THE EFFECT OF TRANSACTION COSTS ON GREENHOUSE GAS EMISSION MITIGATION FOR AGRICULTURE AND FORESTRY

A Dissertation

by

SEONG WOO KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHIOSOPHY

May 2011

Major Subject: Agricultural Economics

The Effect of Transaction Costs on Greenhouse Gas Emission

Mitigation for Agriculture and Forestry

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Approved by:

Chair of Committee,	Bruce A. McCarl
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ABSTRACT

The Effect of Transaction Costs on Greenhouse Gas Emission

Mitigation for Agriculture and Forestry. (May 2011)

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Climate change and its mitigation is rapidly becoming an item of social concern. Climate change mitigation involves reduction of atmospheric greenhouse gas concentrations through emissions reduction and or sequestration enhancement (collectively called offsets). Many have asked how agriculture and forestry can participate in mitigation efforts. Given that over 80 percent of greenhouse gas emissions arise from the energy sector, the role of agriculture and forestry depends critically on the costs of the offsets they can achieve in comparison with offset costs elsewhere in the economy. A number of researchers have examined the relative offset costs but have generally looked only at producer level costs. However there are also costs incurred when implementing, selling and conveying offset credits to a buyer. Also when commodities are involved like bioenergy feedstocks, the costs of readying these for use in implementing an offset strategy need to be reflected. This generally involves the broadly defined category of transaction costs. This dissertation examines the possible effects of transactions costs and storage costs for bioenergy commodities and how they affect the agriculture and forestry portfolio of mitigation strategies across a range of carbon dioxide equivalent prices. The model is used to simulate the effects with and without transactions and storage costs. Using an agriculture and forestry sector model called FASOMGHG, the dissertation finds that consideration of transactions and storage costs reduces the agricultural contribution total mitigation and changes the desirable portfolio of alternatives. In terms of the portfolio, transactions costs inclusion diminishes the desirability of soil sequestration and forest management while increasing the bioenergy and afforestation role. Storage costs diminish the bioenergy role and favor forest and sequestration items. The results of this study illustrate that transactions and storage costs are important considerations in policy and market design when addressing the reduction of greenhouse gas concentrations in climate change related decision making.

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CHAPTER I

INTRODUCTION

Climate change and the social reaction to it has become a widely discussed issue. The IPCC (Intergovernmental Panel on Climate Change) asserts that climate change effects are likely inevitable, may be irreversible and that resultant damages are uncertain (IPCC, 2007a). Furthermore they and the number of other scientific groups recommend that mitigative actions be taken to reduce GHG (Greenhouse Gas) emissions (IPCC, 2007b; National Academy of Sciences, 2010).

Mitigation of GHG emissions has become a widely discussed policy alternative. In 1992, 165 signed the UNFCCC (United Nations Framework Convention on Climate Change), which is an organization aimed at achieving long-term stabilization of GHG concentrations in atmosphere. In particular, the UNFCCC seeks to stabilize atmospheric concentrations at a level that would protect from dangerous human interference with the climate in 1992 (United Nations, 1992).

Many researchers have examined ways to achieve such stabilization (see for example the work by the Energy Modeling Forum and the review in IPCC 2007b). As part of this total effort a number of researchers have examined the potential participation in GHG mitigation by agriculture and forestry.

This dissertation follows the style of *American Journal of Agricultural Economics*.

Given that over 80 percent of the emissions arises from the energy sector EPA (Environmental Protection Agency) the role of agriculture and forestry depends critically on the costs of the emission reductions they generate in comparison with costs of generating emission reductions elsewhere in the economy. Consequently a number of researchers in examining agriculture and forestry participation in GHG emission reductions economic contributions have looked at the relative costs of potential strategies. However in looking at this most analysts have looked only at the producer level costs. But producer level costs are only part of the story as there are costs incurred when implementing, selling and conveying offset credits to a buyer like a power plant needing GHG offsets. In particular, the offsets still need to be conveyed to the buyer and where commodities are involved, the costs of readying these for use in implementing the emission offset strategy need to be reflected. This generally involves the broadly defined category of transactions costs. Hahn and Hester (1989) indicate that the magnitude of transaction costs will have important consequences not only for the size and efficiency of markets, but also for their overall structure. Furthermore Stavins (1995a) and Atkinson at el. (1991) review cases where high transactions costs have caused strategies to not be implemented. This dissertation investigates the role of transactions and storage costs as they affect the potential cost of agriculturally based GHG mitigation options.

Objective

This dissertation examines the possible effects of transactions costs and storage costs for bioenergy commodities and how they affect the agriculture and forestry portfolio of desirable on GHG mitigation strategies given a carbon dioxide equivalent price. In particular, this work will look at two items; 1) the effects of transactions costs in general and those that vary by GHG mitigation strategy, 2) the effects of storage costs and losses for bioenergy commodities. In doing this analysis, we consider the impact that factoring in transaction and storage costs/storage losses have on the optimal portfolio of GHG emissions and the total volume of the emission offsets it can be generated at any given carbon dioxide equivalent price.

Plan of Dissertation

The dissertation is organized as follows. Chapter I provides the introduction. Chapter II discusses the background for agricultural and forest reconsideration in emission reductions including carbon sequestration and introduces the conceptual framework for consideration of transaction costs. Chapter III considers transactions costs empirically as they influence the economic portfolio of agricultural and forest tree GHG emission reductions. Chapter IV reviews the literature on possible storage costs and examines the empirical effects of including storage costs by considering dry matter losses with indoor or outdoor forms of storage. Chapter V summarizes the overall dissertation findings and draws conclusions and implications plus also discusses limitations and recommends further research directions.

CHAPTER II

ECONOMICS OF TRANSACTIONS COSTS

Introduction

Transaction costs were first defined to discuss possible forms of organization by Coase (1937). In the context of institution, transaction costs are the costs of running the economic system (Arrow, 1969) or an expense of organizing and participating in a market and in a government policy (Gorden, 1994). Coase (1960) also introduced the concept of transaction cost in an environmental context. Falconer (2000) defines transaction costs in an agricultural context as expenditure for assistance from agricultural or conservation consultants, mapping, and telephone calls related to costs of participating in a market and labor expenses for information search. In this study, transactions costs are defined as costs to a firm incurred in making an economic exchange. When products are bought in the market, only the market price of the product is paid, however, there can be additional costs that are incurred to conduct the transaction and receive the product.

