tillage adoption since the owners of two-thirds of the nation's cropland have yet to adopt it. The South lags behind the nation in total conservation tillage adoption; 10 percent or less of cropland in most southern states is under conservation tillage (USDA 1997a). However, the proportion of no-till to all conservation tillage methods is higher than the national average in most southern states (USDA 1997a).

The more important challenge to a carbon market raised by the previous discussion is the negative relationship between total carbon stored and carbon accumulation. If the carbon market rewards carbon accumulation more than established carbon sinks, rational agents will plow up soil and harvest mature forests to make room for more "new" carbon. Furthermore, soil carbon sequestration efforts may be favored over afforestation projects since soil has the potential for much longer periods of carbon accumulation: 50–140 years, as compared to forests which achieve maximum carbon sequestration in 15–30 years (Barnwell *et al.*; Lal *et al.*). And yet, in the long run, forests could be greater carbon sinks (i.e., achieving greater carbon stores per acre). Even where forest strategies would be implemented, the bias would be towards planting trees with shorter rotations (softwood rotations average 25–40 years and hardwood about 40–

60 years) rather than those with the greatest total carbon storage potential (hardwoods). Carbon accumulation represents a short-term objective, since it will offset current CO_2 emissions. Focusing on established carbon sinks is clearly a long-run strategy, since ultimately more carbon will be stored if it is not periodically released. The ultimate challenge for a carbon market is to create new carbon sinks via land-use changes without losing established sinks, an issue discussed in greater detail below.

How much will it cost?

Given the wide array of sequestration estimates, it is not surprising that assessments of carbon market prices vary from $15 per ton to $348 per ton (Sandor and Skees). Narrowing the focus to the specific costs of carbon sequestration based on converting agricultural land to forest and conservation tillage does not provide any additional convergence of estimates.

Agricultural Land Conversion to Forests

For a detailed comparison of studies estimating the costs of converting agricultural land to forests, the reader is referred to the works of Tweeten, Sohngen, and Hopkins and McCarl and Schneider, both of which compare numerous previous studies. The estimates range from $1 to $145 per ton of carbon, with $25 per ton being a rough average. The wide variation results in part from different assumptions regarding carbon sequestration rates, amounts of carbon sequestered, the ability to harvest the timber, total land requirements, interest rates, etc. (Adams *et al.*, 1998). An important criticism of several studies is their reliance on the price of prevailing agricultural rents to determine the cost of conversion (Plantinga, Mauldin, and Miller). This method ignores other possible income streams and opportunity costs (e.g., recreation) from the land as well as additional compensation costs. The payment to farmers may have to exceed lost agricultural rents since the decision to convert land is in the short-term irreversible, creating an option value for keeping land in agriculture (Plantinga, Mauldin, and Miller). Moreover, farmers may have to either acquire forestry management skills or hire a forest manager. Opportunity cost estimates derived from current land-use allocations (i.e., the acreage of forestry versus agriculture) using an econometric model may help resolve these limitations (Plantinga, Mauldin, and Miller; Stavins). However, even if the appropriate land uses are recognized, opportunity cost estimates may still be wrong. For example, Sedjo, Sohngen, and Jagger point out that the opportunity cost of remote forests are often overestimated since they include high timber extraction costs, which are not an issue in establishing permanent forest carbon sinks.

While the limitations of these studies are important to recognize, this body of literature provides some important insights into preliminary costs of a forest carbon sequestration program. For instance, most argue that increasing marginal costs will plague land conversion (Parks and Hardie; Adams *et al.*, 1993). Increasing the amount of acreage devoted to forest will ultimately lead to the incorporation of primary agricultural land, which would have higher rents. Ultimately great land conversion out of agriculture could lead to higher food prices and, thus, higher land prices (Adams *et al.*, 1993). Also, it seems most likely that forest conversion will occur primarily on marginal cropland, as that is where it will be most competitive (i.e., the opportunity cost of lost yield on marginal lands will be lower). The historic record of the Conservation Reserve Program (CRP) supports this theory.

