

# **Influences of Permanence on the Comparative Value of Biological Sequestration versus Emissions Offsets**

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## **Abstract**

We use a net present value framework to examine the impact of non-permanence on the economics of land-based biological carbon sequestration. Contingent on assumptions about discount rates, management, and carbon prices trajectories, and payment contract design, we find the adjusted value of carbon sequestration relative to permanently available emission offsets to be between 38 and 55 percent for agricultural soil offsets and between 51 and 99 percent for afforestation offsets. Simulations with an Agricultural Sector Model show the empirical effect of sequestration value discounts on the total potential of U.S. agricultural sinks to mitigate greenhouse gas emissions within a multi-strategy setting.

**Key words:** Agricultural Sector Model, carbon price trajectory, carbon sequestration dynamics, economics of greenhouse gas emission mitigation, forest sink discounting, mathematical programming, net present value, saturation, volatility.

# **INFLUENCES OF PERMANENCE ON THE COMPARATIVE VALUE OF BIOLOGICAL SEQUESTRATION VERSUS EMISSIONS OFFSETS**

## **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 increasing economic opportunities for farmers and foresters (Dixon et al.; Sampson and Sedjo; Marland and Schlamadinger). However, there seem to be doubts in the international community regarding issues of permanence, leakage, monitoring, measurement, and transaction costs. Here, we investigate the effects of permanence, examining the influence of 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 also treat the concept of rental of carbon sequestered through LBS, and examine bridge-to-the-future scenarios, which introduce nonconstant future GHGE offset prices. Finally, we investigate the implications that permanence-related price discounts may have on the potential contribution of LBS activities to GHGE offset efforts.

## **Background**

Permanence is a concern with respect to sequestration because of an ecosystems-limited ability to take up carbon, which we will call saturation, and 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 different saturation and volatility characteristics.

## **Saturation**

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

## **Volatility**

LBS-sequestered carbon is also commonly considered nonpermanent because 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 an 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.

## **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 an initial outlay for development and implementation of an activity that generates offsets and 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: a maintenance cost to keep the carbon sequestered, possibly even after saturation has been achieved.

## **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 that several purchase opportunities present themselves. The opportunities involve offers from those who can directly reduce emissions, sequester carbon in agricultural soils, and 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?

## **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 that offsets emissions for many years;
- (b) adoption of reduced tillage on cropped soils that saturate after 20 years; or
- (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 into the atmosphere. These dynamic considerations imply that a comparison of sequestration methods should adjust for the time value of emissions offsets, as argued in Richards and in Fearnside, Lashof, and Moura-Costa.

Thus, we use a net present value framework, much like that used in Feng, Zhao, and Kling, and we 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:

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

where  $p$  is a constant real price of emission offsets,  $r$  is the discount rate,  $T$  is the number of years in the planning horizon,  $E_t$  is the quantity of emissions offset in year  $t$ , and  $C_t$  is 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 assume equal incremental carbon generation potential offset rates and implementation costs for all—one unit of carbon per period at a price of one unit. Second, we evaluate the incremental costs and returns caused by use of each offset strategy over a period of 100 years. Third, we use a 4 percent real discount rate. Fourth, to keep the mathematics more straightforward, we use linear approximations for the annual sequestration rates. For example, we have a one-unit offset for every year until the point of saturation, and a zero offset thereafter. Emissions from any carbon dioxide released after the saturation point (e.g., from harvest or reversion to conventional tillage) also are approximated linearly.

### **The Value of an Emission Offset**

First, we consider a direct GHGE offset. These offsets would come about from such things as fuel-switching and using less fertilizer. We assume that opportunity yields a one-unit emission offset for one monetary unit per year. We also assume that the program can be continued over the whole 100-year period. Application of our net present value framework shows that the break-even real carbon price ( $p$ ) for this is 1.00.

### **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. we assume that saturation occurs in year 20. We 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 agricultural practice and program payments beyond year 20. Namely, farmers are paid to switch tillage for 20 years, and then one of the following occurs:

- (A-I) At the end of the 20 years the payment ceases. In turn, farmers acting in their own best interest revert back to conventional tillage. Subsequently,

we assume that the sequestered carbon volatilizes and is 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 of 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, thereby maintaining 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 three years when the subsidy is discontinued (case A-III). The 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 that saturating agricultural soil carbon that requires a subsidy for the practice to be continued is worth only 38 to 56 percent as much as the one-unit break-even price for the emission offset. 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 an 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.

