# THE COMPARATIVE VALUE OF BIOLOGICAL CARBON SEQUESTRATION

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*A. Abstract*

*Carbon sequestration via forests and agricultural soils saturates over time. Consequently, sequestration credits have a smaller value than permanent emission offsets. Net present value analysis reveals value reductions between 45 and 62 percent for soil carbon absorption and between 1 and 49 percent for forest based carbon savings. Value adjustments are contingent on a multitude of assumptions including the dynamics of management decisions, alternative mitigation payment trajectories, and others. Agricultural sector analysis indicates little impact of value discounts on total emission abatement. However the economically optimal mitigation strategy mix shifts away from agricultural soil and forest sequestration to biofuel strategies.*

*B. JEL Classification*

C61 - Optimization Techniques; Programming Models; Dynamic Analysis
Q000 - Agricultural and Natural Resource Economics: General
Q230 - Renewable Resources and Conservation; Environmental Management: Forestry
Q250 - Renewable Resources and Conservation; Environmental Management: Water; Air; Climate

## II. INTRODUCTION

Emerging policies directed toward greenhouse gas emission (GHGE) reductions are causing governments and industries to consider the merits of GHGE mitigation possibilities. Land-based biological sequestration (LBS) is being evaluated as one potential way to achieve net GHGE reductions. Some have argued that LBS strategies are relatively inexpensive ways of lessening GHGE mitigation costs, as well as ways of increasing economic opportunities for farmers and foresters (see Dixon et al., 1993; Sampson and Sedjo, 1997; Marland and Schlamadinger, 1999). However, sequestration has been criticized as a viable policy option because the atmospheric benefits may not be permanent. In November 2000, the Hague negotiations for the Kyoto Protocol, the international agreement targeted at controlling GHG concentrations, failed in part to disagreement between members of the European Union and a coalition of the US, Canada, Japan, and Australia on the inclusion of LBS in the Protocol. Subsequent negotiations have resolved some of these issues, but LBS remains a controversial element of international climate policy. Doubts in the international community regard issues of permanence, leakage, monitoring, measurement and transactions costs. Here we investigate the effects involving permanence examining the influence of characteristics involved with permanence on the relative value of an LBS offset versus a direct emission offset. Specifically, we estimate the relative value to a carbon purchaser of LBS and emission offsets as they arise over time. We will also treat the concept regarding the rental of LBS generated sequestered carbon and the bridge to the future concept involved with future paths of carbon prices. We also investigate the implications that permanence related price discounts has on the potential contribution of LBS activities to GHGE offset efforts.

## III. BACKGROUND

Permanence is a concern with respect to sequestration because of (1) an ecosystems limited ability to take up carbon which we will call saturation and (2) the fact that management options can cause the sequestered carbon to be released which we will call volatility. Here we examine the relative value of sequestration and emission offsets given their differing saturation and volatility characteristics.

### *A. Saturation*

LBS activities exhibit saturation when storage reservoirs fill up due to physical or biological capacity. Two prominent forms of LBS are: (1) reductions in agricultural soil tillage intensity and (2) establishment of trees on currently unforested lands (afforestation). In terms of tillage, West et al. (2000) summarize the observed carbon increments over time arising from about forty tillage change experiments. Their results show that by year 20 the carbon increments us all the forty experiments have dropped essentially to zero – evidence of saturation. On the forestry side afforestation carbon is be sequestered in both soil and standing trees. Data from Birdsey (1996) show forest carbon sequestration reaches a limit with soil carbon saturating and trees eventually growing at a declining rate although this takes a longer time than in agriculture. However forest cases become yet more complex when harvesting is introduced as significant fractions of the carbon are retained in harvested wood products.

### *B. Volatility*

LBS sequestered carbon is also commonly thought of as not being permanent since its storage form is often volatile and subject to subsequent release through land use change, tillage change, harvesting, fires, or other natural and anthropogenic disturbances. For example cutting down a LBS-developed forest and plowing the soil up for farmland quickly releases much of the sequestered carbon. Replacing no-till agriculture with a moldboard plowing system also quickly releases carbon.

