Jointly Estimating Carbon Sequestration Supply from Forests and Agriculture

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Alterations in agricultural and forestry (AF) land use and/or management provide a prospective way of mitigating net greenhouse gas (GHG) emissions. A number of AF practices are known to stimulate the absorption of atmospheric carbon or reduce GHG emissions at relatively modest cost with generally positive economic and environmental effects. Individual groups have advocated pursuit of afforestation, forest management alterations, tillage alterations, biofuel production expansions along with other initiatives. However, ultimately many of these strategies are competitive since they draw from a common land base. Thus, an investigation of the comparative role for AF mitigation based practices jointly across the two sectors appears in order.

AF practices partially involve sequestration reducing atmospheric GHGs through photosynthetic processes by plants or trees and subsequent fixing carbon into soils, plants or trees. AF sequestration activities exhibit saturation where storage reservoirs fill up due to biological capacity. They also generally store carbon in a potentially volatile state. For example, cutting down a forest and plowing the soil up for intensive farming quickly releases much of the sequestered carbon. Program costs involve development costs and operation costs as well as a maintenance cost to keep the carbon sequestered possibly even after saturation has been achieved. Comparison of the relevant role of sequestration versus other mitigation strategies considering these characteristics is another question we address herein.

This paper examines the marginal net GHG emission abatement curve across the spectrum of AF activities, focusing in part on the relative desirability of sequestration in forests and agricultural soils. The analysis will consider the effects of competition for land and other resources between AF mitigation activities and traditional production. In addition, analysis is done on the influence of permanence issues involved with saturation and volatility.

Approach

A two-pronged approach will be taken to the analysis of this question. First, following McCarl and Schneider (2001), we will use AF sector modeling to develop information on the marginal abatement cost curve describing the volume of GHG emission offsets at different farmer-received carbon prices (i.e. market prices less brokerage fees and other transactions costs) ignoring permanence issues. That analysis will be done in the context of the total spectrum of U.S. based AF responses to a net greenhouse gas mitigation effort. In particular, the role of AF sequestration efforts in the total portfolio of potential agricultural responses will be examined at alternative carbon price levels. The strategies considered are identified in Table 1. The characteristics of the underlying model are briefly summarized in the project description section below.

Second, following a paper by McCarl and Murray (2001), we will use a dynamic net present value framework to investigate the question of how a firm having to buy emission credits for the foreseeable future might factor in sequestration saturation and volatility to the prices it would be willing to pay for sequestration offsets in order to make them functionally equivalent to GHG emission reductions. In turn, we will use the sector modeling methodology to investigate the implications for the role of soil carbon sequestration in a total AF mitigation effort.

Project Description -- Sector Modeling

The basic approach used for generating the marginal abatement curve and the likely role of alternative mitigation strategies involves estimation of the curve and an examination of the strategies employed at alternative carbon prices. The analytical framework employed had to be capable of looking at the quantity employed of the mitigation strategies listed in Table 1 as well as the interrelationships between enterprises that compose the AF sectors. For example, expanded biofuels could lower corn production and raise corn prices which in turn may impact exports, livestock diets, livestock herd size, and manure production as well as land allocation to reduced tillage and forests. The sector model captures these and other interactions.

The sector model used is a mathematical programming based, price endogenous representation of the agricultural sector (ASM - McCarl et al., 2000b, Chang et al., 1992), modified to include GHG emissions accounting by Schneider, 2000, and hereafter called ASMGHG). ASMGHG was also expanded to include forestry possibilities for carbon production by including data on land diversion, carbon production and economic value of forest products as generated from a forestry sector model (FASOM-Adams et al., 1996, Alig et al., 1998) using 30-year average results over the 2000-2029 period. 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. Modeled environmental impacts include levels of greenhouse gas emission or absorption for carbon dioxide, methane, and nitrous oxide; surface, subsurface, and ground water pollution for nitrogen and phosphorous; and soil erosion. ASMGHG simulates the market and trade equilibrium in agricultural markets of the U.S.

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.

ASMGHG was repeatedly solved for carbon prices ranging from $0 to $500 per ton of carbon equivalent. The 100-year global warming potentials of 1 for carbon dioxide, 21 for methane, and 310 for nitrous oxide were used to convert methane and nitrous oxide emissions to carbon dioxide equivalency. In turn the estimates were multiplied by 12/44 to convert from a carbon dioxide equivalent to a ton carbon equivalent basis.