The CRP record in the South suggests the potential land-allocation relationship and land-conversion price between cropland and forestland for that region. Of the total US acres enrolled in CRP during 1986–93, nine of the ten states which enrolled the greatest percentage of acreage planted to trees are located in the South (CRP database). In Georgia, almost 90 percent of the state's CRP acres were planted to trees (Table 1). The average rental rates required by farmers in the South to switch from crops to trees ranged from $38 in Florida to

Table 1. Selective CRP statistics for the South and the US during 1986–93

State	Average Rental Rate	% CRP Land Planted to Trees
Alabama	$43	51%
Arkansas	$48	54%
Florida	$38	86%
Georgia	$43	89%
Kentucky	$58	(less than 1%)
Louisiana	$44	35%
Mississippi	$43	57%
North Carolina	$46	56%
Oklahoma	$44	(less than 1%)
South Carolina	$43	75%
Tennessee	$50	5%
Texas	$39	(less than 1%)
Virginia	$53	36%
US	$53	6%

Source: USDA, ERS, CRP data base http://usda.mannlib.cornell.edu/data-sets/land/89003.

$58 in Kentucky (Table 1). It is important to understand the limitations of these rental rate estimates. The CRP bidding process went through a number of adjustments during its operation. Bids in the earlier phases were probably higher than they needed to be to achieve land conversion. Therefore, the average rental values reported in Table 1 might overestimate the true marginal costs of land conversion for that period.

The CRP data suggest that when farmers in the South are given an option, most will choose to convert their land from crop production to trees. This result is most likely influenced by the presence of a strong timber industry, thus giving landowners the opportunity to gain additional profit from the land by harvesting its timber. Clearly, they may not get the same opportunity under a carbon sequestration program. While it is difficult to draw any strong conclusions from the CRP rental rates as to the possible costs of converting land to carbon sequestering forests, the rental values are in the range of other estimates of the marginal cost for forestland conversion.

Further insight into the relative land conversion costs of the South can be found in those studies that have taken a regional perspective. Although the Moulton and Richards study is somewhat dated and has been criticized for overestimating carbon sequestration potential, the regional comparisons of relative carbon sequestration potential and costs in the study should still be valid. Results from their study show the South to have a lower per-unit average cost for sequestering more carbon, with values about 30 percent less per ton than the rest of the US. In contrast, Plantinga, Mauldin, and Miller's results suggest that the marginal costs of afforestation in the South (as represented by S. Carolina) are not substantially lower than costs in the Midwest (Wisconsin) and East (Maine). The Adams *et al.* (1999) study finds that when more complete cost estimates are considered (measuring cost as the net change in producer and consumer surpluses for both forest and agricultural markets), an afforestation program would cost more in the South than in the North.

The South would probably have a unique advantage in a market that rewarded established forest carbon sinks. In the South, private owners control almost 90 percent of the region's forests, compared to 58 percent in the US (Moulton and Birch). Over half of the private forests are less than 10 acres and almost 90 percent are less than 50 acres (Moulton and Birch). The fact that many of the private forests are relatively small suggests that the forests are not significant sources of income for the owners. Indeed, private forest owners in the South are primarily white-collar workers, retirees, or blue-collar workers; very few are farmers (Moulton and Birch). A national survey of forest owners (Moulton and Birch) asked for the primary reason behind their ownership of forestland. Thirty-eight percent of southern owners replied that it was part of their residence or farm, making this the most common reply. Only 12 percent stated that investment was their primary incentive while even fewer (4 percent) listed timber production (Moulton and Birch). Thus, many forest owners in the South may be willing to enter a carbon sequestration program and forego possible harvesting revenues at a lower price than more profit-oriented landowners elsewhere in the nation.

Conservation Tillage Adoption

Estimates of soil sequestration costs on active agricultural cropland are sparse. Clearly, millions of metric tons of carbon are being sequestered at no cost, since many farmers have already adopted conservation tillage practices. Babcock and Pautsch report cost estimates ranging from $0 to $400 per ton of carbon sequestered through conservation tillage (minimum and no-till) on cropland in 12 Midwestern states. The costs increase as soil carbon stocks continue to accumulate (i.e., the first carbon stores are the cheapest). This is a fairly intuitive result since, as mentioned above, soil carbon accumulation rates slow as more carbon is stored. As with land conversion, increasing marginal costs seem to be evident in this type of carbon sequestration program as well.

There is clearly a joint product for farmers to consider when analyzing the decision to adopt conservation tillage. Conservation tillage and other BMPs are likely to reward farmers with higher marginal profits, even without carbon sequestration, since they tend to increase agronomic productivity (i.e., crop yields) and decrease the costs associated with erosion, irrigation, and nutrient control (Day, *et al.,* Lal *et al.,* McCarl, Gowen, and Yeats; Tweeten, Sohngen, and Hopkins). However, the variability of farm profits is also increased under these practices, which may diminish their appeal for risk-averse farmers (McCarl and Schneider).