### *C. Cost Implications of Saturation and Volatility*

Saturation and volatility introduce additional terms that must be considered when examining the cost of an LBS offset. In particular both emission and sequestration efforts involve

1) an initial outlay for development and implementation of an activity that generates offsets and
2) operating expenses for keeping that activity going over time.

However the combination of saturation and volatility for LBS strategies also introduces a potential third cost item which is a

3) maintenance cost to keep the carbon sequestered possibly even after saturation has been achieved.

## IV. CONTEXT FOR GREENHOUSE GAS EMISSION OFFSET PURCHASES

Before proceeding with economic analysis, it is useful to consider the context for GHGE offset purchases. Suppose a firm or country has a capped amount of greenhouse gases (GHG) it can emit. To exceed that amount it must obtain rights. Suppose that entity wishes to pursue a production pattern that will emit GHGs in excess of its annual limit for the foreseeable future. Assume several purchase opportunities present themselves. The opportunities involve offers from those who can: a) directly reduce emissions, b) sequester carbon in agricultural soils, and c) sequester carbon in forests. In this context the main question investigated herein becomes: How do the different saturation and volatility characteristics manifest themselves in the price that the entity would be willing to pay for a unit of carbon for each opportunity?

## V. AN ANALYTICAL APPROACH FOR COMPARING THE VALUE OF OFFSETS

GHG emission offsets occur over time. Offsets could involve the development of enterprises such as:

a) an emissions reducing fuel-switching project which offsets emissions for many years;
b) Adoption of reduced tillage on cropped soils that saturates after 20 years;
c) Establishment of a forest on agricultural lands that sequesters carbon for 60+ years.

In cases b and c if the reduced tillage or forest use were eventually discontinued there would be future releases of the sequestered carbon back to the atmosphere. These dynamic considerations imply that a comparison involving sequestration should adjust for the time value of emissions offsets as argued in Richards (1997) and Fearnside, Lashof, and Moura-Costa (2000).

Thus, we will use a net present value framework much like that used in Feng, Zhao, and Kling (2000) and we will solve for the constant real emissions price which equates the net present value of the GHGE offset by a strategy with the net present value of the costs for strategy implementation. From a mathematical standpoint, we solve for p in the following equation

$$\sum_{t=0}^{T}(1+r)^{-t}pE_t = \sum_{t=0}^{T}(1+r)^{-t}C_t$$

where p is a constant real price of emission offsets,

r is the discount rate,

T the number of years in the planning horizon,

$E_t$ the quantity of emissions offset in year t, and

$C_t$ the cost of the emissions offset program in year t.

To proceed with the analysis we make several assumptions. First, to facilitate comparison across the offset options, we will assume equal incremental carbon generation potential offset rates and implementation costs for all -- 1 unit of carbon per period at a price of 1 unit. Second, we will evaluate the incremental costs and returns caused by use of each offset strategy over a time period of 100 years. Third, we will use a 4 percent real discount rate. Fourth, to keep the mathematics more straightforward, we will use linear approximations for the annual sequestration rates. For example, we will have a 1 unit offset for every year until the point of saturation and zero thereafter. Emissions from any CO2 released after the saturation point (e.g., from harvest or reversion to conventional tillage) are also linearly approximated.

*A. The Value of an Emission Offset*

Suppose we first consider a direct GHGE offset. Such offsets would come about from fuel-switching, less fertilizer use, etc. We will assume that opportunity yields a one-unit emission offset for one monetary unit per year. We also assume that program can be continued over the whole 100 year period. Application of our net present value framework shows the breakeven real carbon price (p) for this is 1.00.