Results -- Sector Modeling

Knowledge regarding the GHG consequences of AF actions is growing rapidly. The data underlying this study may be obsolete tomorrow and could even be improved by substantial efforts today to incorporate recent scientific developments. Consequently, we highlight general findings, relevant to consideration of the appropriate role for AF participation in GHG abatement that, to the extent possible, rise above the flaws in the underlying data.

AF Provides Cost Effective Emissions Offsets Particularly Through Sequestration.

Figure 1 shows the amount of carbon offsets gained at carbon prices ranging from $0 to $500 by broad category of strategy. Note in those results that up to 423MMT carbon equivalent can be offset by AF means (Table 2). Primary low-cost strategies involve soil carbon sequestration and to some extent afforestation, fertilization, and manure management. To place these costs in perspective, one should note Weyant and Hill's (1999) report of non-agricultural compliance costs for the Kyoto Protocol international GHG agreement showed estimated abatement costs varying between $50 to $100 per metric ton of carbon depending on trading regimes. Results ranged as high as $227. At the $50 to $100 price range, AF activities in the U.S. could produce GHG offsets of approximately 140-240 MMTCE.

A Portfolio of AF Strategies Seems Desirable.

Today many different GHG emission (GHGE) mitigating agricultural strategies are being considered and often individually advocated. Our results show that a portfolio solution appears to be appropriate. Figure 1 shows the total response of mitigation over the total range of carbon prices. The results show a role for biofuels, forests, agricultural soils, methane, and nitrous oxide based strategies. The figure also shows that different strategies take on different degrees of relative importance depending on price level. While soil carbon sequestration peaks at around $50 per ton, biofuel offsets are not competitive for prices below $50 per ton. Reliance on individual strategies appears to be cost increasing. For example reliance solely on agricultural soil carbon (Figure 2 – economic potential line) means it would cost $40 to achieve 70 MMT while consideration of the total portfolio leads to a cost below $20 per ton for the equivalent GHG quantity (from table 2).

Difference Between Technical, Economic, and Competitive Economic Potential

Estimates for the sector abatement potential frequently ignore cost and resource competition. Lal et al., 1998, for example, compute total agricultural soil carbon (ASC) potential, but do not specify the cost of achieving it. Figure 2 displays ASC technical, economic, and competitive economic potential. The total technical potential in this case is 125 MMT annually but under reliance only on ASC this does not occur even for prices as high as $500 per ton. At lower prices substantially less carbon is sequestered. Furthermore, when ASC strategies are considered simultaneously with other strategies, the carbon price ($500 per ton) stimulates at most75 MMT or 60% of maximum potential while sequestration falls to 570 MMT (46%) at a $200 price because other strategies are more efficient at that payment level. In essence, agriculture possesses a backward-bending GHG mitigation supply function due to inter-sectoral substitution at the higher carbon prices.

Concentration on Single Strategies Can Cause Leakages in Other Categories.

Figure 3 shows the relationship between a carbon price-induced increase in forest-based offsets and emissions in the rest of the AF sector. We consider a policy that compensates for forest carbon only from afforestation (i.e., land use change from agriculture to forest) and not for forest carbon increments from existing forestland. The results indicate that the anticipated gains in forestry are in some cases augmented and in other cases offset by emissions in the rest of the AF sectors. This complex relationship occurs because land moving out of agriculture into forests places pressure on the remaining cropland, stimulating production intensification in terms of irrigation, tillage and fertilization. Thus, we find more emission intensive technologies on fewer acres of agricultural cropland. Leakage also occurs in forestry, where the underlying FASOM results show up to a 50 percent of the direct GHG gains from afforestation are offset, largely through changes in market conditions inducing the movement of traditional forestland into agriculture (deforestation) or reducing the management intensity of forests (McCarl (1998) shows such results).

Mitigation Based Offsets are Competitive With Food and Fiber Production.

Achieving net GHGE offsets requires that AF operations change. Many of the strategies divert land or inputs away from crop or possibly timber production. On the agricultural side, Table 2 shows that crop prices generally rise the more mitigation is undertaken while production falls. Exports are also strongly affected. On the forestry side, afforestation can cause price declines as timber supply is augmented by the increased land in forests. At higher carbon prices, increasing land competition among strategies leads to increased afforestation and biofuel usages of croplands but reduced agricultural soil sequestration.