The Bottom Line

Farmers could potentially reap significant returns from a carbon sequestration market, especially given the joint product of carbon sequestration and crop production. If farmers were paid $30 per ton, sequestering 200 MMT of carbon per year could add $6 billion to the gross income of the farm sector (Sandor and Skees). The net impact of limiting GHG emissions on the agricultural sector, however, also needs to be considered. Several studies have examined this issue, arguing that GHG regulations will lead to higher energy prices and, thus, higher production costs, bringing down net farm income (Francl; McCarl, Gowen and Yeats). A recent USDA study contradicts these earlier findings and reports an insignificant impact on the net cash returns for producers (Office of the Chief Economist).

Implementation Issues: Efficiency and Equity Challenges

The remainder of this paper deals more directly with the impediments facing the creation of an efficient and equitable carbon market. The most fundamental barriers can be grouped into three broad areas: 1) transaction costs, 2) risk, and 3) perverse incentives. Efficient markets are characterized by minimized transaction costs, adequate monitoring and enforcement, and sufficient trading volume (Hahn and Stavins).

Transaction Costs

All costs of trade, including transaction costs, must be analyzed and minimized to achieve an efficient market for carbon. The primary costs surrounding the actual transaction of a permit trade are those associated with searching, bargaining, monitoring, regulation and enforcement. The reliability of carbon measurement, as discussed above, may not be as significant as others have made it out to be; the costs associated with measurement and verification, however, are the bigger issue. Obviously measurement costs decrease as the number of measurements declines. Thus, making estimates for large areas based on a few measurements may help minimize costs but at the expense of reliability. The transaction costs of measurement are positively correlated with accuracy and reliability. However, as noted above, some degree of inaccuracy due to generalization can be tolerated in a market and not lead to great inefficiency.

The measurement required to establish a baseline that reflects current carbon stores has been cited as a source of significant transaction costs in other studies (Sedjo, Sohngen, and Jagger). It seems, however, that periodic surveys of land-use and management practice changes could be undertaken at fairly low cost if current technology (e.g., GIS) and survey work were utilized. This assumes that it is the change in carbon levels rather than the total carbon storage estimate that is at issue. Although the periodic estimates may not be completely precise, they may be sufficient and even unnecessary if the right market incentives are in place.

The transaction costs associated with bargaining (i.e., the trading process between agents) could be high when dealing with the agriculture sector since there are many potential sellers of very small amounts of carbon. This is a significant issue for the forest sector and, thus, the South. The USDA Forest Service projects that by 2010 privately owned (non-industry) forests will account for 18 percent of all US forest carbon sequestration (Birdsey and Heath). This estimate would probably be much higher for the South, since, as previously noted, private owners control almost all of the region's forests. Although these private forest owners could take advantage of a carbon market, the transaction costs for a firm wanting to purchase carbon offsets would be high. Since the vast majority of private forests in the South are less than 50 acres, the firm would probably have to purchase carbon sequestration rights from a substantial number of individuals to achieve a sufficient quantity of carbon offsets.

Risk

Risk can greatly reduce the trading volume in a tradable permit market, leading to thin markets and sub-optimal market clearing prices (McCann). In addition to the risk of measurement error, the carbon market literature also stresses the significant challenges posed by political risk (i.e., the risk that national and international agencies will not impose any CO_2 emission reduction regulations, thus negating the economic value of carbon sinks). While political risk is an important factor to consider in any environmental market, the fact that numerous companies and governments are forging ahead with carbon trades suggests the market challenge of this risk, like measurement risk, may be overstated (especially for a domestic market). The potential rewards (in terms of less future regulation penalties, better company image, and potential trading gains) and costs for most companies seem to more than compensate for the political risk. The more serious challenges are the risks landowners face when changing land-use and management practices and carbon "yield" risk. These two risks could seriously limit landowner participation in a carbon market (McCarl and Schneider).