*B. The Relative Value of an Agricultural Soil Offset*

Now suppose we consider an agricultural soil based offset coming about by changing tillage from an intensive system to a reduced tillage system. Based on West et al. (2000) we assume that saturation occurs in year 20. We will also assume for comparability that the system sequesters one unit of carbon per year for the first 20 years and zero thereafter at a cost of one unit per year for as long as the payment is in place. We consider three different possibilities about the practice and program payments beyond year 20. Namely, farmers are paid to switch tillage for 20 years and then

- A-I) at the end of the 20 years the payment ceases. In turn, farmers acting in their own best interests revert back to conventional tillage. Subsequently we assume that the sequestered carbon volatizes, being released over three years in equal increments of 6.67 units.
- A-II) the payment continues with farmers being paid for the full 100 years to continue the practice maintaining the sequestered carbon but carbon accumulation ceases at year 20.
- A-III) at the end of the 20 years the payment ceases. However, farmers acting in their own best interest maintain the practice and thereby the carbon.

The carbon and cost profiles differ across the scenarios. The cumulative amount of additional carbon rises in linear fashion up to year 20 then either remains the same (cases A-II and A-III) or drops to zero over 3 years when the subsidy is discontinued (case A-III). Total program cost rises until year 20 then stays the same under cases A-I and A-III or continues to rise for the entire 100 years (Case A-II).

When we compute the real price (p) that equates the net present value of the sequestration offsets with the value of the reduction, we get 2.64 for case A-I where the carbon is released, 1.80 for case A-II where the farmer is paid well past the saturation point and 1.00 for case A-III where the practice continues without subsidy. This shows relative to the one unit breakeven price for the emission offset that saturating agricultural soil carbon that requires a subsidy for the practice to be continued is only worth 38 percent to 56 percent as much. Thus, while the emission reductions are valued at the amortized cost of generating them, the saturating and volatile nature of agricultural soil sequestration will result in a discount if either the carbon is released or the cost continues beyond the saturation point and the free lunch of case A-III does not occur. Under a 50 percent discount this implies that for a LBS agricultural soil activity to be competitive with a direct emissions reduction costing $100 a ton, it would have to cost $50 or less per ton.

### *C. Expanding to Consider Forestry Offsets*

Now consider a forest-based offset. In general, such offsets would come about from afforestation, lengthening harvest rotations, ceasing harvests altogether or improving management. For simplicity we only consider afforestation herein. Forest carbon sequestration entails four types of carbon gains or emission offsets. First, forest soils hold more carbon than agricultural soils since: a) trees have larger root systems, b) forest soils are disturbed less frequently, and c) forests deposit and retain more surface matter litter. Second, standing trees hold carbon in their leaves, limbs and trunk. Third, harvested timber products are substantially made up of carbon and may be placed in long-term storage through their use in buildings, furniture, etc. Fourth, a sizeable portion of harvested forest carbon offsets GHGE as it replaces fossil fuel energy and accompanying emissions. This occurs both through the trees used as fuel wood and the use of milling residues for co-generation.

Forestry offsets also exhibit saturation and volatility. Volatility occurs upon harvest where lands either revert to agriculture or have much of their above and belowground biomass removed in the harvesting process. Soils saturate and trees eventually becoming mature where net growth is matched by losses. We set up scenarios that evaluate various dimensions of the problem in Table 1, including:

1. Timing of forest harvest (if it occurs at all)
2. Whether reforestation occurs after harvest
3. The period of time over which payments occur
4. Use of harvest products for pulp or saw timber which influences residency time for harvested carbon as well as for biofuels.

The time to saturation and post harvest forest carbon profiles where set up based on the Birdsey 's data for southeastern U.S. pine plantations. Birdsey and Heath's (1995) data for onsite forest carbon from the FORCARB model is supplemented by data on the amount of carbon removed from the site at harvest, decay rates for the logging debris, and the carbon disposition by pool (product, landfill, energy use, and emissions) over time (see Row and Phelps, 1991).