### **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, in this paper we consider only afforestation. Forest carbon sequestration entails four types of carbon gains or emission offsets. First, forest soils hold more carbon than agricultural soils because trees have larger root systems, forest soils are

disturbed less frequently, and 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 such things as buildings and furniture. 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 through 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 aboveground and belowground biomass removed in the harvesting process. Soils saturate and trees eventually become mature, where net growth is matched by net losses. We set up scenarios that evaluate various dimensions of the problem in Table 1, including

- timing of forest harvest (if it occurs at all);
- whether reforestation occurs after harvest;
- the period of time over which payments occur; and
- the 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 were set up based on Birdsey's data for southeastern U.S. pine plantations. Birdsey's data for onsite forest carbon from the FORCARB model (Birdsey and Heath) is supplemented with 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 (Row and Phelps).

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 the following scenarios:

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

**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%

(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, and 51 percent without (case F-III). When the land is reforested, landowners may need to be subsidized only 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 a potential willingness 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).

### **Leasing**

Some researchers have paid attention to leasing rather than buying GHGE offsets. In particular, Marland and Fruit, and Bennett and Mitchell each extol the attractiveness of potential leasing, where at the end of the lease period all bets are off and the leaser must find other carbon. Colombia advanced a similar proposal in the context of the Kyoto Protocol negotiations (United Nations 2000). To investigate the implications of leasing, we examined the case of a 20-year lease where when the lease ends there are no more payments and there is no guarantee that the carbon stays sequestered. Thus, we use the assumption that the carbon volatilizes 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. Therefore, it appears that leased carbon does have value but would trade at a substantial discount.

## **Bridge to the Future**

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

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

The bridge-to-the-future argument is in line with the rising then falling price scenario.

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 declining prices over time, prices which peaked at some point in the next 100 years, and rising prices over time. We assumed the annual change in prices was 1 percent in this exercise. The subsequent results for the above cases include leasing but exclude the forest variants without biofuel credits. The results in Table 2 show that the LBS and leasing opportunities are worth the most the closer the peak price is to today. This is more general than the finding of Feng, Zhao, and Kling, which implies 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, it provides an incentive for delayed sequestration.

## **Sensitivity to Assumptions**

The analytical framework used here embodies a number of assumptions. We performed several experiments to determine the sensitivity of the results to alternative assumptions. In particular we examined the effect of the following alternatives.

*Discount Rates.* We examined rates from 4 to 8 percent and found the value of the saturating assets increased the higher was the discount rate. For example, in agricultural soil case I, the saturating carbon was worth only 38 percent as much as an emission offset

**TABLE 2. Effect of nonconstant 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%

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). 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 that using an exponential function for saturation effects increases the relative values of the saturating strategies relative to the linear pattern used above.

### **Implications of Permanence-Related Discounts for Strategy**

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, the contributions can be grouped into the following categories.

1. *Emissions reductions.* Agriculture's global share of anthropogenic emissions has been estimated to be about 50 percent of methane, 70 percent of nitrous oxide, and 20 percent of carbon dioxide (IPCC). The methane emissions are from rice, livestock, and termites. The nitrous oxide emissions largely are 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.

### **Methodology**

Given the preceding 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? To address this question, we derive empirical marginal GHGE abatement curves. These curves estimate the amount of AF-sector-developed net emission reductions stimulated under alternative carbon prices. The interrelated nature of the AF sectors implies that a complex process underlies these abatement curves. For example, an increase in no-till agriculture may alter

corn production, which may alter corn prices and 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 previously discussed strategies in the context of total sectoral interaction. While it would have been advantageous to use data observations on landowner responsiveness to carbon prices in an econometric estimation of marginal abatement curves, this is not possible because no prices are currently available for carbon. Consequently, we used a mathematical-programming-based, price-endogenous model of the agricultural sector (ASM) (McCarl et al.), modified by Schneider to include GHG features (hereafter called ASMGHG). This was coupled with data from the Forest and Agricultural Sector Optimization Model (FASOM) (Adams et al.) 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 United States and 28 major foreign trading partners. The model is constrained by domestic and foreign supply and demand conditions and by 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. To account for the fact that each GHG has a different global warming potential (GWP), GHG quantities were adjusted to 100-year GWP equivalents so that each gas was transformed to an equivalent GWP effect of one ton of carbon. These GWP adjustments are scalar values of 21 for methane and 310 for nitrous oxide, which is based on the molecular weight of carbon in carbon dioxide (IPCC). 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.