Transaction costs may be divided into three general categories, search and information costs, bargaining and decision costs, and policy and enforcement costs. Many studies have discussed these types of transaction costs. Specifically, Rasmusen (2001) details transaction costs as taxes, registry fees, brokers' fees, costs for monitoring, reporting and third party verification, legal fees, and fees imposed by government regulation. Griffin (1991) points out that information generating costs are incurred even when there are no transactions. Monitoring and enforcement costs can also be significant, but these costs are typically borne by the responsible governmental authority rather than trading partners (Stavins, 1995b). Michaelowa (2002, 2005) define the transaction cost of GHG projects under the KP (Kyoto Protocol) at three different stages:

- Pre-project implementation costs -- search costs, negotiation costs, baseline determination costs, approval costs, validation costs, review costs, and registration costs
- Pre-project implementation -- monitoring costs, verification costs, review costs, certification, and enforcement costs.
- Trading cost -- transfer costs and registration costs.

Typically, transaction costs are negligible. However, there are two circumstances in which transaction costs might be relatively high and need to be considered: when transfer is expensive because of technological reasons; and, when institutions are designed to impede trade (Stavins, 1995a). High transaction costs of in EPA's Emissions Trading Program are a good example. In this case, transaction costs are high because of environmentalists' intended effect of making it difficult to trade (Hahn, 1989). Under such conditions, transaction costs should be measured and taken into consideration by decision makers, especially for policy-making purposes. Fang et al. (2005) emphasizes the importance of including public sector costs in assessing policy options. McCann and Easter (2000) analyzed the public sector transaction costs of no-point source pollution abatement in agriculture. Agricultural programs have traditionally exhibited substantial transactions costs.

The objective of this chapter is to review how transaction costs have been estimated or measured in previous studies and provide an economic discussion of transaction costs of GHG emission reductions in agriculture.

Literature Review

If transaction costs are to be incorporated into policy evaluation, they need to be measured (McCann and Easter, 1999). Two methods are used to estimate transaction costs. For one method, Williamson (1993) suggests that researchers may be able to measure a lower bound of transaction costs indirectly. For the other method, transaction cost can also be estimated based on the difference between the supply and demand curves (Hearne and Easter, 1995; Archibald and Renwick, 1998).

Few empirical studies have examined transaction costs by using econometric techniques. Stavins (1993) considered three reasonable functional forms – constant, increasing, and decreasing marginal transaction costs. The existence of transaction cost implies that the performance of a tradable GHG permit system will depart, possibly substantially, from the least-cost ideal. Akinson and Tientenber (1991) examined cases where the transaction costs caused market participation to be substantially lower than was expected.

Measurement and estimation of transaction costs are different depending on different research contexts. Table 1 lists how transaction costs are measured or estimated in previous studies. A discussion of the methods follows.

For GHG ETS (Emission Trading Scheme), few studies that report the marginal cost of producing GHG offsets have taken account of transaction costs. For example, Jaraite et al. (2009) report an average regulatory cost of participation in the first phase of the EU ETS is about $223,000 per entity with about $75,000 for small emitters, $156,000 for medium emitters, and $821,000 for large emitters. In per tone of CO2 emissions terms, the average regulatory cost is $0.12 per tone of CO2 with $3.08 for small emitters, $1.33 for medium emitters and $0.08 for large emitters. The reported costs include early implementation costs (setup costs, including time and staff commitment, consultancy costs, and some capital costs, mainly for metering equipment), monitoring, reporting and verification costs (staff costs, consulting costs, auditing costs) and costs of trading (costs of transacting).

In an agri-environmental context, Falconer (2000), Falconer and Sounders (2002), and McCann et al. (2005) estimate the magnitudes of regulatory cost by doing empirical analysis. Falconer (2000) estimates overall regulatory costs that are related to the certification and auditing of organic farming in some EU countries range between $118 and $155 per hectare. Falconer and Sounders (2002) examined the cost of contract negotiation and transactions of conservation payments for agricultural land in England with estimates between $950 and $3,470 per hectare. Although these estimates are not a

Table 1 Methods of Measurements of Transaction Costs Reported

Article	Data Source	Sample Size	Definition of Transaction Costs	Project Type	Estimates
Coase(1960), Williamson(1985), Oates(1986), North(1990), Stavins(1995b)			Number and Diversity of Agents, Technology, Policy under Consideration, Level of Uncertainty, Asset Specificity, Institutional Environment, Amount of Abatement, Size of the Transaction		
Laura McCanns(2000)	Surveys by NRCS	1,446	Research and Information, Enactment, Design and Implementation, Support and Administration, Prosecution, Monitoring	Resource Conservation	38% of total conservation cost ($12.52 /Acre)
Fichtner et al.(2003)	AIJ	64	Technical Assistance, Follow-up, Administration, Reporting	32 Energy efficiency, 27 renewable energy, 3 forestry, 1 afforestation, 1 agriculture	$0.05~261 per tCO2
Mooney(2003)	Empirical & Estimated Costs by LLC	3,146	Measuring and Monitoring	Forestry	3% to 10.6% of the value of a C-Credit
Michaelowa et al. (2002)	Swedish AIJ	51	Normalized Technical Assistance and Administration	RE, EE, Mix	$0.16~15.5 per tCO2*
Michaelowa and Jotzo `(2005)	PCF	4	Pre-implementation, Implementation(first 2years) and Certification	Agriculture, Electricity	$0.02~0.09 per tCO2*
Antinori and Sathaye(2006)	Surveys using LBNL spreadsheet	41	Search, Negotiation, Feasibility, Monitoring and Verification, Regulatory Approval	Forestry, fuel switching, fuel capture, renewable, energy efficiency	$0.03~4.46 per tCO2
Galik et al.(2009)	Calhoun Experimental Forest Data	17,172	Design, Implement, Monitor an Offset Project, Measuring Verifying, Registering	1 Energy(1605(b)) 4 Forestry(GFC, CCX, CAR, VCS)	$10.23 per mtCO2e
English et. al(2009)	Carbon Prices by EPA		Quantification and Verification, Probability of Leakage, Probability of Natural Event, Verification and Documentation, Aggregation, Documentation and Monitoring	Change in tillage practice, Afforestation, Planting herbaceous energy crops, Methane capture	40% 30% 20% 20%

* Assuming a Swedish krona exchange rate of 8 krona per US dollar.

direct indicator of the regulatory cost involved in the GHG ETS, they provide some senses of the likely cost of regulation that may be expected in the agricultural sector.

