Harvesting the Greenhouse through Altered Land Management: Economic Potential and Market Design Challenges

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Abstract

An Agricultural Sector Model is used to determine the economic potential of agricultural greenhouse gas emission reduction strategies within hypothetical emission mitigation markets. For a complete set of agricultural land management decisions, emissions and emission reductions of carbon dioxide, methane, and nitrous oxide are accounted for and simultaneously subjected to a wide range of carbon prices. The estimated, competitive emission abatement supply functions for major agricultural strategies are contrasted with two other commonly used measures of abatement potential: single strategy economic potential and technical potential. Specific agricultural production and market characteristics that further impact agriculture's mitigation potential are discussed.

Key words: greenhouse gas emission mitigation market, Agricultural Sector Model, economic potential, environmental policy design, non-point source, cropland heterogeneity, transaction cost, emission leakage.

HARVESTING THE GREENHOUSE THROUGH ALTERED LAND MANAGEMENT: ECONOMIC POTENTIAL AND MARKET DESIGN CHALLENGES

Carbon sequestration in agricultural and forest soils as well as in standing trees has received substantial attention within the policy, energy, and agriculture and forestry (AF) communities. Expanded concern arises from a combination of six principal forces:

1. Greenhouse gas (GHG) links to projected climate change
2. International agreements as manifest in the Kyoto Protocol
3. International pressures to reduce emissions
4. High-cost emission offsets in other sectors of the economy
5. Congruence of carbon sequestration activities with other AF-related societal desires like water quality and income distribution
6. Potential emergence of a GHG offset market

This interest is beginning to stimulate U.S. policy action, with bills being introduced in Congress and discussions in both environmental and agricultural agencies regarding policy and/or program design. Many factors need to be considered in formulating appropriate policy and programs. Substantial literature is emerging regarding soil science and forest management aspects of and potential for carbon sequestration (see Lal et al. 1998; Follett, Kimble, and Lal 2001; and IPCC 1996, 2000, and 2001). However, while this interest is founded in the technical potential that AF might generate, the real degree to which AF producers might meaningfully participate depends on key economic and market implementation issues. In this paper we will examine such potential, exploring economic potential for AF participation in a GHG market, and characteristics of AF GHG emission offsets that must be accommodated in market design to achieve meaningful AF participation.

Greenhouse Gas Emission Mitigation in Agriculture and Forestry: Concept and Technical Potential

Before discussing economic and market implementation issues, we will briefly review the mechanisms through which AF can participate, as well as the magnitude of the technical estimates for participation potential. Following the arguments in McCarl and Schneider (1999, 2000), AF may mitigate GHG emissions by

- creating or expanding sinks to enhance terrestrial absorption of atmospheric GHGs (carbon sequestration);
- reducing GHG emissions generated during AF operations; and
- providing products that substitute for GHG-intensive products and thereby displace emissions.

Each of these points will be discussed below.

Carbon Sequestration

Atmospheric carbon dioxide (CO_2) buildup is an important forcing agent behind projected climate change (Schlesinger 2001; North 2001; IPCC 1996, 2001). Terrestrial carbon sequestration offers a possible way of reducing concentrations. Carbon dioxide is exchanged continuously between the terrestrial biosphere and the atmosphere. Chlorophyllic plants absorb carbon dioxide through photosynthesis and use the contained carbon to build organic matter. Thus, carbon directly accumulates as plants grow. At the end of plant life, most of the organic carbon is quickly released to the atmosphere through microbial decomposition or through combustion. However, some of the carbon enters other terrestrial pools (humus, wooden furniture, and others).

Scientists estimate that about 80 percent of global carbon is stored in soils or forests (IPCC 2000) and that a substantial proportion of the carbon originally contained in soils and forests has been released due to past AF activities and deforestation. Collectively, these facts imply that there is substantial potential for AF activities to sequester carbon (Lal et al. 1998).

There are two fundamental physical processes through which carbon sequestration can be enhanced: increasing the amount of carbon accumulated in soils or trees and decreasing microbial decomposition and combustion (IPPC 1996; Paustian et al. 2001). Management actions that increase soil and tree carbon storage include expanding forested areas, delaying the time of forest harvest, increasing forest growth rates through enhanced silvicultural practices, adopting agricultural practices that minimize soil disturbance and erosion, increasing retention of crop or logging residue, and maximizing water- and nutrient-use efficiency of crop production.

The Intergovernmental Panel on Climate Change (IPCC) and leading U.S. physical scientists have estimated the technical potential of such practices (Table 1). With a projected U.S. Kyoto Accord target in the neighborhood of 700 million metric tons (MMT),[1] these estimates suggest that there is technical potential for sequestration activities to cover a large share of the U.S. obligation.