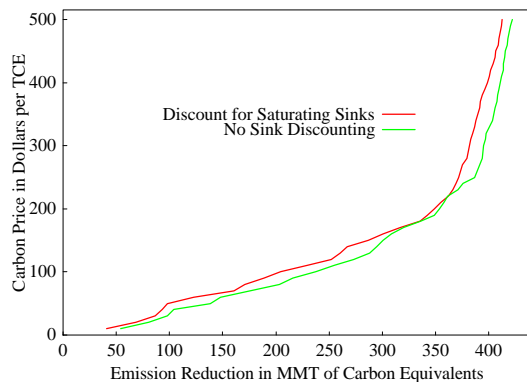
ASMGHG incorporates a relatively complete inventory of the total spectrum of U.S.-based AF responses to a net greenhouse gas mitigation effort. The strategies considered are identified in Table 3. Definitions of those strategies and further details on ASMGHG and the processes underlying this study can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

**TABLE 3. Mitigation strategies included in the analysis**

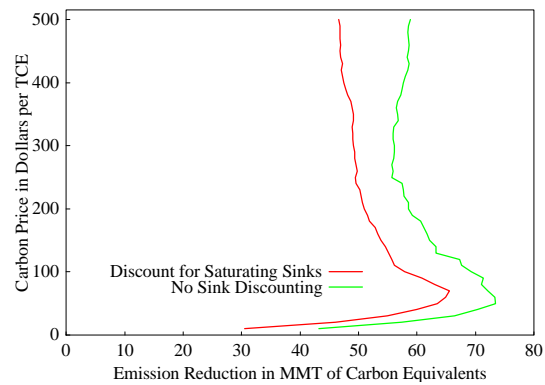
Strategy	Basic Nature	Greenhouse Gas Effected		
		CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Afforestation/timberland management	Sequestration	X		
Biofuel production	Offset	X	X	X
Crop mix alteration	Emission, sequestration	X		X
Crop fertilization alteration	Emission, sequestration	X		X
Crop input 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	

### Empirical Results on the Effect of Permanence Discounts

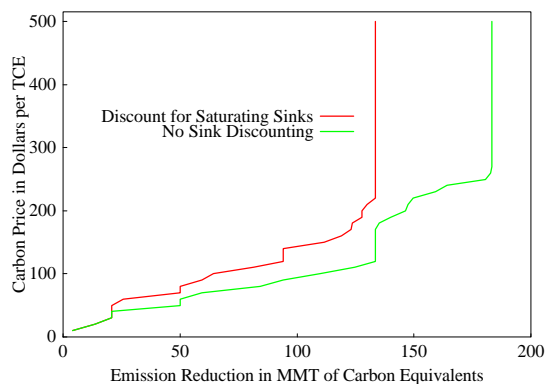
For illustrative purposes, we ran the agricultural and forest sector model with and without permanence discounts. Specifically, in one case we ran the model with equal prices for all opportunities while in the other case we ran the model with the price applied to carbon from tillage changes on agricultural soils equal to 0.50 of a full credit and the price 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 for the total portfolio of chosen AF options appear in Figure 1.



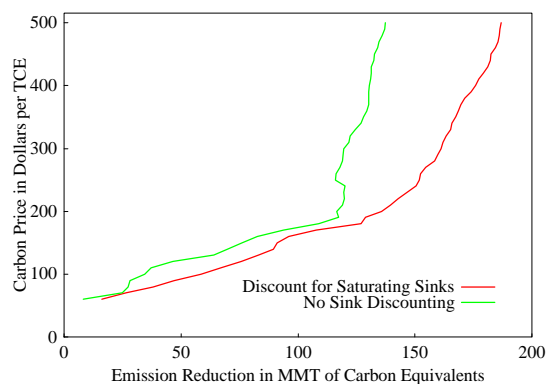
Panel A - Emissions offsets in total



Panel B - Offsets arising on agricultural soils



Panel C - Offsets arising in forests



Panel D - Offsets arising from biofuels

**FIGURE 1. Annual net greenhouse gas emissions abatement from agriculture and forestry in million metric tons**

The aggregate marginal abatement curve is given in Panel A of Figure 1. All quantities are expressed in million metric tons of carbon equivalent (MMTC) per year. For instance, at a price of \$100/ton, the AF activities included in this analysis could generate roughly 300 MMTC per year, which offsets just one-fifth of total GHG emissions for the United States 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 with the Kyoto Protocol would be roughly \$23/ton of carbon (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 MMTC/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 downward 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, unlike the LBS sequestration strategies.

### **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 its volatility, generally causes the offsets generated to be worth less than emission reduction offsets. The agricultural soil offsets examined herein are worth only 38 percent as much as an emissions offset if the carbon saturates, payments stop, and it volatilizes 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 to 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 sectorwide analysis.

In this paper, we incorporate permanence adjustments to the price paid for LBS and simulate the effect on marginal abatement functions from the agricultural and forestry sectors. In aggregate, the effects of discounting are somewhat modest; however, discounting can affect materially the composition of economically optimal strategies within the AF sector. Thus, whether the market or policymakers impose 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 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 thus can be adopted immediately. However, if the carbon prices rise over time due to worsening climate impacts or increasingly stringent emission caps, for instance, 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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