Beyond regulatory costs, trading costs, such as cost of listing, brokerage, and transaction settlement, can also be significant. According to ECX (2009), the cost of trading for small and medium emitters is about $0.038 per allowances in the EU ETS Alston and Hurd (1990) estimate that transaction costs of administering the farm program ranged from 25 to 50 cents for each dollar distributed. McCann and Easter (2000) find that the magnitude of transaction costs is about 38 percent of total costs or over 50 percent of direct payments for conservation efforts. Fitchtner et al. (2003) find the mean share of total project transaction costs is 13 percent for energy efficiency projects and about 20 percent for renewable energy projects. Michaelowa (2002, 2005) reports the total transaction cost of a large project reaches 0.4 ~ 0.9$/t CO2 and 0.5~1.4$/t CO2 for a small project with around 14 percent spent on transaction costs and a further 14 percent on taxes in their standard research scenario.

In some cases, transaction costs vary due to the type of project. Antinori and Sathaye (2006) estimate how transaction costs change due to different types of project by considering projects in energy efficiency, forestry, renewable energy, fuel switching, and landfill gas based on project type, market maturity, and location. They found that the total transaction costs were significantly lower for forestry projects and mature markets and higher for projects in South America. Transaction costs, in their study, ranged from $0.03 per tonne of carbon dioxide for large projects to $4.05 per tonne of carbon dioxide for smaller ones, with a weighted average $0.26 per tonne of carbon dioxide for all projects. The finding of economies of scale suggests that small projects have cost barriers to overcome. Galik et el. (2009) analyze a hypothetical forest management GHG offset project. They consider high and low values for key transaction cost parameters with project sizes of 100, 1000, or 10,000 hectares. They found that the average transaction costs are much lower in larger projects with a mean transaction cost of $10.23 per metric ton CO2e. This was because certain fixed costs remain constant, while variable costs decrease per unit area for larger projects (Mooney et al. 2004). Because of the high transaction cost and low absolute volumes of sequestered carbon, it is unlikely that small landowners will participate in a carbon market directly.

McCann (1997) analyzed Natural Resource Conservation Service cost share and technical assistance data and found that transaction costs represented 38 percent of the total conservation cost. Wallis and North (1986) estimated the transaction cost “sector” for the U.S. and found that transaction costs in public and private sector amounted to about ¼ to ½ of GNP. English et al. (2009) estimate the GHG offsets transaction costs discounts of the activities of agricultural and forestry to EPA’s carbon prices: 40 percent from tillage practices, 30 percent from afforestation, 20 percent from methane capture, and 20 percent from production of bioenergy crops.

Mooney et al. (2003) conclude that:

• Efficiency of a project depends on the price of C credits

• Transaction costs are the largest in areas with greatest heterogeneity, and

• Transaction costs are less than 3 percent of the value of a C-credit in their case study.

Transaction costs have number of components that are discussed below (expanding upon McCarl, 2003, lecture notes).

Assembly Costs

Emitting entities such as power or petroleum company would likely need large quantities of offsets (with for example emissions of large power conglomerates in the 100s of millions of tons) compared to what a farmer could produce. It is not economically efficient for an offset purchaser in quest of 100,000 tons to deal with a single farmer. An offset of 100,000 tons at an average sequestration rate of 0.25 tons per acre (as found in West and Post) would require 400,000 acres. Considering a rough average farm size of 400 acres (the average of U.S. farm was 418 acres in 2007), this offset would involve 1,000 farmers. Thus, there would be a role for intermediaries (brokers or aggregators) in the market who would aggregate emission offsets generated by agricultural producers into a large enough groups to stimulate power plant interests and in turn sell permits. Costs arise in such a process.

Assembly costs include not only initial assembly but in the longer run any costs incurred in keeping the group of farmers together and dispersing payments. This element of transactions cost is potentially very expensive and also may depend on the implementation regime. For example, governments might aggregate group of farmers and in turn sell offset permits. Crop insurance is such a scheme and there transactions costs are about 25 percent for brokers.

Measurement and Monitoring

Conveyance will also require measurement and monitoring to establish that offsets are being produced and continue to be produced. This requires the development of a low cost measurement and monitoring approach that involves a sampling based scheme integrating field level measurement, computer simulation, and remote sensing on some dynamic and geographically appropriate basis.

Certification

Certain bodies may develop and certify offset quantity estimates for practices and then monitor that the practice continues. For example a government rating could be established that indicates the number of offset credit from a tillage change under a set of circumstances. Costs of obtaining such a certification as borne either by private parties or by the government would be transaction cost components.

Enforcement

Contact enforcement may require hearings and the setup of an enforcement entity. Enforcement problems may arise between traders or within an assembly group. Some estimate is needed of costs that will be encountered for the enforcement of permit contractual obligations.

Additional Adoption Cost Incentives

Cost may well be encountered involving education and training of agricultural producers on how to alter their practices so that they produce emission offsets most efficiently. These costs need to be estimated in a way so that one does not double count the producer adoption benefits.

Procedures for and Cost of Risk/Liability for Adverse Outcomes

Certain classes of offsets are volatile and subject to uncertainty including possible destruction by extreme whether events, fires, floods, etc. Contracts may include procedures to insure against certain types of adverse outcomes. These procedures may involve contract enforcement mechanisms, insurance, or some sort of planned safely margin where more offsets are produced than are sold enabling slack for unanticipated shortfalls.

Transaction Costs in GHG Emission Reductions

Transaction costs can affect the potential GHG emissions offsets from agricultural sector. It follows that the decision of whether or not to mandate agriculture in the ETS would crucially depend on whether the transaction cost plus production cost of GHG emission reductions in the sector are relatively high or relatively low compared to other sectors in the ETS. Examining this issue is not an easy task. Over the last ten years or so, a number of studies have estimated ‘abatement cost curves’ for GHG emission reductions in agriculture (Hyman et al. 2002, McCarl and Schneider 2000; Moran et al.