Emission Reductions

The IPCC (1996) estimates that on a global basis, agriculture emits about 50 percent of all methane, 70 percent of all nitrous oxide, and 20 percent of all carbon dioxide. Methane (CH_4) is emitted in AF through enteric fermentation of ruminant animals, anaerobic livestock manure decomposition, rice cultivation, and termites. Possible abatement strategies include altering crop choice, livestock herd size, livestock feeding and rearing practices, and manure management. Nitrous oxide (N_2O) emissions arise from manure, legumes, and fertilizer use and can be abated by reducing livestock herd size and changing crop mixes and fertilization practices. Carbon dioxide is emitted from fossil fuel usage, mineralization of soil organic matter, deforestation, and biomass decomposition or burning. Emissions can be reduced by decreasing production fuel use;

TABLE 1. Estimate of global potential contribution to change in carbon stocks by source (in million metric tons of carbon per year)

Source	IPCC 2000 Global Estimate	U.S. Estimate
Cropland management	125	75-208 (Lal et al.)
Grazing land management	240	29.5-110 (Follett, Kimble, and Lal.)
Forest management	170	
Agroforestry	26	300 (Birdsey)[a]
Afforestation	390	
Cropland to grassland	38	6-14 (Lal et al.)
Wetland restoration	4	
Degraded land restoration	3	11-25 (Lal et al.)

[a] This estimate arose from the U.S. Cop 6 negotiating position for annual sequestration by forests under business as usual without additional incentives (UNFCCC 2000).

changing the allocation of land among crops, pasture, grass lands, and forests; increasing forest harvest intervals; improving crop residue management; and restoring degraded land. Forest management practices that reduce emissions include diminished deforestation or logging, protection of forest reserves, and improved disturbance management with respect to fire and pest outbreaks.

The relative magnitude of these emission sources varies substantially across countries, with the greatest differences occurring between developing and developed countries. Deforestation and land degradation mainly occur in developing countries while developed countries slightly increase their forest base (FAO 1997). Developed country agriculture generally uses more capital-intensive production systems,[2] resulting in higher fossil-fuel-based emissions.

Product Substitution

AF biomass products may replace fossil-fuel-intensive products such as electrical power and liquid fuels. The use of biomass energy mitigates carbon dioxide emissions because most of the carbon released at combustion time is recycled carbon. Kline, Hargrove, and Vanderlan, for example, estimate that only 5 percent of the carbon emitted through poplar-fed electrical power plants pertains to fossil fuels. The remaining 95 percent pertains to carbon photosynthetically absorbed from the atmosphere during biomass growth. Use of pure fossil fuel products, on the other hand, increases atmospheric carbon dioxide concentrations by 100 percent of the contained carbon dioxide plus emissions related to extraction and processing of these fuels.

Forestry products also can be used as substitutes for fossil-fuel-intensive steel and concrete in construction (Marland and Schlamadinger [1997]; Brown [1999]; and Brown et al. [1996] elaborate on this point). Finally, there may be gains from substituting cotton and other fibers for petroleum-based synthetics.

Economic Potential

An appraisal of the economic potential for AF-generated GHG offsets entails four important matters, some of which we consider here and some of which we leave for future research. These include

- factors that would cause an AF producer to adopt a strategy,

- appropriate appraisal scope,
- competition across alternative strategies, and
- multi-gas trade-offs.

After discussing each, we will provide empirical data on economic potential.

Agricultural and Forestry Producer Adoption

While policymakers and others may desire certain GHG offset practices to be used in AF, the farm or forest operator ultimately controls the practices employed. Farmers and foresters adopt those practices that maximize their well-being. Well-being, however, is a complex good involving many dimensions, such as

- practice profitability,
- risk and uncertainty,
- time availability of resources required to use the practice,
- amount of training and/or learning required to employ the practice,
- willingness to adopt the degree of management required to employ the practice,
- consistency of the practice with existing equipment complement,
- willingness and ability to invest in new equipment required to employ the practice,
- desire for environmental stewardship coupled with the environmental attributes of practice, and
- necessity to perform in compliance with imposed regulations.

Some practices currently used by farmers and foresters are desirable from a GHG emission mitigation point of view. In such cases, the operator has judged the practice superior to other alternatives, even in the absence of adoption incentives. However, in other cases the desired practices are not used. To convince farmers to adopt such practices, regulations or incentives are needed. The incentives may be a mixture of direct instruments (such as carbon-related payments) and indirect instruments (such as sequestration shortfall insurance, investment subsidies, and training programs).