Adopting Mitigation Strategies Impacts Environmental Quality

Many of the proposed agricultural mitigation actions (tillage intensity reduction, manure management, land retirement etc.) have long been discussed as strategies which simultaneously improve environmental quality. Consequently, one may expect benefits in terms of erosion control, runoff etc. which are created simultaneously with emissions abatement. Table 2 shows changes in a few selected environmental parameters as carbon equivalent prices increase. For the most part, these results confirm declining rates of nitrogen and phosphorous runoff as well as reduced erosion. However, reliance on biofuels causes the environmental co-benefits largely stabilize at prices around $200 per ton.

Permanence Issues -- Saturation and Volatility

Yet another question regarding sequestration involves the way a decision maker might view AF sequestration relative to say an emissions reduction given the opportunity to buy one or the other. To investigate this question, we follow McCarl and Murray (2001) and use net present value analysis to find the breakeven carbon price one would be willing to pay for nominally equal cost and carbon potential sequestration and emission offset opportunities.

The basic procedure discovers the breakeven price for carbon that renders the net present value of a stream of carbon equivalent offsets equal to program costs. Specifically, we solve the following equation for p:

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

where r is the discount rate -- assumed to be 4%, T the number of years in the planning horizon - assumed to be 100, p a constant real price of emission offsets, E_t the emissions offset in year t, and C_t the cost of the emissions offset program in year t. Then by comparing prices for different possibilities we can determine the effect of saturation and volatility.

Results -- Saturation and Volatility

For illustrative purposes we will consider three hypothetical cases that allow comparison of relative carbon prices by opportunity. McCarl and Murray (2001) consider many more.

Case A: Emissions offset - Suppose an emission offset can be obtained which annually offsets one unit of carbon for the full 100 years at a cost of 1 monetary unit (e.g. one dollar) per year. The breakeven price for this is one unit ($1 per unit carbon).

Case B: Saturating Agricultural Soil Carbon - Consider an agricultural soil carbon case that sequesters an average amount of one carbon unit per year but then saturates after 20 years consistent with the findings in West et al. If payments stop after 20 years, the carbon preserving practice ceases, releasing (volatilizing) the carbon into the atmosphere over the next 3 years. Given these characteristics we find a breakeven price of 2.64 units. Alternatively, if the practice is subsidized for the remaining 80 years, this price amounts to 1.80. This implies that the saturating/volatile soil carbon is worth between 36 percent and 55 percent of the emissions offset.

Case C: Forest carbon – In this example, carbon in forests will saturate after trees reach maturity in about 80 years. The sequestered carbon is volatile because the trees may be harvested releasing soil and standing tree carbon, but also placing carbon into products that

> provide longer term storage or fuel offsets. A forest reserve that sequesters a unit for 80 years costing one monetary unit has a break-even price of 1.02 or just a 2 percent discount. A 20-year harvest pattern for pulpwood stands with fuel credits counted leads to prices in the range of 65-70% of emissions while a 50 year saw timber stand comes out at 85-87%. Other cases in McCarl and Murray (2001) range as low as 51%.

For illustrative purposes we then reran the sector-modeling framework but multiplied the price applied to carbon from tillage changes on agricultural soils by 0.50 and that from forests by 0.75. In turn, the total portfolio of options (Figure 3 panel a) chosen shifts with agricultural soil (panel b) and forestry shares declining (panel c) but biofuels gaining (panel d). The agricultural soil maximum fell by about 10 percent while the forestry adjusted down by about one fourth. Further it took higher prices to achieve equivalent sequestration levels. 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. Meanwhile, agricultural soil carbon credits are 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 over biofuels switches into a slight disadvantage.

Conclusions

Agricultural and forest carbon sequestration are important components of a possible total societal response to a greenhouse gas emission reduction initiative. Our analysis shows that the magnitude of their role and the relative importance of alternative strategies depends upon the price that landowners face for changes in GHGs, expressed in carbon equivalents (a “carbon price”). At low prices, agricultural soil sequestration appears highly competitive with other GHG mitigation strategies within and outside of the AF sectors, but saturation and volatility will likely lead to price discounts. Forest based sequestration and biomass offsets gain in importance at higher carbon prices.