2008; Beach et al. 2008; McKinsey & Company 2009). All of these studies have a common feature, that is, they consider abatement costs across regions and activities without considering transaction costs.

Another common feature is that they estimate the marginal abatement cost curve with a steeper slop when the reduction of GHG emissions from the agricultural sector goes 20 percent beyond current emission levels (Hyman et al. 2002). Studies indicate that 5 to 25 percent of agricultural emission reductions, depending on agricultural activities and regions, could be achieved with a net benefit to farmers who undertake abatement. Benefits to farmers could range from a few US dollars, up to several hundred US dollars per ton of CO2 equivalent (McCarl and Schneider 2000; Beach et al. 2008; Moran et al. 2008; McKinsey & Company 2009). This suggests that farmers could earn money from GHG offset production by using technologies, such as low crude protein diets, improved land and soil management, reduced nitrogen fertilizer application, and aerobic manure management techniques that reduce GHG emissions.

Economic Consideration for Transaction Costs

McCann et al. (2005) argue that transaction costs have been considered similar to waste and as something to be minimized in the past. “These costs are not ‘money down a rathole but are expended in exchange for transactions services (Randall, 1981)”. Nevertheless, different types and magnitudes of transaction costs could be efficient or inefficient, just as efficient or inefficient allocations of inputs can occur in a production process.

Transaction costs are not usually considered in empirical evaluations of alternative environmental or natural resource policies, however, they are recognized in some theoretical work (Stavins, 1995a; Fullerton, 2001). This lack of consideration is partly because transaction costs are difficult to define and measure in the real world. This does not mean that transaction costs should be ignored however. In fact, policy makers should make a point of taking into account transaction costs (including administrative costs) when making public policy decisions.

An economic analysis of transaction costs can be employed to investigate the effects on the competitiveness of individual mitigation strategies. This analysis could be undertaken from a perspective of a benevolent regulator (a government agency) who aims to achieve a GHG emission reductions target at a minimum cost to the economy. Suppose a carbon price arises through some political or market process within the society, and it is assumed to be exogenous. The cost of reducing GHG emissions pertaining to the regulated entities or sectors has three components: the actual cost of abatement, the cost of regulation including administration, monitoring, verification, enforcement, and the trading costs (Ancev, 2011).

For an individual GHG emitter, emissions may reduce to match an initial allocation of allowances and thus generate extra allowances that could be sold in the market. On the other hand, emissions may not be reduced at all, thus creating an allowance deficit that requires the purchase of allowances in the market. Those emitters who find it relatively less costly to reduce emissions would likely to do so and create an allowance surplus. Those emitters who find it relatively more costly to reduce emissions would therefore buy these surplus allowances. In the case of GHG ETS and especially in the case of relatively small emitters that buy or sell small quantities of emission allowances, these transaction costs could be quiet substantial relative to the total value of the trade in allowances (Betz et al. 2010).

Graphical Analysis

If the agricultural sector can achieve a significant reduction of its GHG emissions with transaction costs relatively lower compared to other sectors in an ETS, then transaction costs have a potential to create significant benefits to the agricultural sector when the cost of meeting a cap on GHG emissions has been imposed by an ETS.

If an economic sector is able to reduce emissions at a relatively low transaction costs plus any GHG offset production costs, the sector could reduce emissions to levels below those specified by the initial emission allowances allocated to the sector. Therefore, a surplus of allowances would be created that could be offered to the market at comparably low transaction costs.

However, if some other economic sector has to incur a relatively high transaction costs in addition to any GHG offset production costs firms seeking to reduce emissions will look at possibilities to purchase additional emission allowances at a lower total cost, rather than to reduce emissions on their own. This will create an excess demand for emission allowances in the ETS and will result with higher prices for allowances, thereby inflating the overall cost of meeting the cap imposed by the ETS. Figure 1 shows the relationships of sectors with low marginal abatement costs and high marginal abatement costs. The supply curve of low marginal abatement costs is S_1 and the supply curve of high marginal abatement costs is S_2. The supply and demand for emission reductions in the market are S and D, respectively. The demand curve is buyer's demand for GHG emission reductions offsets. Agricultural producers and others who have excess emission reductions to sell as GHG offsets are depicted by the supply curve. A buyer and a seller would trade the emission reductions at a price P and a quantity Q in the market, market equilibrium. Also the firm of low transaction costs has emission reductions at q_1 and the firm of high transaction costs has emission reductions at q_2. If transaction costs are incurred, the supply curve, S_1, of the firm of low transaction costs shift to right to S_1* and the supply curve, S_2, of the firm of high transaction costs shift to the left to S_2*. Thus, the total supply curve, S, would shift to the left to S* decreasing the reduction of emissions. In the overall market, the price of emission reductions would

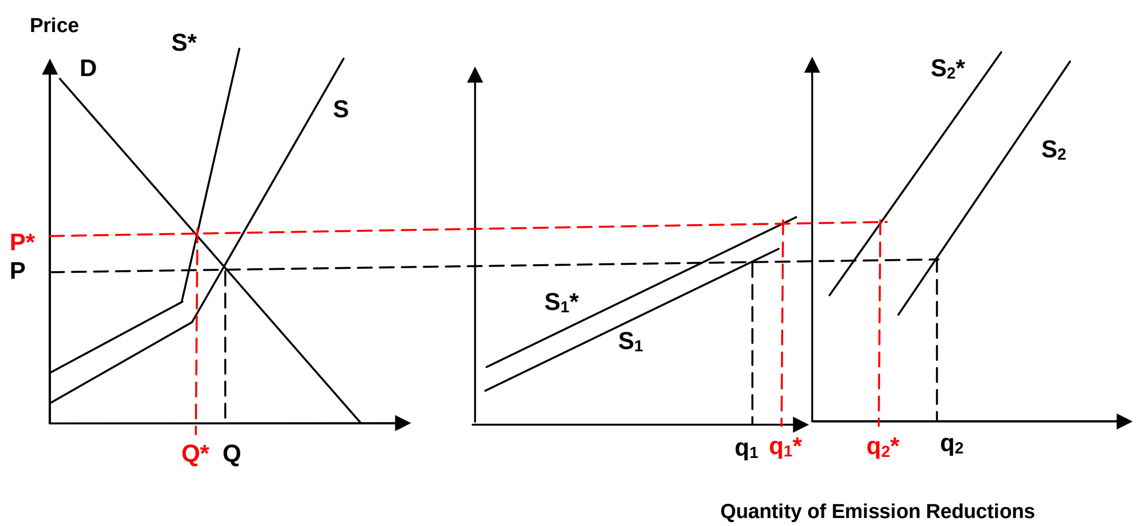

Figure 1 Effect of Transaction Costs on the Market for Emission Reductions

increase from P to P* and the quantity of emission reductions would decrease from Q to Q*. Therefore, the effect of transaction costs is P* - P** which is the seller can have a new price P** and the buyer can pay a new price P*.