Consider for example the adoption of no-till farming as opposed to conventional moldboard plowing. Discussions with farmers (see Bennett 1999) reveal reservations about the adoption of no-till due to factors such as

- potential yield losses due to slower warming of untilled soils during cool spring planting seasons;
- potential yield reductions due to other factors;
- potential cost increases, particularly for weed and insect control;
- need to acquire new expensive equipment;
- critical reliance on the effectiveness of chemical weed control compounds and the need for continued efficacy of weed control;
- learning time to effectively employ the practice; and
- willingness on behalf of older farmers to switch practices.

All of these factors affect the magnitude of the financial incentives required to stimulate adoption. A lower bound on the needed incentive could be calculated as the foregone net income due to average yield loss (note yield gains are possible) plus the net value of any cost change. In developing efficient policies, however, incentives above and beyond lost income may be needed to overcome other barriers to adoption. Babcock et al., for example, indicate that nominally profitable practices may not always result in full adoption.

Appropriate Appraisal Scope

Appraisal scope is an important factor when considering the potential role of AF activities for GHG emission mitigation. The economic potential can be appraised at the field, farm, regional, or sector level. Farm-level assessments may report the incentives needed to induce participation on individual parcels. However, such appraisal results are based on current prices and thus may be misleading. The following small calculation will illustrate why AF GHG mitigation efforts might substantially impact market prices for traditional AF commodities. U.S. cropland amounts to approximately 325 million acres. The literature suggests an annual maximum potential for agricultural carbon sinks of around one and a half tons of carbon per acre of cropland through afforestation (Newell and Stavins). As a result, the total annual agricultural-cropland-based contribution to carbon storage may be bounded at about 325 million tons. The annual U.S. provisions of the Kyoto Protocol, however, likely would be in the neighborhood of 700 million tons.

Given the relatively high demand for emission reductions, large amounts of traditional cropland would be diverted to forests or biofuel production if these agricultural mitigation strategies were more cost efficient than strategies from other sectors. Large crop acreage reductions, however, would imply similar reductions in crop production, leading to higher market prices. Higher market prices for traditional AF commodities would raise the opportunity cost of mitigation strategies and thus make AF mitigation more expensive the more cropland is involved. To account for these complex interactions, a sector-level approach that simultaneously analyzes mitigation impacts and impacts on the traditional agricultural sector is needed.

Competition Across Alternative Strategies

The economic and technical potentials of certain AF GHG emission mitigation strategies are not independent of the level of other strategies. For example, the more cropland farmers allocate to biofuels, the less cropland is available for establishing permanent forests or adopting friendly tillage practices. Complementary relationships also emerge; farmers may supply corn for ethanol processing and at the same time sequester soil carbon through minimum tillage and offset emissions by reducing fossil fuel usage. Thus, simultaneous consideration of potential strategies rather than independent appraisal would appear to be appropriate.

Multiple Gas Trade-offs

AF enterprises contribute to emissions of multiple GHGs. A crop-livestock farm releases carbon dioxide when combusting the fuel necessary to operate field machinery, emits nitrous oxide through fertilizer applications, releases methane through enteric fermentation from ruminant animals or as a manure by-product, but possibly augments the soil carbon stock by using reduced tillage. Trade-offs between these emissions may occur if, for example, more fertilizer is needed under reduced tillage or if usage of growth hormones for animals alters the required acreage to produce feed.

Multiple gases can be considered using the global warming potential (GWP) concept. The GWP compares the radiative force of the various GHGs relative to carbon dioxide over a given time (IPCC 1996). The one-hundred-year GWP for carbon dioxide equals 1. Higher values for methane (21) and nitrous oxide (310) reflect a greater heattrapping ability. Thus, multiplying an emission quantity by the GWP forms a “carbon equivalent” measure after factoring in an adjustment for the molecular weight of carbon in carbon dioxide.

Economic Potential: Empirical Findings

Now we turn our attention to economic estimates of potential, although we do not have a full accounting of the disincentives that are not profit related.

Methodology

Following McCarl and Schneider (2001) we use AF sector modeling to estimate the economic potential for GHG mitigation under different farmer-received carbon prices (i.e., market prices less brokerage fees and other transactions costs). At each hypothetical carbon price, our model solves for the new AF sector market equilibrium. The volumes of induced GHG net emission reductions as well as other impacts are computed as the deviation from the zero carbon price baseline equilibrium. Our analysis simultaneously considers the full spectrum of U.S.-based AF responses to a net greenhouse gas mitigation effort, thus taking into account the complex, interrelated nature of activities in the AF sectors. For example, use of a biofuel mitigation strategy could alter corn production and corn prices, which in turn may impact exports, livestock diets, livestock herd size, and manure production as well as land allocation to biofuels and forests. The mitigation strategies involved are summarized in Table 2 and are defined in Schneider.