Bibliography

Adams, D.M., R.J. Alig, J.M. Callaway, and B.A. McCarl., *The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Applications*, USDA Forest Service Report PNW-RP-495, 1996

Alig, R.J., D.M.Adams and B.A.McCarl. "Impacts of Incorporating Land Exchanges Between Forestry and Agriculture in Sector Models", *Journal of Agricultural and Applied Economics*, 30(2), 389-401, 1998.

Chang, C.C., B.A. McCarl, J.W. Mjelde and J.W. Richardson. "Sectoral Implications of Farm Program Modifications." *American Journal of Agricultural Economics*. 74(1992):38-49

Lal, R., J. M. Kimble, R. F. Follett, and C. V. Cole. *The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect*, 128 pp., Sleeping Bear Press Inc., Chelsea MI,1998.

McCarl, B.A. "Carbon Sequestration via Tree Planting on Agricultural Lands: An Economic Study of Costs and Policy Design Alternatives." Paper presented at the Energy Modeling Forum, Snowmass CO, http://agecon.tamu.edu/faculty/mccarl/mitigate.html, 1998.

McCarl , B.A. and , B.C. Murray. "Harvesting the Greenhouse: Comparing Biological Sequestration with Emissions Offsets", Unpublished Paper, Department of Agricultural Economics, Texas A&M University, College Station, TX, 2001.

McCarl, B.A. and U. Schneider, "Harvesting Gasses from the Greenhouse: Economic Explorations Regarding the Role of Agriculture and Forestry" Unpublished Paper, Department of Agricultural Economics, Texas A&M University, College Station, TX, 2001.

McCarl, B. A., D. M. Adams, R. J. Alig and J.T. Chmelik, "Analysis of Biomass Fueled Electrical Powerplants: Implications in the Agricultural & Forestry Sectors", *Annals of Operations Research*, 94, 37-55, 2000a.

McCarl, B.A., C.C. Chang, J.D. Atwood, W.I. Nayda*; Documentation of ASM: The U.S. Agricultural Sector Model*, http://agecon.tamu.edu/faculty/mccarl/asm.html, 2000b.

MacCracken, C.N., J.A. Edmonds, S.H. Kim, and R.D. Sands. “The Economics of the Kyoto Protocol,” in *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, special issue of *The Energy Journal*, John Weyant (ed.). 1999.

Schneider, U. *Agricultural Sector Analysis on Greenhouse Gas Emission Mitigation in the U.S.*, PhD Dissertation, Department of Agricultural Economics, Texas A&M University, December 2000.

U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996*. EPA-236-R-98-006, Washington DC, March 1998.

Weyant, John P., and Jennifer Hill. “Introduction and Overview,” in *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, special issue of *The Energy Journal*, John Weyant (ed.). 1999.

Williams, J. R., C. A. Jones, J. R. Kiniry, and D. A. Spaniel.:1989, "The EPIC Crop Growth Model." *Transactions of The American Society of Agricultural Engineers*. 32 :497-511.