CHAPTER III

ECONOMIC POTENTIAL OF GHG EMISSION REDUCTIONS: EFFECTS OF INCLUDING TRANSACTION COSTS IN ELIGIBILITY

Introduction

The assembling of a group of farmers to sell carbon offsets to an emitting entity usually involves searching and negotiating activities as well as compliance processes such as monitoring and certification of GHG offsets. Transaction costs would thus be incurred. These transaction costs have been identified as one of the greatest hurdles for tradable permit systems (Hahn and Hester, 1989). Their magnitude can have important consequences for the size and efficiency of, not only, the GHG offset market, but other markets as well. Agricultural programs have traditionally exhibited substantial transaction costs as referenced above (Alston and Hurd, 1990; McCann and Easter, 2000).

In fact, higher prices whether resulting from sizable transaction costs or not have consequences for many sectors of the economy through increased production costs and intermediate product prices (Schneider and McCarl, 2005). For U.S. agriculture, higher fossil energy prices could raise farmers' spending on diesel and other fossil fuels, irrigation water, farm chemicals, and grain drying. Meanwhile, higher fossil fuel prices can make biofuels a more attractive alternative for fossil fuels and thus likely encourage biofuel feedstock production. Schneider and McCarl (2005) examined both sides of this issue estimating the economic and environmental consequences of a carbon tax inducing higher energy prices on United States agriculture. To do this they employed a price endogenous agricultural sector model and solved that model over a range of carbon tax scenarios.

Agriculture has been considered as an industrial sector that can provide low-cost options for carbon sequestration to produce GHG offsets. However, to get access to large volumes of carbon credits produced by the agricultural sector, differential transaction costs may be encountered. How transaction costs influence the GHG emission reductions alternatives in agriculture is an important question. The answer has implications for farmers' carbon income and the role that agriculture can play in GHG sequestration. This chapter aims to examine the impacts of transaction costs through adjusted carbon dioxide equivalent prices on the portfolio of agriculture activities in an emission reductions program. Scenarios were developed for both full eligibility and limited eligibility, where eligibility relates to which GHG emission reductions and sequestration options is legitimate to provide carbon credits. The current science of carbon sequestration suggests that not all practices should be eligible for carbon payments. The limited eligibility scenarios include only GHG offsets that can be delivered with certainty only (Daigneault et al., 2009).

Methodology and Assumptions

A 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 allocated to biofuels and forests. Following McCarl and Schneider (2001), an agriculture sector model that takes feedback effects into account was used for this study. The marginal GHG abatement cost curve describing the volume of GHG emission offsets deliver at different farmer-received carbon prices (i.e. market prices less brokerage fees and other transactions costs) was derived using this agricultural sector model. This study assumes that carbon sequestered will not be released back into the atmosphere. A wide spectrum of U.S. based agricultural responses to a net greenhouse gas mitigation effort is included in the analysis. In particular, the role of agricultural sequestration efforts in the total portfolio of potential agricultural responses was examined at alternative carbon price levels.

The Forest and Agriculture Sector Optimization Model with Greenhouse Gases, FASOMGHG (Adams et al., 1996), [1] was used to simulate agricultural sector response to different carbon prices.

FASOMGHG mitigation estimates will generally not be as high as estimates found in the Richards and Stokes (2004) study, because FASOMGHG employs economic

[1] FASOMGHG is a partial equilibrium economic model of the U.S. forest and agriculture sectors, with land use competition between them, and linkages to international trade. FASOMGHG includes most major GHG mitigation options in U.S. forestry and agriculture; accounts for changes in CO2, CH4, and N2O from most activities; and tracks carbon sequestration and carbon losses over time. It also projects a dynamic baseline and reports all additional GHG mitigation as changes from that baseline. FASOMGHG tracks five forest product categories and over 2,000 production possibilities for field crops, livestock, and biofuels for private lands in the conterminous United States broken into 11 regions and 63 subregions. Public lands are not included. FASOMGHG evaluates the joint economic and biophysical effects of a range of GHG mitigation scenarios, under which costs, mitigation levels, eligible activities, and GHG coverage may vary (US EPA, 2005).

feedback effects (e.g., timber and agricultural price effects) that will temper sequestration responses, in contrast to studies that estimate mitigation cost functions without market feedback effects (US EPA, 2005).

The basic approach of sector modeling used for comparing the relative desirability of alternative mitigation strategies involves estimation of the amount of GHG net emission reductions supplied in the U.S. agriculture and forestry sectors and the choice of strategies under alternative carbon prices. Daigneault et al. (2009) introduced the concept of full eligibility and limited eligibility for GHG emission reductions strategies in the agricultural and forestry sectors, as detailed in Table 2 and Table 3. Typically, N2O is not included in the full eligibility for agricultural GHG mitigation response.

The agricultural and forestry responses to GHG mitigation considered by this study are detailed below.

Afforestation and Timberland Management

Forest based carbon sequestration can be stimulated by afforestation of agricultural lands, increasing rotation length, or changing management intensity through improved silvicultural practices. The underlying data reflect regionally specific conversion of crop and pasture lands to and from trees as well as rotation and management changes.