Our model is a new version of the U.S. Agricultural Sector Model (ASM) (McCarl et al. 2001, Chang et al. 1992). It is a mathematical programming based, price-endogenous sector model of the agricultural sector, modified to include GHG emissions accounting by Schneider (2000), and hereafter called ASMGHG. Recently ASMGHG has been expanded to include data from a forestry sector model (Adams et al. 1996; Alig, Adams, and McCarl 1998). ASMGHG depicts production, consumption, and international trade in 63 U.S. regions for 22 traditional and 3 designated energy crops, 29 animal products, and more than 60 processed agricultural products.

Environmental impacts include levels of GHG emission or absorption for carbon dioxide, methane, and nitrous oxide; surface, subsurface, and groundwater pollution for nitrogen and phosphorous; and soil erosion. ASMGHG simulates the market and trade

TABLE 2. Mitigation strategies included in the analysis

Strategy	Basic Nature	Greenhouse Gas Affected		
		CO_2	CH_4	N_2O
Afforestation/timberland management	Sequestration	X		
Biofuel production	Offset	X	X	X
Crop mix alteration	Emission, sequestration	X		X
Crop fertilization alteration	Emission, sequestration	X		X
Crop input alteration	Emission	X		X
Crop tillage alteration	Emission	X		X
Grassland conversion	Sequestration	X		
Irrigated/dry land conversion	Emission	X		X
Livestock management	Emission		X	
Livestock herd size alteration	Emission		X	X
Livestock production system substitution	Emission		X	X
Manure management	Emission		X	
Rice acreage	Emission		X	

equilibrium in agricultural markets of the United States and 28 major foreign trading partners. Domestic and foreign supply and demand conditions are considered, as are regional production conditions and resource endowments. The market equilibrium reveals commodity and factor prices, levels of domestic production, export and import quantities, GHG emissions management strategy adoption, resource usage, and environmental impact indicators. We solved ASMGHG repeatedly for carbon prices ranging from $0 to $500 per ton of carbon equivalent (TCE).

Estimates of Economic Potential: Results

Scientific evidence and the number of inquiries regarding AF GHG mitigation are growing rapidly. The data underlying this study, while the best available to us as at this time, will be old and obsolete tomorrow and could be improved by substantial efforts today. Consequently, we will not concentrate on specific empirical results. Rather, we will highlight general findings that we believe are highly relevant to consideration of the potential for AF sequestration and, to the extent possible, that rise above the flaws in the underlying data.

Cost Effectiveness of Emission Reductions

Figure 1 shows the amount of carbon equivalent emissions abated at carbon prices ranging from $0 to $500 by broad category of strategy. Low-cost strategies primarily involve soil carbon sequestration and, to some extent, afforestation, fertilization, and manure management. Up to a total of about 400 million metric tons of carbon equivalent (MMTCE) can be offset through AF (Table 3). To place cost estimates in perspective, one could contrast our findings to Weyant and Hill's (1999) multi-model study of non-agricultural Kyoto compliance costs sponsored by the Energy Modeling Forum (EMF). Across EMF studies, abatement costs vary with assumptions on emissions trading and baseline emissions. In the presence of carbon emissions trading among Annex I regions, U.S. abatement costs were generally in the range of $50 to $100 per metric ton of carbon but reached as high as $227. The costs of achieving particular GHG emission reduction levels were much higher without international trade in carbon emissions rights.

Effective Emissions Mitigation Strategies

Many different GHG emission (GHGE) mitigating agricultural strategies are possible and a number are often individually advocated. Our results indicate that a portfolio of strategies appears appropriate. Figure 1 shows the usage of the major mitigation