Left alone, our model forest saturates after 80 years. Under the first group of scenarios we keep the forest at least until saturation. To be parallel with the agricultural cases we considered cases where:

F-I) payments cease upon saturation and the stand is harvested and we get p=1.07 or a 93 percent value when fuel offsets are counted which falls to 91 percent without consideration of fuel.

F-II) payments continue until year 100 and the stand remains in its saturated state after year 80 where we find p = 1.02 or 98 percent of that for emissions offsets.

Next we turn our attention to a group of scenarios involving managed forests which are harvested for products and which volatilize part of their carbon upon harvest. First, we consider short rotation lands, primarily managed for pulpwood, which are harvested after 20 years. When such lands are harvested and revert back to agriculture we get a relative value of 65 percent with fuel offsets considered, 51 percent without (Case F-III). When the land is reforested that may mean landowners only need to be subsidized for the first rotation (analogous to the agricultural case A-III), then the "discount" factor with fuel considered actually rises above 1.0 to 1.254. This indicates that one would actually be willing to pay a premium for a 20-year sequestration project that produced this result, because it generates higher net discounted benefits than an emission reduction program alone.

When we consider longer rotations of 50 years, which is primarily a saw timber (lumber and plywood) management regime (cases F-VI, F-VII and F-VIII), we find higher relative values because the carbon accumulates in the forest longer and because the products have longer shelf lives than those made with pulpwood (paper and paperboard).

### *D. Leasing*

Some attention has been paid to leasing rather than buying GHGE offsets. In particular, Marland and Fruit (2000) and Bennett and Mitchell (year****) independently argue the attractiveness of potential leasing where at the end of the lease period all bets are off and the lesser must find other carbon. A similar proposal has been advanced in the context of the Kyoto Protocol negotiations by Colombia (see Colombia, 2000). To investigate the implications of leasing, we examined 20-year lease where when the lease ends there are no more payments and no guarantee that the carbon stays sequestered. Thus we used the assumption that the carbon volatilized immediately upon completion of the lease. Under these circumstances we find that the leased carbon is worth 36 percent as much as an emission offset. Thus it appears that leased carbon does have value, but would trade at a substantial discount.

### *E. Bridge to the Future*

One argument regarding LBS is that it offers a relatively cheap mitigation option that can be exercised now allowing reductions and buying time until future GHGE rates are reduced by technological change. This raises the specter of non-constant future emission offset prices. In such an arena several possibilities advance themselves. Future prices might

a) rise as regulations are tightened in an escalating attempt to develop an emissions cap that will stabilize atmospheric GHG concentrations;
b) rise as increasing emissions increase atmospheric GHGs and the damages due to marginal GHG increments rise;
c) fall from current estimates as innovation is stimulated by GHG markets; or
d) initially rise but then fall as innovation occurs.

The bridge to the future argument is in line with the rising then falling price in case d.

We thought it desirable to examine the effect of such scenarios on the relative values of the offset possibilities. To do this we compared constant real price results with results under: (1) declining prices over time, (2) prices which peaked at some point in the next 100 years and (3) rising prices over time. We assumed the annual change in prices was 1 percent in this exercise. The subsequent results for the above cases including leasing and the forest variants with biofuel credits. The results in Table 2 show that the LBS and leasing opportunities are worth the most the closer the price peak is to today. This is more general than the finding of Feng, Zhao, and Kling which imply that sequestration should be undertaken as soon as possible. In our analysis, the relative value of LBS activities is greatest when the prices reach their peak. If that occurs in the future, this provides an incentive for delayed sequestration.

*F. Sensitivity to Assumptions*

The analytical framework used here embodies a number of assumptions. Several experiments were done to determine the sensitivity of the results to alternative assumptions. In particular we examined the effect of alternatives involving

Discount rates. We examined rates from 4-8 percent and found the value of the saturating assets increased the higher the discount rate. For example, in agricultural soil case I the saturating carbon was worth only 38 percent as much as an emission offset under a 4 percent discount rate but under an 8 percent rate this rose to 63 percent (as also shown in Feng, Zhao and Kling, 2000). The reason for this is that under saturation, most of the benefits accrue in the earlier years, which have a higher discounted value.