Table 2 GHG Mitigation Strategies Full Eligibility Included in Analysis

Sector/Strategy	Basic Nature	CO_2	CH_4	N_2O
Forestry				
Afforestation	Sequestration	X		
Reforestation	Sequestration	X		
Harvested Wood Products	Sequestration	X		
Agriculture				
Manure Management	Emission		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, Sequestration			X
Grassland Conversion	Sequestration	X		
Irrigated /Dry land Mix	Emission	X		X
Rice Acreage	Emission	X	X	X
Enteric fermentation	Emission		X	
Livestock Herd Size	Emission		X	X
Livestock System Change	Emission		X	X
Biofuels				
Conventional Ethanol	Fossil Fuel Substitution	X	X	X
Cellulosic Ethanol	Fossil Fuel Substitution	X	X	X
Biodiesel	Fossil Fuel Substitution	X	X	X
Bioelectricity	Fossil Fuel Substitution	X	X	X

Source: Daigneault et al., “Implications of Offset Eligibility Provisions on GHG Mitigation for U.S. Forestry and Agriculture Carbon Sinks”, 2009.

Biofuel Production

Offsets of GHG emission from fossil fuel usage were examined by considering substitution of biofuels for fossil fuels. In particular, the model allows for poplar, switchgrass, and willow, crop residues and forest industry byproducts and waste to fuel electrical power plants and cellulostic ethanol plants, grains for conversion into ethanol and corn oil, soybean oil, waste cooking oil, and animal fats to make biodiesel. The emission savings were computed on a BTU basis assuming biomass substitution for coal in power plants and ethanol substitution for gasoline. In estimating emission offsets the

Table 3 GHG Mitigation Strategies Limited Eligibility Included in Analysis

Sector/Strategy	Basic Nature	CO_2	CH_4	N_2O
Forestry				
Afforestation	Sequestration	X		
Reforestation	Sequestration			
Harvested Wood Products	Sequestration			
Agriculture				
Manure Management	Emission		X	X
Crop Mix Alteration	Emission, Sequestration	X		
Crop Fertilization Alteration	Emission, Sequestration	X		
Crop Input Alteration	Emission	X		
Crop Tillage Alteration	Emission, Sequestration			
Grassland Conversion	Sequestration			
Irrigated /Dry land Mix	Emission	X		
Rice Acreage	Emission	X		
Enteric fermentation	Emission			
Livestock Herd Size	Emission			
Livestock System Change	Emission			
Biofuels				
Conventional Ethanol	Fossil Fuel Substitution	X	X	X
Cellulosic Ethanol	Fossil Fuel Substitution	X	X	X
Biodiesel	Fossil Fuel Substitution	X	X	X
Bioelectricity	Fossil Fuel Substitution	X	X	X

Source: Daigneault et al., "Implications of Offset Eligibility Provisions on GHG Mitigation for U.S. Forestry and Agriculture Carbon Sinks", 2009.

emissions accounting was the savings from not using traditional fossil fuels less the emissions from the energy involved in raising, hauling and processing the biofuels.

Crop Fertilization Alteration

Nitrous oxide emissions are a byproduct of nitrogen fertilization. In turn, nitrogen fertilization also influences carbon sequestration rates. The IPCC good practice inventory guidelines were used to estimate nitrous oxide emissions per unit fertilizer applied. These formulas basically had about 1.25 percent of applied nitrogen being released as nitrous oxide.

Crop Input Substitution

A number of the inputs used in crop production are fossil fuel based or embody substantial GHG emissions in their manufacture. Carbon content estimates including upstream manufacturing carbon emissions were incorporated in the analysis for diesel, gasoline, natural gas, electricity, and fertilizers using the IPCC good practice guidelines. Thus, changes in crop mix, crop management, livestock numbers, etc. alter input use and resultant emissions patterns.

Crop Mix Alteration

Not all crops emit GHGs equally because of differences in fertilizer applied, tillage practices, chemical inputs, harvest requirements, irrigation intensities, and post harvest processing among other factors. The carbon dioxide, nitrous oxide, and methane emissions are affected by crop mix choices.

Crop Tillage Alteration

Energy intensity and soil carbon content are sensitive to choice of tillage method. Emission estimates for soil carbon increments were derived from a 63 region, 10 crops, and 5 soil type crop simulation study using the EPIC (Erosion Productivity Impact Calculator) crop growth simulator (Williams et al., 1989). The carbon sequestration rates pertaining to tillage changes were average results for the first 70 years of EPIC results (2000-2070) from treating all U.S. croplands for sequestration. Estimates were also developed on emissions from fossil fuels used in the alternative tillage systems as well as applying an altered mix of chemical inputs based on USDA Natural Resource Conservation Service production budgets.

Grassland Conversion

Reversion of cropland back to grassland is another mitigation strategy considered. Such a reversion generally increases soil carbon and, in addition, affects nitrous oxide emissions by displacing fertilizer used in crop production.

Irrigated / Dry Land Conversion

Changes in the allocation of land between irrigated and dry land usages affect soil carbon, nitrous oxide emissions, and fossil fuel use needed for water delivery and other crop production requirements.

Livestock Management

Methane emissions per animal may be influenced by giving growth hormones to animals or by increasing the use of grain relative to forage in feeding. Growth hormone based alternatives were incorporated based on EPA data.

Livestock Herd Size Alteration

Livestock produce methane and nitrous oxide generally as a function of the total size of the livestock herd through manure and ruminant enteric fermentation. Thus a simple mitigation alternative is to cut the size of the total herd.

Livestock Production System Substitution

Mitigation may be pursued through the substitution of livestock production systems for one another. In the case of beef cattle, slaughter animals can be produced using either grazing or feedlot operations. The relative GHG emission rate varies across these alternatives, i.e., feedlot production has lower per animal emissions.

Manure Management

Manure is a source of methane and nitrous oxide. The manure handling system can influence emissions. For example methane emissions are greater the more water is involved in the system, however, methane recovery systems could be employed to harvest this additional methane.

Rice Acreage

Decomposition of plant material in flooded rice fields leads to methane emissions. While alternative management systems may affect the amount of methane released, no consistent data are currently available. Thus, the only rice related mitigation alternative examined here involves reductions in acreage.