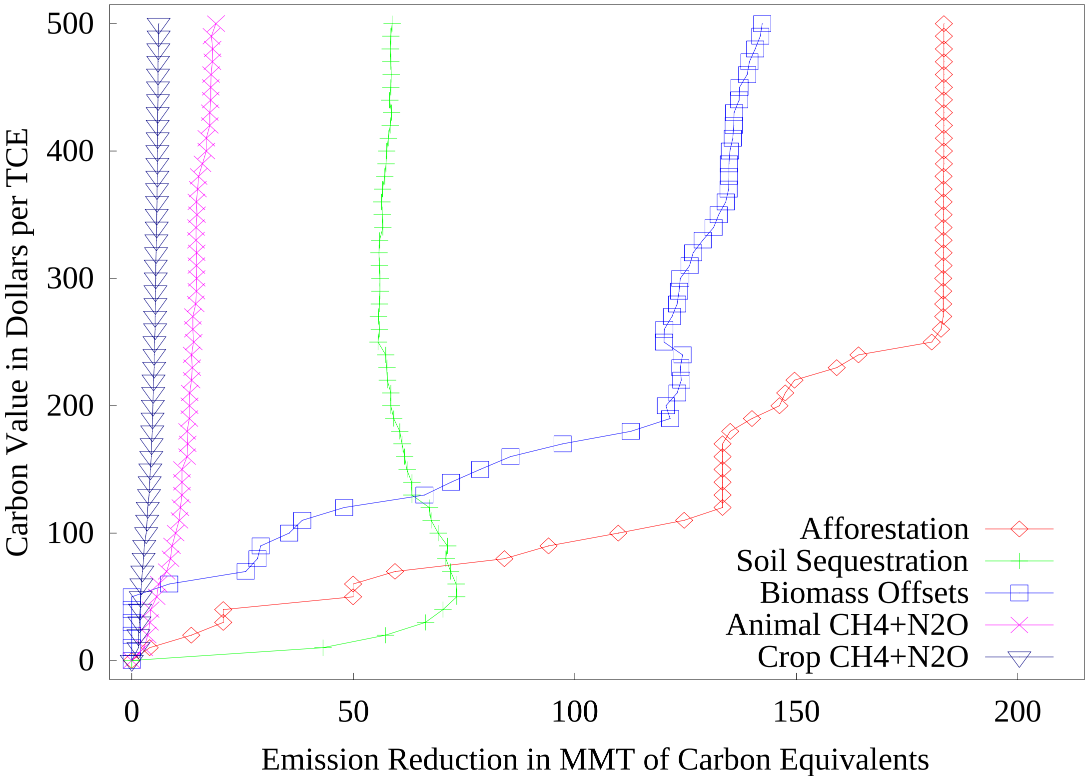


Figure 1 **Agricultural Mitigation Potential at $0 to $500 per Ton Carbon Equivalent Prices**

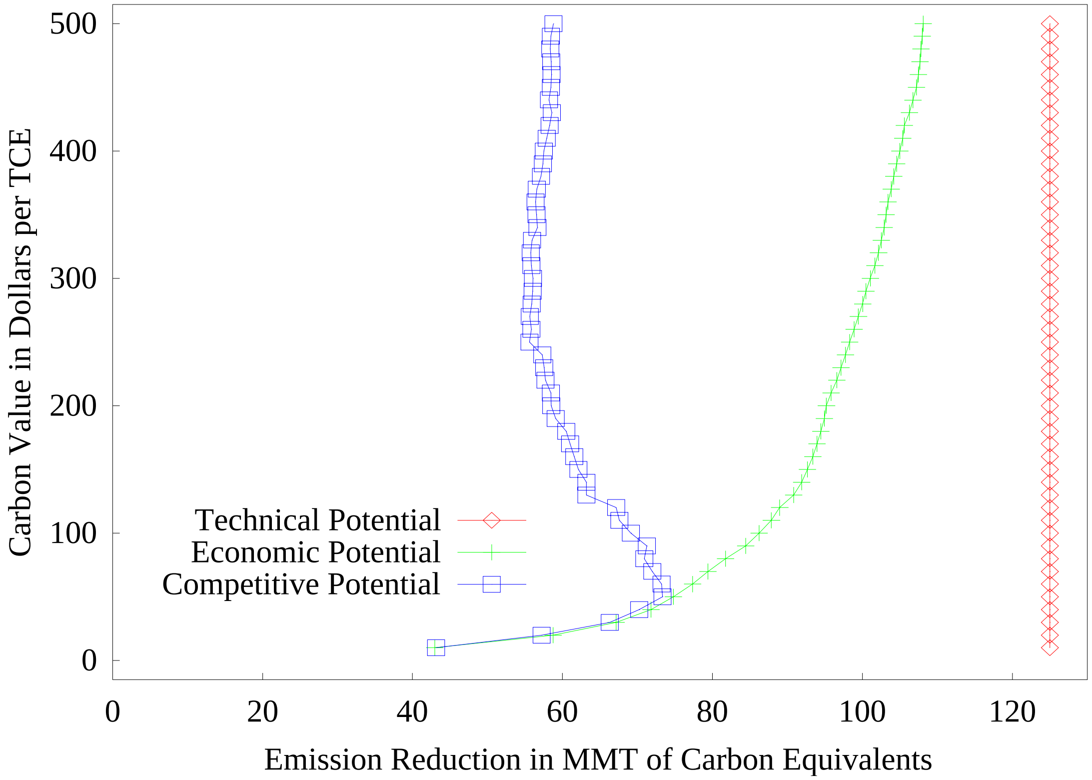


Figure 2 **Agricultural Soil Carbon, Technical, Sole Source Economic and Competitive Economic Response**