Nonlinear Approaches to Saturation. We found use of an exponential function for saturation effects increases the relative values of the saturating strategies relative to the linear pattern used above.

## VI. IMPLICATIONS OF PERMANENCE RELATED DISCOUNTS FOR STRATEGY USE

Agricultural and forestry (AF) activities may contribute to net emission reduction efforts not only through LBS activities but also in a broader setting. Following McCarl and Schneider (2000), the contributions can be grouped into

1. Emissions reductions – Agriculture's global share of anthropogenic emissions has been estimated to be about fifty percent of methane, seventy percent of nitrous oxide, and twenty percent of carbon dioxide (2001). The methane emissions are from rice, livestock and termites. The nitrous oxide emissions largely from manure and fertilization. The carbon dioxide emissions come

from deforestation, tillage intensification, and fossil fuel use. Management may be employed to reduce contributions from these sources.

2. Creation or expansion of LBS sinks as discussed above.
3. Provision of substitute, less emission intensive, products -- AF can produce commodities which substitute for GHGE intensive products and thereby displace emissions. This principally involves biofuels or substitute building products.

Given these options, what are the implications of permanence discounts for the absolute desirability of agricultural offsets to offset purchasers and the relative desirability of LBS activities compared to other agricultural possibilities? This section of the paper examines that question.

### *A. Methodology*

To address the question just stated, we derive empirical marginal GHGE abatement curves. These curves estimate the amount of AF sector developed net emission reduction stimulated under alternative carbon prices. The interrelated nature of the AF sectors implies a complex process underlies these abatement curves. For example, an increase in no-till agriculture may alter corn production which alters corn prices and may cause a response in terms of livestock diets, livestock herd size and manure as well as an alteration in land values which influences land allocation to biofuels and forests. These changes all have implications for GHGE. Thus the analytical framework employed must depict simultaneous implementation of all of the strategies discussed above in the context of total sectoral interaction. While it would be advantageous to use data observations on landowner responsiveness to carbon prices to econometrically estimate marginal abatement curves, this is not possible because carbon has not been priced to date. As a consequence we used a mathematical programming based, price endogenous sector model of the agricultural sector (see McCarl et al., 2001) modified to have GHG features by Schneider (2000) and hereafter called ASMGHG coupled with data from a forestry sector economic and carbon accounting model (see Adams et al., 1996) to generate estimates of the abatement curve.

ASMGHG depicts production, consumption and international trade in 63 U.S. regions of 22 traditional and 3 biofuel crops, 29 animal products, and more than 60 processed agricultural products. Environmental impacts such as levels of greenhouse gas emission or absorption for carbon dioxide, methane and nitrous oxide plus chemical use, and soil erosion are included. ASMGHG simulates the market and trade equilibrium in agricultural markets of the U.S. and 28 major foreign trading partners. The model is constrained by domestic and foreign supply and demand conditions, and resource endowments. The market equilibrium reveals commodity and factor prices; levels of domestic production, export and import quantities; management adoption, resource usage and environmental impact indicators. ASMGHG was subjected to carbon prices from $0 per ton to $500 per ton. GHG quantities were transformed into tons of carbon equivalents using the 100-year global warming potentials (GWP) of 21*44/12 for methane and 310*44/12 for nitrous oxide (see IPCC, 2001). The Forest and Agricultural Sector Optimization Model (FASOM) was used to provide data on the afforestation option by running the model under a series of carbon prices to generate a carbon price-dependent function of carbon quantities and land requirements for afforestation. In turn that function was imbedded in ASMGHG to develop coverage of relevant GHGs across the agriculture and forest sectors.

ASMGHG incorporates a relatively complete inventory of the total spectrum of U.S based AF responses to a net greenhouse gas mitigation effort. The strategies considered are identified in Table 3. Definitions of those strategies and further details on ASMGHG and the processes underlying this study can be found in Schneider (2000), and McCarl and Schneider (2000).