Table 4 Lists of All Greenhouse Gas Model Accounts

GHG Type	Context
Forest_SoilSequest	Carbon in forest soil
Forest_LitterUnder	Carbon in litter and understory of forests that remain forests
Forest_ContinueTree	Carbon in trees of forests that remain forests
Forest_AfforestSoilSequest	Carbon in forest soil of afforested forests
Forest_AfforestLitterUnder	Carbon in litter and understory of afforested forests
Forest_AfforestTree	Carbon in trees of afforested forests
Forest_USpvtProduct	Carbon from US private forests consumed producing forest products
Forest_USpubProduct	Carbon from US public forests consumed producing forest products
Forest_CANProduct	Carbon in US consumed but Canadian produced forest products
Forest_USExport	Carbon in US produced but exported forest products
Forest_USImport	Carbon in US consumed but imported from non-Canadian source
Forest_USFuelWood	Carbon in US consumed fuel wood
Forest_USFuelResidue	Carbon in US residue that is burned
Forest_USresidProduct	Carbon from US residues consumed producing forest products
Forest_CANresidProduct	Carbon from Canadian residues consumed producing forest products
Carbon_For_Fuel	Carbon emissions from forest use of fossil fuel
Dev_Land_from_Ag	Carbon on ag land after it moves into developed use
Dev_Land_from_Forest	Carbon on forest land after it moves into developed use
AgSoil_CropSequest_Initial	Carbon in cropped ag soil from initial tillage
AgSoil_CropSequest_TillChange	Carbon in cropped ag soil from tillage change
AgSoil_CropSequest_CropChange	Carbon gain from different crops
AgSoil_PastureSequest	Carbon in pasture land
Carbon_AgFuel	Carbon emissions from ag use of fossil fuel
Carbon_Dryg	Carbon emissions from grain drying
Carbon_Fert	Carbon emissions from fertilizer production
Carbon_Pest	Carbon emissions from pesticide production
Carbon_Irrg	Carbon emissions from water pumping
Carbon_Ethl_Offset	Carbon emission offset by conventional ethanol production
Carbon_Ethl_Haul	Carbon emissions in hauling for conventional ethanol production
Carbon_Ethl_Process	Carbon emissions in processing of conventional ethanol production
Carbon_CEth_Offset	Carbon emission offset by cellulosic ethanol production
Carbon_CEth_Haul	Carbon emissions in hauling for cellulosic ethanol production
Carbon_CEth_Process	Carbon emissions in processing of cellulosic ethanol production
Carbon_CEth_Residue_Offset	Carbon emission offset by cellulosic ethanol production from crop and log residues
Carbon_CEth_Residue_Haul	Carbon emissions in hauling for cellulosic ethanol production from crop and log residues
Carbon_CEth_Residue_Process	Carbon emissions in processing of cellulosic ethanol production from crop and log residues
Carbon_BioElec_Offset	Carbon emission offset from bioelecticity production

Table 4 Continued

GHG Type	Context
Carbon_BioElec_Haul	Carbon emissions in hauling for bioelecticity production
Carbon_BioElec_Process	Carbon emissions in processing of for bioelecticity production
Carbon_BioElec_Residue_Offset	Carbon emission offset from bioelecticity production from crop and log residues
Carbon_BioElec_Residue_Haul	Carbon emissions in hauling for bioelecticity production from crop and log residues
Carbon_BioElec_Residue_Process	Carbon emissions in processing of for bioelecticity production from crop and log residues
Carbon_Biodiesel_Offset	Carbon emission offset from Biodiesel production
Carbon_Biodiesel_Haul	Carbon emissions in hauling for Biodiesel production
Carbon_Biodiesel_Process	Carbon emissions in processing of Biodiesel production
Methane_Liquidmanagement	Methane from Emission savings from improved manure technologies
Methane_EntericFerment	Methane from Enteric Fermentation
Methane_Manure	Methane from Manure Management
Methane_RiceCult	Methane from Rice Cultivation
Methane_AgResid_Burn	Methane from Agricultural Residue Burning
Methane_BioElec	Methane emissions of biomass power plants below coal power plants
Methane_Biodiesel	Methane emissions from biodiesel production
Methane_Ethl	Methane emission savings from Corn ethanol processing
Methane_CEth	Methane emission savings from cellulosic ethanol processing
NitrousOxide_Manure	Livestock Manure Practices under Managed Soil Categories under Agriculture Soil-sequestration Management
NitrousOxide_BioElec	Nitrous oxide emissions of biomass power plants over coal power plants
NitrousOxide_Biodiesel	Nitrous Oxide emissions from biodiesel production
NitrousOxide_Ethl	Nitrous oxide emission savings from Corn ethanol processing
NitrousOxide_CEth	Nitrous oxide emissions from cellulosic ethanol processing
NitrousOxide_Cropland_Direct	N2O from N Fertilization Application and other direct under Managed Soil Categories under Agriculture Soil-sequestration Management
NitrousOxide_Cropland_Volat	N2O Emissions from Indirect soils volatilization
NitrousOxide_Cropland_Leach	N2O Emissions from Indirect soils Leaching Runoff
NitrousOxide_Cropland_Sludge	N2O Emissions from sewage slued used as crop fertilizer
NitrousOxide_Nfixing	Emissions from N fixing crops
NitrousOxide_CropResid	Emissions from Crop residue retention
NitrousOxide_Cropland_Histosoil	N2O Emissions from Temperate histosol area
NitrousOxide_Cropland_AgResid_Burn	N2O Emissions from Agricultural Residue Burning
NitrousOxide_Pasture_Direct	Nitrous oxide direct emissions from Pasture
NitrousOxide_Pasture_Volat	Nitrous oxide emissions from Pasture volatilization
NitrousOxide_Pasture_Leach	Nitrous oxide emissions from Pasture leaching

The transaction costs, reflected in the model as percentage reductions of the farmer-received carbon prices, were determined based on the expert opinion of members of the FASOMGHG development team after consulting various literatures on transaction costs in agricultural and forestry activities. As shown in Table 5, values of low (5%), medium (15%), high (35%), and very high (40%) are assigned to different agricultural and forestry GHG mitigation options. According to a major international trader of GHG offsets, a 15percent transaction cost would be reasonable in relationship to crop insurance having a 25 percent transaction cost. If measurement and monitoring (applies to tillage based soil carbon) are counted, another 5 percent in transaction costs might be added. Costs of some GHG strategies were lowered due to scale effects (e.g. 5 percent is assumed for the bioenergy option because of the large scale industrial processes involved). Some transaction costs were raised due to the extreme technical challenges in measuring and certifying emissions (N2O from fertilization for example).