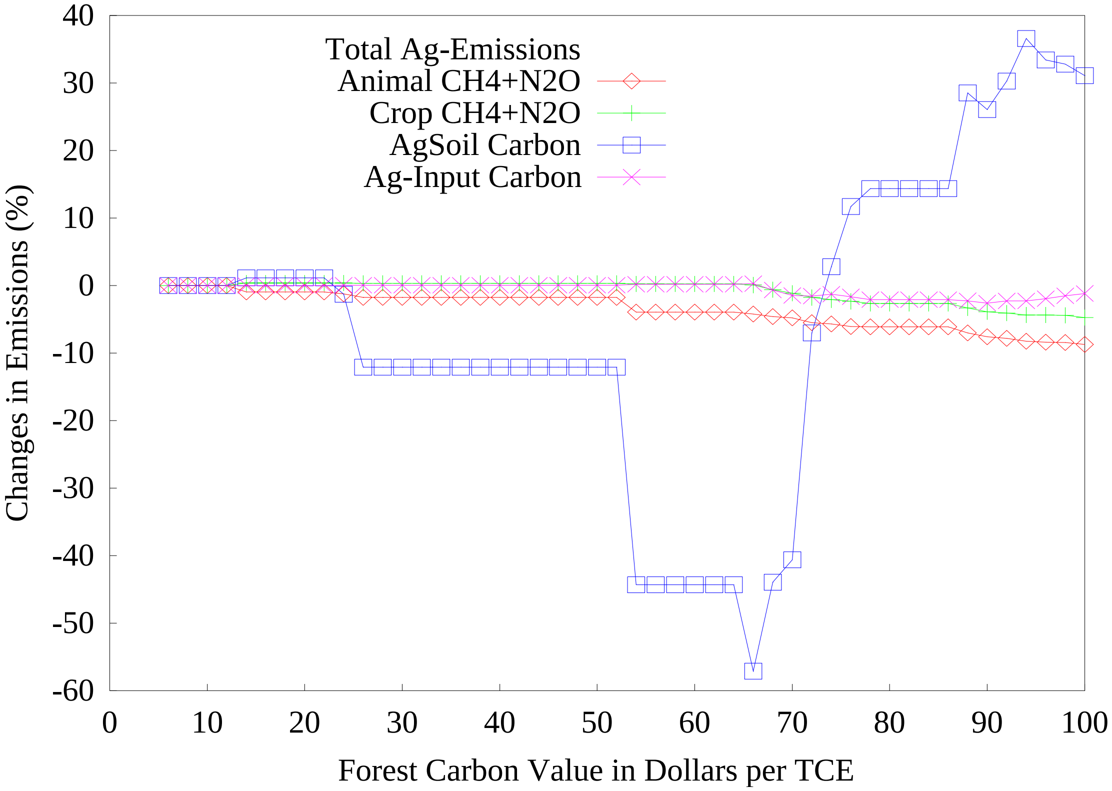
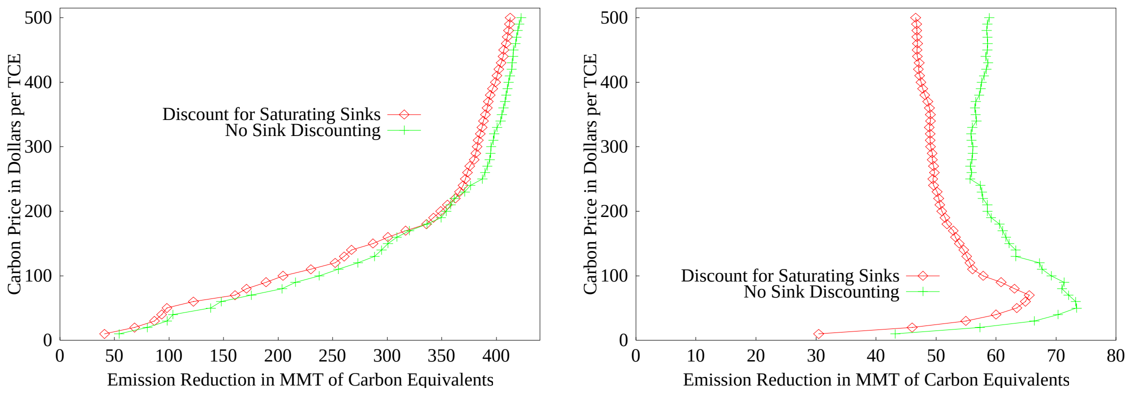
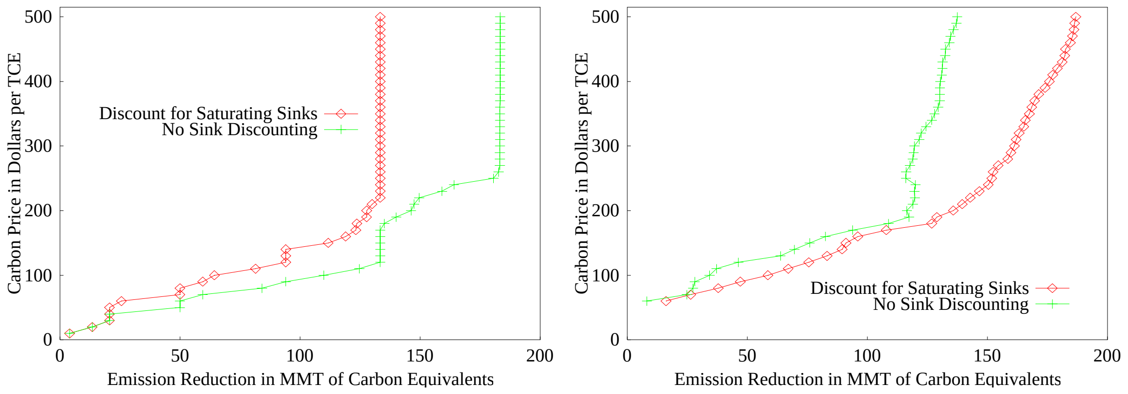