*B. Empirical Results on the Effect of Permanence Discounts*

For illustrative purposes we ran the agriculture and forest sector model with and without permanence discounts. Specifically, in one case we ran the model with equal prices for all opportunities while in the other case we ran with the price applied to carbon from tillage changes on agricultural soils equal to 0.50 of a full credit and that from forests equal to 0.75. These adjustments are representative of the permanence discount factors estimated in the first part of the paper. The results in terms of the total portfolio of AF options chosen appear in Figure 1.

The aggregate marginal abatement curve is given in Panel A of Figure 1. All quantities are expressed in million tons of carbon equivalent (MMTCE) per year. For instance, at a price of $100/ton, the AF activities included in this analysis could generate roughly 300 MMTCE per year, which offsets just one-fifth of total GHG emissions for the U.S. in 1990. However, it seems likely that an actual carbon price would be less than $100/ton. For instance, one estimate of the U.S. cost of compliance to the Kyoto Protocol (1997) would be roughly $23/ton of carbon (see Council of Economic Advisors, 1998). If the carbon market price were in this range, LBS offsets from AF would be more modest – less than 100 MMTCE/year.

The results in Panel A show that discounting for permanence causes a somewhat modest upward shift in the cost of achieving any given volume of offsets from the total AF portfolio; i.e., buyers would have to pay higher prices to achieve equivalent AF sequestration levels. In addition, the presence of discounts causes the optimal portfolio to shift. Namely the agricultural soil (Panel B) and forestry shares (Panel C) decline, with the agricultural soil maximum falling by about 10 percent while forestry offsets adjust down by almost one third. Meanwhile, the share in the undiscounted biofuel option rises (Panel D), reflecting the fact that the direct GHGE reductions from biofuel strategies need not be adjusted for impermanence as do the LBS sequestration strategies.

We note that discounting impacts forest credits relatively more than agriculture at the higher carbon prices even though forest credits are discounted less. This happens because, at high prices, biofuels closely compete with forestry as a land use. Agricultural soil carbon credits stay attractive at low carbon prices, as there is not a close competing mitigation activity. Thus as we discount soil carbon, it is still used a major option for low carbon prices but you have to pay more for it. When we discount forest carbon, the slight advantage of forests over biofuels switches into a slight disadvantage substantially reducing afforestation.

## VII. CONCLUSIONS: SQUARING UP VARIOUS OFFSET CATEGORIES

The notion that land based biological greenhouse gas sequestration is impermanent, as manifest in its saturation over time and volatility generally causes the offsets generated thereby to be worth less than emission reduction offsets. The agricultural soil offsets examined herein are only worth 38 percent as much as an emissions offset if the carbon saturates and payments stop then it volatizes at the end of the program. The value rises to 55 percent if the practice is maintained by continuing subsidies. Under most forest scenarios, sequestered carbon in forests is worth from 51-99 percent as much as an emissions reduction program, contingent on assumptions about the length of the harvest rotation, whether reforestation occurs, and whether credits for fuel offsets are applied. These discounts lower the potential contribution of sequestration in a sector wide analysis.

In this paper, we incorporate permanence adjustments to the price paid for LBS and simulate the effect on marginal abatement functions from the agriculture and forestry sectors. In aggregate, the effects of discounting are somewhat modest, however, discounting can materially affect the composition of economically optimal strategies within the AF sector. Thus, whether the market or policymakers imposes such price adjustments on sellers and buyers of GHGE offsets can have a substantial effect on the distribution of mitigation activities – and land uses – within the AF sectors.