The profit risk landowners face from changing land-use and management practices may inhibit their participation in a carbon market, especially if carbon prices are low. The revenue uncertainty arising from converting agriculture land to forest is amplified by the irreversibility of the decision. In fact, if carbon prices are fairly certain, the irreversibility of the decision (and thus the loss of potentially high agricultural gains) will be the primary source of risk. The risk farmers face from changing cultivation practices results from yield (and ultimately profit) variability (Day *et al.,* McCarl and Schneider). Studies have found that farmers view risk as a major factor in not using BMPs, even though they have proven to generate operating cost savings. One study found that farmers perceive the risk of changing their practices to exceed $40 per acre (Feather and Cooper). Again, with less certain farm profits, a farmer's willingness to participate in a carbon market decreases.

Both sellers (e.g., farmers) and buyers (e.g., carbon emitting firms) of carbon reduction units also face carbon yield risk. Carbon yield refers to the actual level of carbon sequestered. Expectations of future carbon sequestration levels will have to be based on estimates, which are subject to sampling, modeling, and estimation error (EPA). Some carbon sequestration dynamics are still not clearly understood, as it is a complex process (Sedjo, Sohngen, and Jagger). Further, as with crops there is no guarantee that a certain carbon level, or yield, will be obtained since numerous variables can affect the carbon sequestration process. For example, events such as hurricanes or extreme rainfall events may cause major setbacks in building a carbon sink (Moulton and Kelly). This may be particularly true in the case of forest carbon sequestration, where large tracts of forest can be decimated by fires, hurricanes, etc. The challenge to the efficiency of a carbon market is its ability to find a price that attracts enough participants (i.e., the reward outweighs the risks) to avoid a thin market and yet keep the total costs of the market below that of a command-and-control type of effort.

Perverse Incentives

Some landowners have changed farming practices or made land conversions that have unintentionally resulted in increased carbon on their land. It is logical to assume that these individuals made rational decisions and are thus being rewarded for their actions, most likely by increased profits (or at least expected profits). Perhaps the greatest challenge for a carbon market is to avoid creating incentives to reverse previous actions. As discussed above, rewarding carbon accumulation instead of established carbon sinks creates a motive to release "old" stored carbon to gain greater carbon sequestration potential. To avoid perverse incentives, carbon sequestration programs will have to be carefully constructed, balancing long-term and short-run goals. For example, a two-tier pricing structure, one for stored carbon and one for newly sequestered carbon, could be implemented. Market forces, reflecting the relative value of short-term and long-term environmental goals, would determine the equilibrium price differential between the two. As an alternative, a one-time payment (most likely made by the government) could be made to all those with substantial carbon sinks. The discounted, annualized value of this payment would clearly have to exceed annual payment rates for carbon accumulation. Penalties or reimbursement conditions for intentional carbon release could be built into such a system if the land remained in private hands (this would require a baseline estimate of established carbon stores) or the government could purchase the land outright (McCarl).

Rewarding established carbon sinks, however, creates another set of problems: rent-seeking opportunities and equity issues. It is probable that some landowners will seek payment for actions they would have had no intention of making (e.g., cutting down trees or tilling their soil) (McCarl and Schneider). Such rent-seeking activity creates inflated carbon market costs. Further, owners of larger tracts of land will clearly have rent-seeking advantages, since more carbon would be at risk and they would have more political weight in their region.

Addressing the Challenges

Appropriate institutional designs will be required to address the challenges of transaction costs, risk, and perverse incentives, otherwise the benefits of a market-based approach may be overestimated (Hahn and Stavins, 1992; Stavins, 1995; McCann). This topic has been addressed in a few notable studies, but without much specific recognition of farmers' participation (Lee; Fischer, Kerr, and Toman.; Hahn and Stavins; McCann). While the challenges addressed above are significant, they are not insurmountable.

Some farmers are already participating in a carbon emission trading market. IGF Insurance Company, the fourth largest crop insurer in the US, has partnered with CQuest, a firm that helps implement carbon credit trades (i.e., by monitoring, measuring, registering, etc.), to sell carbon emission reduction credits (CERC). Each CERC is the equivalent of one metric ton of atmospheric CO_2 reduced or prevented from an agreed baseline (Caspers-Simmet). These two companies have initially solicited carbon credits from farmers and landowners in Iowa, using IGF's crop insurance agents' network. Farmers and landowners can achieve CERCs from the use of minimum and no-till, cropland retirement, buffer strips, reforestation, improved timber management, power generation from biomass, and methane abatement from livestock waste (Caspers-Simmet). The companies use formulas developed by the USDA Natural Resources Conservation Service (NRCS) to calculate how much carbon is sequestered under alternative conservation practices. Price is negotiated independently for each contract. They have already sold 2.8 million metric tons of carbon credits to a Canadian consortium of regional power utilities (PRNewswire).