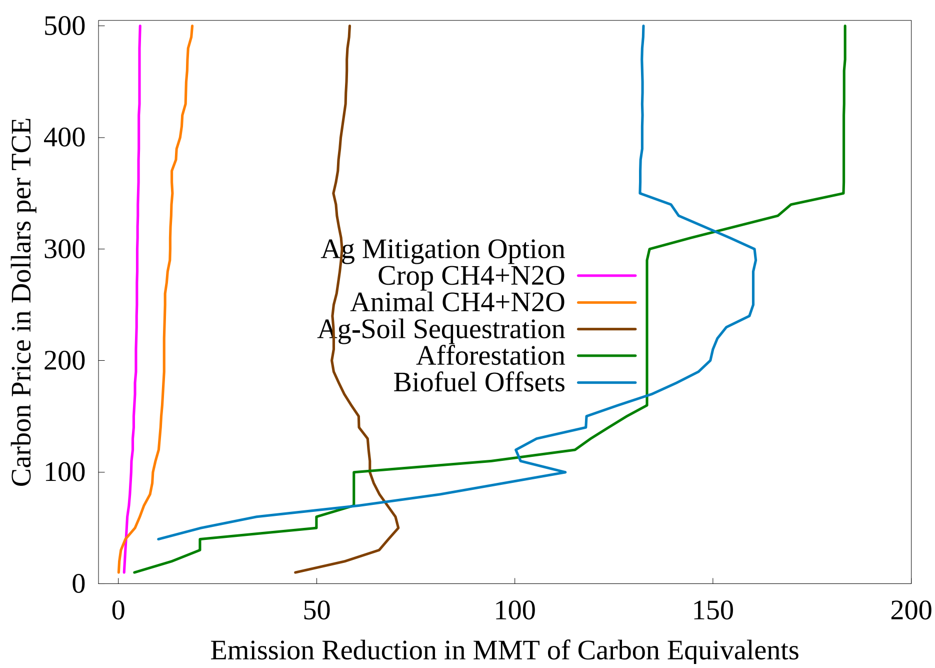

FIGURE 1. Agricultural mitigation potential at $0 to $500 per ton carbon equivalent prices

TABLE 3. Results at selected carbon price scenarios

Category	Carbon Equivalent Price in $/Metric Ton C					
Subcategory	10	20	50	100	200	500
Strategy contribution (1,000 TCE)						
Ag-soil sequestration	44,563	57,074	70,538	63,369	53,785	58,268
Afforestation	4,028	13,445	49,957	59,407	133,380	183,283
Biofuel offsets	0	0	20,799	112,790	149,337	132,424
Fossil fuel ag-inputs	2,575	3,849	5,326	6,965	8,690	10,738
Animal CH_4 + N_2O	-13	204	4,131	8,680	11,508	18,579
Crop CH_4 + N_2O	1,037	1,210	1,655	2,829	4,042	5,053
GHGE mitigation contribution (MMTCE)						
C	0.1	0.3	4.5	12.2	15.9	20.4
CH_4	51.2	74.4	145.8	237.9	339.1	379.4
N_2O	0.9	1.1	2.2	4.0	5.7	8.6
CE	52.2	75.8	152.4	254.0	360.7	408.3
Agricultural market effects (Fisher Index)						
U.S. crop production	99.2	98.5	95.7	86.3	74.0	65.5
U.S. crop prices	100.8	102.0	108.1	129.1	169.8	256.5
U.S. crop exports	97.4	94.8	87.1	59.2	29.1	23.1
U.S. livestock production	100.3	100.1	97.4	92.9	88.1	77.9
U.S. livestock prices	100.1	100.5	104.8	119.1	144.4	195.8
Non-GHG environmental impacts (percent-per-acre change)						
Wind and water erosion	-23.8	-31.3	-42.3	-44.4	-50.7	-49.9
N loss through percolation	-7.2	-9.7	-15.6	-19.1	-19.5	-12.7
N loss in subsurface flow	-8.7	-9.9	-11.7	-9.8	-7.1	-5.1
P loss in sediment	-32.6	-40.7	-50.4	-49.6	-52.0	-50.9

strategies over the total range of carbon prices. The results show a role for biofuels, forests, agricultural soils, methane, and nitrous-oxide-based strategies. Different strategies take on different degrees of relative importance depending on the carbon price level. While soil carbon sequestration peaks at around $50 per ton carbon, biofuel offsets are not competitive for prices below $30 per ton.

Sole reliance on agricultural soil carbon (Figure 2, economic potential line) reduces, for example, 60 MMT carbon at $30 per ton while consideration of the total portfolio achieves the same reduction at a cost between $10 and $20 per ton (Table 3).

Technical, Economic, and Competitive Economic Potential

Contrasting technical, economic, and competitive economic potential can illustrate the impact of economics on GHG emission mitigation potential in AF. We graph such a contrast for three major strategies: agricultural soil carbon sequestration (Figure 2),