The timing of sequestration as a mitigation strategy is important. We evaluate in this paper the effect of different potential future carbon price trajectories. If carbon prices are nearing a peak or falling, then sequestration has a strong relative advantage in the short run. This is particularly important in light of the fact that large scale GHGE reduction may require the adoption of entirely new technologies that are in various stages of development. In contrast, sequestration results from an existing technology endowed by nature and can thus be adopted immediately. However, if the carbon prices rise over time due, for instance, to worsening climate impacts or increasingly stringent emission caps, this reduces the advantage of sequestration as a mitigation strategy relative to emission reduction through technical change. Because we cannot know with certainty which future scenario will prevail, a mixed strategy of sequestration and emissions reduction might be the most prudent path to long-run cost-effective mitigation.

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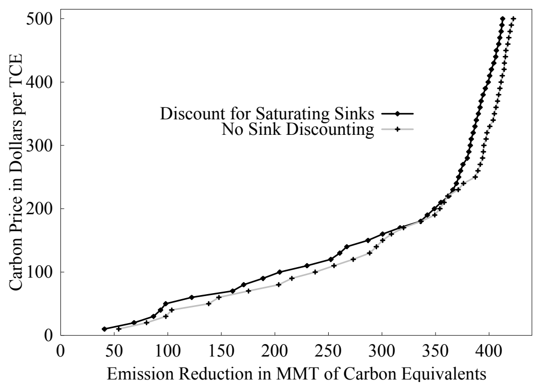
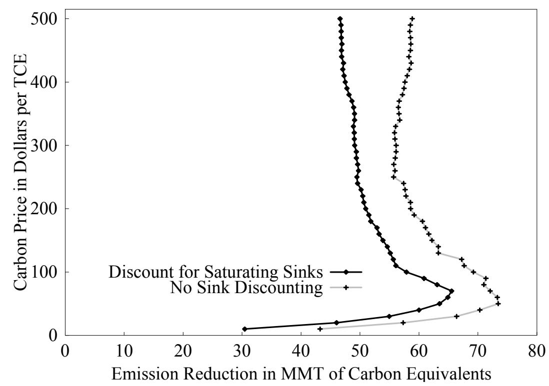
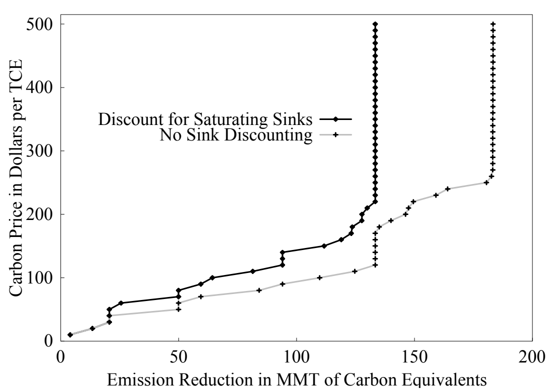