The IGF-CQUEST arrangement offers a working model to consider. IGF is serving as a monitor of farm-level activities, thereby decreasing transaction costs. Since IGF is an insurance company, they understand the problems of moral hazard and monitoring farmers. On the farms to which they sell insurance they have important prior information. Further, they have partnered with the NRCS, which has farm-level conservation plans and models to estimate and verify carbon sequestration. This further reduces transaction costs. IGF is also developing new insurance contracts that will decrease the risk farmers face when adopting management practices to help sequester carbon. For example, cold soils in the spring are an impediment to adopting reduced tillage, since tilling the soil helps it warm faster. To offset this risk, IGF is offering an insurance contract that pays farmers when spring temperatures are significantly below average.

As illustrated by the IGF example, the right institutions can facilitate cost-effective trades. However, since IGF seems to be negotiating contracts on an individual basis, they are still facing significant transaction costs. These transaction costs could be drastically reduced if some type of organization were created to act as an aggregator of individual landowners, thus serving as the link between landowners and the larger CO_2 market. A farmer/forester-owned organization, such as a cooperative, could prove to be the best model for this type of organization. It would aggregate smaller landowners into a single organization large enough to trade more effectively (faster and more efficient transactions) and perhaps more equitably with other agents in the market. The landowners would also capture the broker's share of profits, which could increase market participation at lower permit prices. Such an organization would also solve some monitoring and moral hazard issues. Since each landowner's profits are tied to those of the organization, the incentive to cheat is diminished. Furthermore, measurement and carbon "yield" risk could be avoided at a fairly low cost. For example, ten farmers may estimate that collectively they will be able to sequester 1,000 tons of carbon over a five-year period. To be safe, however, they may only sell 900 tons of carbon to account for any possible discrepancies due to measurement inaccuracies or poor soil performance. The cost to each individual for contracting a lower-than-expected carbon yield would be marginal. In some cases, insurance contracts on extreme weather events may be a more efficient means to hedge against some of the risk associated with carbon yields.

The IGF example also suggests an appropriate role for government in a carbon market beyond acting as regulator (i.e., farm-level monitor) and the agency that could fill that role (the NRCS). Government actions could clearly either help or hinder the evolution of an efficient and equitable carbon market. The Conservation Reserve Program has been used in some studies as a model for a carbon sequestration program (Plantinga, Mauldin, and Miller; Parks and Hardie). With this type of system, the government would pay farmers to sequester carbon. Although the US government has effectively undertaken similar initiatives in the past (the CRP and Wetland Reserves Program), this type of system could crowd out private sector market development. A more efficient use of government resources would be to collect, maintain and distribute updated and comprehensive data and information about land use and carbon sequestration estimates to market agents. This provision of free, unbiased information could significantly reduce some market transaction costs and risks.

Conclusion

A tradable permit market for CO_2 is already more of a reality than an idea. Agriculture can take advantage of such market opportunities by sequestering carbon through land conversion (afforestation) and greater use of conservation tillage. Some farmers in Iowa have already been paid for their conservation efforts. Regional differences in agriculture and forestry will foster different carbon market interactions among US landowners. Farmers in the South could benefit from both converting their marginal land to forests and adopting no-till. The carbon sequestration rate for typical Southern forests is greater than in most other regions in the US. Also, the level of no-till adoption is lower than the national average. However, the characteristics that give the South an advantage in terms of future carbon sequestration potential would give the region a distinct disadvantage in a program that rewarded established carbon sinks. The typically smaller landholdings in the South, especially in the forest sector, could also inhibit landowner participation in a carbon market.

These and other challenges (transaction costs, risk, and perverse incentives) are, however, surmountable. For example, the creation of a cooperative could reduce some transaction costs, help manage risk, and increase market participation of agricultural agents by acting as an aggregator of small landowners. The government could increase market efficiency by acting as a source of free, unbiased information on land use and carbon sequestration estimates. Certainly, many other market details and issues need to be resolved, but the carbon market seems like a significant opportunity for the agricultural sector. The efforts of research need to be focused towards finding optimal institutional arrangements for agricultural agents.

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