Figure 3 Gross and Net Mitigation of Sole Reliance on Forestry Related Strategies



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

Table 1 Mitigation Strategies Included in the Analysis

Strategy	Basic Nature	Greenhouse Gas Affected		
		CO2	CH4	N2O
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	

Table 2 Results at Selected Carbon Price Scenarios[1]

Category Sub-Category	Unit	Carbon Equivalent price in $/metric ton C 10	20	50	100	200	500
Mitigation Strategy							
Crop + Pasture Soil Carbon	1000 TCE	43,135	57,226	73,349	69,148	57,536	58,777
Afforestation	1000 TCE	4,028	13,445	49,957	109,800	183,279	183,319
Biomass	1000 TCE	0	0	0	35,487	134,979	142,294
Fossil Fuel Ag-Inputs	1000 TCE	2,513	4,186	7,081	9,969	12,688	13,097
Livestock Related	1000 TCE	2,830	3,589	5,612	9,872	16,803	19,007
Crop Non-Carbon	1000 TCE	1,503	1,544	1,989	3,203	5,772	6,084
GHGE Mitigation							
CO2	MMTCO2	182	274	478	818	1,405	1,437
CH4	MMTCH4	0.37	0.48	0.78	1.64	3.36	3.70
N2O	MMTN2O	0.03	0.03	0.04	0.06	0.10	0.11
CE	MMTCE	54	80	138	237	411	423
Market Effects							
Production	Fisher Index	99.8	99.5	96.9	89.3	67.8	65.6
Prices	Fisher Index	100.6	101.3	106.2	122.1	237.2	270.6
Net Exports	Fisher Index	99.2	98.4	91.2	67.5	23.8	21.5
Farmers' Welfare	Billion $	0.58	1.21	4.32	11.9	56.99	70.85
Ag-Sector Welfare	Billion $	-0.22	-0.51	-1.42	-5.88	-32.23	-37.45
Other Externalities							
Nitrogen pollution	% Change	-2.05	-1.45	-2.19	-13.53	-39.73	-42.04
Phosphorous pollution	% Change	-33.79	-44.27	-53.00	-57.10	-69.14	-70.11
Erosion	% Change	-23.37	-34.51	-44.98	-52.69	-67.20	-68.17

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[1] All table results reflect simulations without discounting.