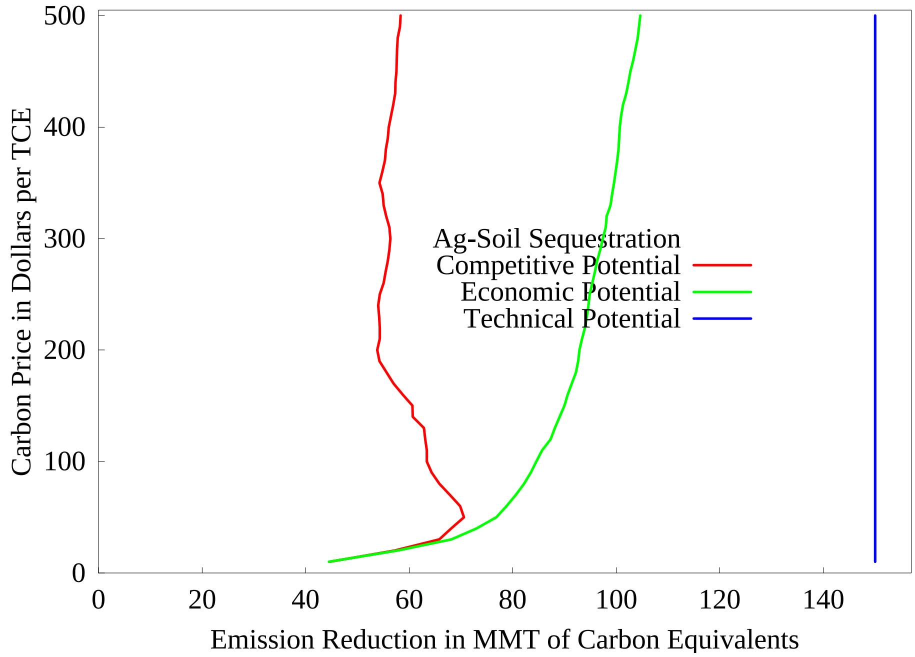

FIGURE 2. Agricultural soil carbon, technical, sole-source economic, and competitive economic response

carbon absorbed through afforestation (Figure 3), and carbon abated through energy crops (Figure 4). Estimates of technical potential ignore cost and resource competition and show that, if fully pursued, one could offset about 150 MMTCE annually with agricultural soil carbon sequestration from crop and pasture lands, about 270 MMTCE with afforestation, and about 330 MMTCE from energy-crop-related mitigation.

However, sole reliance on technical potential does not give a clear picture of implementation potential. Rather, the cost of achieving particular levels must also be considered. Agricultural soil carbon sequestration is the cheapest mitigation strategy for realizing about 50 percent of the technical potential for a relatively low carbon price of $50 per TCE. Biofuel crops and afforestation are more expensive to implement, but their ultimate technical potential is larger than that for agricultural soil carbon sequestration. At $50 per TCE, the economic potential for these two options ranges between 10 and 20 percent of their technical potential. It takes carbon prices as high as $300 per TCE for biofuel-crop-related carbon offsets to get close to the technical potential.

Competition between different mitigation strategies is also important and is illustrated through the difference between economic potential and competitive economic potential. For example, if growing biofuel crops were the only mitigation option

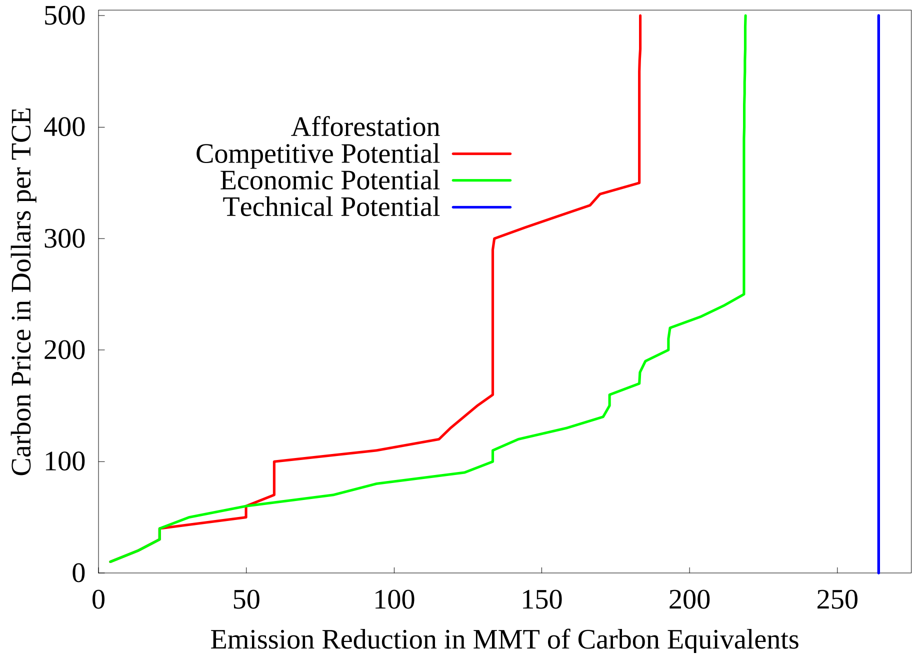

FIGURE 3. Afforestation carbon sink, technical, sole-source economic, and competitive economic response