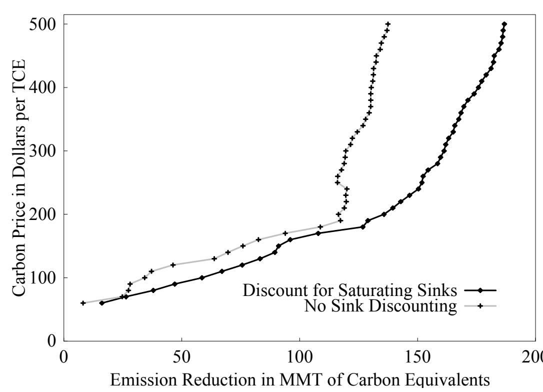

Panel A - Emissions offset in Total




Panel B - Offsets arising on Agricultural Soils




Panel B - Offsets arising in Forests




Panel B - Offsets arising from Biofuels

**Figure 1 Annual Net GHG Emission Abatement from Agriculture and Forestry in Million Metric Tons**

**Table 1 Scenario Descriptions and Terms of Trade for Forest Carbon Offsets**

| Scenario Description | | Defining Assumptions | | | Computed Results | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | With Consideration of Fuel Offset | | Without Consideration of Fuel Offset | |
| Broad Scenario Class | Case | Harvest Age | Reforest After Harvest | Years of Payments | Equivalent price | Value Relative to Emission Offset | Equivalent price | Value Relative to Emission Offset |
| Forest kept to Saturation | F-I | 80 | No | 80 | 1.07 | 93% | 1.10 | 91% |
| | F-II | Never | | 100 | | | 1.02 | 98% |
| Shorter rotation forestry (primarily pulpwood) | F-III | 20 | No | 20 | 1.54 | 65% | 1.95 | 51% |
| | F-IV | 20 | Yes | 100 | 1.44 | 69% | 1.78 | 56% |
| | F-V | 20 | Yes | 20 | 0.80 | 125% | 0.99 | 101% |
| Longer rotation forestry (primarily saw timber) | F-VI | 50 | No | 50 | 1.18 | 85% | 1.26 | 79% |
| | F-VII | 50 | Yes | 100 | 1.15 | 87% | 1.22 | 82% |
| | F-VIII | 50 | Yes | 50 | 1.01 | 99% | 1.07 | 93% |

**Table 2 Effect of Non Constant Price Patterns**

| Scenario | Time of Price Peak | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | No Peak | Year 0 | Year 10 | Year 20 | Year 30 | Year 40 | Year 60 | Year 80 | Year 100 |
| Emission | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| A-I | 38% | 52% | 47% | 34% | 29% | 27% | 26% | 25% | 25% |
| A-II | 55% | 63% | 62% | 58% | 54% | 51% | 48% | 47% | 47% |
| A-III | 100% | 114% | 111% | 105% | 97% | 93% | 87% | 85% | 84% |
| F-I | 98% | 99% | 99% | 99% | 98% | 98% | 97% | 96% | 95% |
| F-II | 94% | 98% | 98% | 97% | 97% | 96% | 93% | 89% | 86% |
| F-III | 66% | 82% | 79% | 69% | 59% | 55% | 52% | 50% | 50% |
| F-IV | 66% | 71% | 70% | 67% | 65% | 63% | 61% | 60% | 60% |
| F-V | 119% | 129% | 127% | 121% | 117% | 114% | 111% | 109% | 109% |
| F-VI | 86% | 95% | 94% | 93% | 90% | 86% | 76% | 73% | 73% |
| F-VII | 87% | 91% | 91% | 90% | 88% | 86% | 82% | 82% | 82% |
| F-VIII | 99% | 104% | 103% | 102% | 101% | 98% | 93% | 93% | 93% |
| Lease | 35% | 49% | 44% | 30% | 27% | 25% | 24% | 23% | 23% |

**Table 3 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 | |

## IX. ACRONYMS AND SYMBOLS

| | |
|---|---|
| AF | = agricultural and forestry, |
| ASM | = Agricultural Sector Model, |
| ASMGHG | = Agricultural Sector Model accounting for Greenhouse Gases, |
| CASMGS | = Consortium for Agricultural Soil Mitigation of Greenhouse Gases, |
| CSITE | = Carbon Sequestration in Terrestrial Ecosystems, |
| $C_t$ | = cost of the emissions offset program in year t, |
| EPA | = Environmental Protection Agency, |
| $E_t$ | = quantity of emissions offset in year t, |
| FASOM | = Forest and Agricultural Sector Optimization Model, |
| FORCARB | = Forest Carbon Model, |
| GHG | = greenhouse gas, |
| GHGE | = greenhouse gas emission, |
| GWP | = global warming potential, |
| IPCC | = International Panel on Climate Change, |
| LBS | = land-based biological sequestration, |
| MMT | = million metric tons, |
| MMTCE | = million metric tons of carbon equivalents, |
| p | = constant real price of emission offsets, |
| r | = discount rate, |
| t | = year index, |
| T | = number of years in the planning horizon, and |
| TCE | = metric tons of carbon equivalents |

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* This work was partially supported by EPA, the CASMGS carbon sequestration center, the CSITE carbon sequestration center, DOE, and the Texas Agricultural Experiment Station.

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