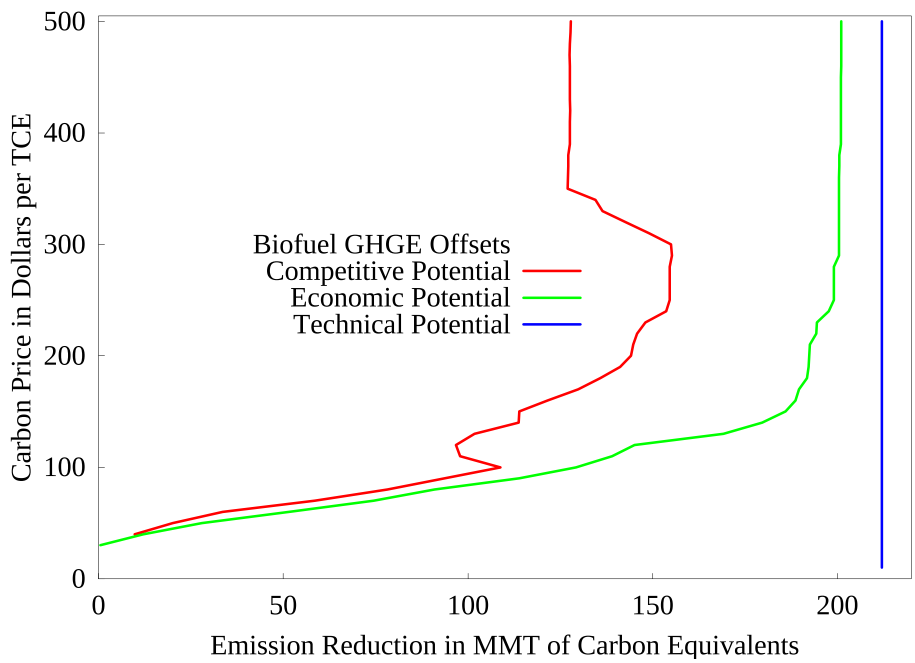

FIGURE 4. Carbon offsets from energy crops, technical, sole-source economic, and competitive economic response

(economic potential), about 192 MMTCE could be abated annually at a carbon price of $200 per TCE. If other options were considered simultaneously (competitive economic potential), the contribution of biofuel crops would diminish to about 133 MMTCE or by about 30 percent due to competition for land and other resources. The afforestation sink exhibits a similar pattern. In case of agricultural soil carbon sequestration, however, competition among strategies leads to a declining abatement contribution for carbon prices above $50 per TCE because the other strategies are dominant in that range, diverting land and demanding more intensification, which leads to a greater tillage intensity. This behavior demonstrates that higher carbon prices do not necessarily increase the GHG mitigation contribution of all strategies.

Impacts of Adoption on Environmental Quality

Many of the proposed agricultural mitigation actions (e.g., tillage intensity reduction, manure management, and land retirement) have long been discussed as strategies that simultaneously improve environmental quality. Consequently, one may expect benefits in such areas as erosion control and nutrient runoff, which are created simultaneously with emissions abatement. Table 3 lists changes in a few selected environmental parameters as carbon equivalent prices increase. For the most part, rates of nitrogen and phosphorous runoff and erosion decline. Environmental co-benefits largely stabilize at prices around $50 per ton. Higher carbon prices increase biofuel acreage at the expense of traditional crop production. As prices for traditional crops go up, intensive crop production becomes more profitable, but maintaining yield-reducing mitigation strategies becomes more costly. Thus, for carbon prices above $200 per ton we encounter a mixed environmental response from the traditional crop sector. Total traditional acreage declines, but emissions per acre partially increase.

Characteristics of Agriculture and Forestry Greenhouse Gas Markets

Economic and technical potentials are not the sole predictors of whether AF GHG mitigating strategies will be important. In order for AF GHG credits to be sold to a potential buyer, three major cost components must be overcome. Namely, compensation must offset

1. cost to adopt a practice as discussed above;
2. transaction costs borne by the producer to sell the commodity (Stavins 1995), including any costs of required monitoring and verification that has to be undertaken by the producer; and
3. costs accruing to market intermediaries for assembling, marketing, and certifying net emission reduction quantities.

If, however, the sector receives subsidies from farm programs or other environmental initiatives because of co-benefits that are generated by the AF GHG policies, then these payments will offset some of the costs.

To date, quantitative analysis of only the first of the three cost categories has been explored in depth as discussed above. The remaining costs and the issue of co-benefits are likely to be much more complicated. The reason for this is that markets for GHG credits, particularly those associated with AF, will face a number of unique challenges. Even when compared with other environmental markets, such as the sulfur dioxide case, AF GHG markets will face enormous challenges (Stavins 1998, 2000). There are (at least) eight characteristics of AF GHG markets that make such markets particularly problematic.

Non-point source. Emissions and sequestration are geographically widespread. Quantifying credits and monitoring compliance monitoring will likely require some mix of mobile efforts, sampling, computer modeling, and remote sensing. These costs must be borne by either the market participants or market intermediaries.

Cost heterogeneity. Implementation costs and resultant emission mitigation quantities vary geographically, even for the same strategy. Differentiating factors include land-use history, soil and climate conditions, and various others. Certification and incentive programs need to recognize this diversity to provide incentives where they are most likely to generate the greatest benefit per dollar.

Targeting. Designing programs to address problems concerning non-point source and cost heterogeneity is difficult. However, society has been designing and refining approaches to soil erosion and forest improvement incentives for more that 50 years in programs such as the Conservation Reserve Program. Offset market designers may wish to review approaches used in soil erosion, water quality markets, and wetlands markets in setting up rules and market practices for carbon markets.

Permanence. Soil and forest sinks saturate. Payments may be needed to retain the sequestered carbon after saturation. McCarl and Murray conducted a net present value analysis on tillage-change-induced soil carbon gains. They found soil carbon to be worth one-half or less relative to an equivalent amount of sustainable emissions offsets. Grading standards may be needed to adjust for saturation rates across strategies.

Leakage. Actions in one place cause reactions elsewhere so that less production here implies more elsewhere. McCarl (1998) examined afforestation incentives, finding that large-scale conversions of farmland into forestland causes large counter movements of existing forestland into farmland. These unintended land conversions offset close to 50 percent of the carbon gained from afforestation. Grading standards may be needed to adjust for differential leakage potential across strategies.

Costs of market intermediaries. It is anticipated that the primary purchasers of credits in a CO_2 credit market would be large sources such as power plants. AF sellers, on the other hand, may be made up of many small farmers and foresters. Assuming a one-third ton per acre carbon potential, the purchase of one 100,000-ton lot of carbon mitigation credits would require assembling, monitoring, and verifying performance across 300,000 acres or about 500 square miles. This task would involve about 600 producers, given an average farm size of 500 acres. If such a market is to succeed, brokers will be needed to negotiate between buyers and sellers. Assembly and coordination costs would not be trivial. Alston and Hurd (1990) estimate the costs of distributing deficiency and loan rate payments to be about 40 percent of the money distributed. The size of these transaction costs could exclude small acreage producers.

Sweetening returns to reflect co-benefits. Many AFS strategies generate co-benefits. Some strategies improve water quality or create more favorable patterns of rural income. Public subsidies or other environmental markets may exist or could be developed that favor strategies that generate co-benefits. These co-benefits would influence the optimal mix of AF policies and must be taken into account in designing markets for AF GHG mitigation.

Property rights and existing practices. Some producers already employ certain mitigation practices and therefore have already created a stock of carbon in their soil and forest stocks. This sequestered carbon could be released if the producer reverts back to traditional practices. What incentives should be created to ensure the continued sequestration of existing stocks of carbon? The answer to this question has complicated implications for both equity and efficiency.

If a market-based approach to mitigating GHGs is to succeed, each of the issues noted above must be addressed. Moreover, the good that is transacted in environmental markets is defined by the regulations that create the market. Depending on how the rules are written, the resulting market can look like that for commodities traded on the Chicago Board of Trade, or like the market for used cars advertised in the local newspaper (Woodward and Kaiser 2000). However, it should not be assumed that a more efficient market is necessarily “better.” Efforts to increase market efficiency may directly conflict with the need to monitor non-point sources, accommodate heterogeneity, account for leakage and permanence, and recognize co-benefits. The greatest challenge for such markets may be finding a way to balance the need to create the appropriate incentives for each AF producer with the competing need to create a market that is not overburdened by transaction costs.

Concluding Remarks

Agriculture and forestry offer the potential to mitigate a significant quantity of greenhouse gases through direct emissions reductions, biofuel offsets, and carbon sequestration involving trees, land use change, and tillage change. However, practical economic potential is smaller than technical potential. Furthermore, a number of market design issues must be worked out to manage program transaction costs and place agricultural activities on an even footing with non-agricultural activities. We firmly believe that future agriculture and forestry producers will operate in a society that values GHG emission reductions and that these values will be expressed through markets and price signals. Determining how to best design those markets and predicting their real potential are important tasks for future research.

Endnotes

[1] The Kyoto Protocol would require the United States to limit net emissions to 1990 levels less 7 percent (UNFCCC) between 2008 and 2012. Using Environmental Protection Agency emissions inventory data (EPA 2000), such an agreement would imply annual carbon emission reductions of about 300 million tons relative to 1990 plus offsets for emissions growth by 2010 (which by linear extrapolation is around 400 million more tons), for a total in the neighborhood of 700 million tons.

[2] Aggregate estimates of tractor inventory show developed countries using about three times as many tractors as developing countries on an agricultural area that is 40 percent smaller (FAO 1999).

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