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.

The 50 categories of GHG stocks and fluxes in agriculture and forestry listed above can be grouped into six major categories: afforestation, forest management, soil carbon sequestration, biomass, agricultural CH4 & N2O, and crop management fossil fuel. In the case of limited eligibility, only bioenergy, forest sequestration, manure handling, and fossil fuels would receive carbon payments. The limited eligibility was set based on communications with government officials.

Table 5 Assumptions of Transaction Costs Scenario of GHG Accounts

Transaction Costs Scenario	Low	Medium	High	Very high
	5%	15%	35%	40%
Forest_SoilSequest			x	
Forest_LitterUnder		x		
Forest_ContinueTree		x		
Forest_AfforestSoilSequest			x	
Forest_AfforestLitterUnder		x		
Forest_AfforestTree		x		
Forest_USpvtProduct			x	
Forest_USpubProduct			x	
Forest_USFuelWood			x	
Forest_USFuelResidue			x	
Forest_USresidProduct			x	
Carbon_For_Fuel	x			
Dev_Land_from_Ag				x
Dev_Land_from_Forest				x
AgSoil_CropSequest_Initial			x	
AgSoil_CropSequest_TillChange			x	
AgSoil_CropSequest_CropChange			x	
AgSoil_PastureSequest				x
Carbon_AgFuel	x			
Carbon_Dryg	x			
Carbon_Fert	x			
Carbon_Pest	x			
Carbon_Ethl_Offset	x			
Carbon_Irrg	x			
Carbon_Ethl_Haul	x			
Carbon_Ethl_Process	x			
Carbon_CEth_Offset	x			
Carbon_CEth_Haul	x			
Carbon_CEth_Process	x			
Carbon_CEth_Residue_Offset	x			
Carbon_CEth_Residue_Haul	x			
Carbon_CEth_Residue_Process	x			
Carbon_BioElec_Offset	x			
Carbon_BioElec_Haul	x			
Carbon_BioElec_Process	x			

Table 5 Continued

Transaction Costs Scenario	Low	Medium	High	Very high
	5%	15%	35%	40%
Carbon_BioElec_Residue_Offset	x			
Carbon_BioElec_Residue_Haul	x			
Carbon_BioElec_Residue_Process	x			
Carbon_Biodiesel_Offset	x			
Carbon_Biodiesel_Haul	x			
Carbon_Biodiesel_Process	x			
Methane_Liquidmanagement		x		
Methane_EntericFerment				x
Methane_Manure		x		
Methane_RiceCult		x		
Methane_AgResid_Burn				x
Methane_BioElec	x			
Methane_Biodiesel	x			
Methane_Ethl	x			
Methane_CEth	x			
NitrousOxide_Manure				x
NitrousOxide_BioElec	x			
NitrousOxide_Biodiesel	x			
NitrousOxide_Ethl	x			
NitrousOxide_CEth	x			
NitrousOxide_Cropland_Direct				x
NitrousOxide_Cropland_Volat				x
NitrousOxide_Cropland_Leach				x
NitrousOxide_Cropland_Sludge				x
NitrousOxide_Cropland_Histosoil		x		
NitrousOxide_Cropland_AgResid_Burn				x
NitrousOxide_Pasture_Direct				x
NitrousOxide_Pasture_Volat				x
NitrousOxide_Pasture_Leach				x

Table 6 Four Scenarios of Eligibility with Transaction Costs Scenarios

Scenario	Full Eligibility	Limited Eligibility
No Transaction costs	X	X
With Transaction costs	X	X

Table 6 summarizes the four big categories of scenarios defined by different combinations of eligibility and transaction costs. For each big category of scenarios, FASOMGHG was solved under carbon dioxide equivalent prices ranging from $0 to $500 per ton of carbon dioxide equivalent.

Results

FASOMGHG produced results of the four scenarios; full eligibility without transaction costs, full eligibility with transaction costs, limited eligibility without transaction costs, and limited eligibility with transaction costs. Table 7 shows the changes in the amount of carbon offsets relative to the base at carbon dioxide equivalent prices ranging from $0 to $500 for each of the scenarios of strategies.

The trends in the results of the two scenarios of full eligibility with and without transaction costs are similar. As the carbon dioxide equivalent prices increased, the amount of reductions in emissions also increases. When the per ton carbon dioxide equivalent price reaches $200, the agriculture CH4&N2O based emission reductions options turn positive relative to the base. Although the sign of the crop management fossil fuel stays negative, the magnitude reduces as carbon equivalent prices increase,

Table 7 GHG Offsets Relative to Base with Transaction Costs Scenarios

		Carbon Dioxide Equivalent Price in $/metric ton						
Full Eligibility no TC	**Unit**	**Base**	**$10**	**$20**	**$50**	**$100**	**$200**	**$500**
Afforestation	1000TCE	244	1,539	7,616	19,283	24,972	27,537	29,010
Forest Mgt.	1000TCE	58,870	62,085	62,994	62,260	64,040	66,136	64,850
Soil C Seq.	1000TCE	83,387	83,534	84,835	90,960	95,771	98,445	98,803
Biomass	1000TCE	9,164	9,827	11,429	16,749	24,054	26,452	28,195
Ag CH4&N2O	1000TCE	-17,081	-16,875	-16,347	-5,727	-799	2,066	5,544
Crop Mgt. Foss. Fuel	1000TCE	-10,941	-10,759	-10,542	-9,694	-9,046	-8,482	-7,788
Total	1000TCE	123,642	129,351	139,984	173,831	198,992	212,153	218,614
Full Eligibility with TC								
Afforestation	1000TCE	244	1,540	7,616	19,283	24,974	27,537	29,010
Forest Mgt.	1000TCE	58,866	62,085	62,992	62,260	64,033	66,137	64,850
Soil C Seq.	1000TCE	83,396	83,534	84,837	90,960	95,771	98,445	98,803
Biomass	1000TCE	9,165	9,827	11,429	16,749	24,054	26,452	28,195
Ag CH4&N2O	1000TCE	-17,081	-16,876	-16,347	-5,727	-799	2,066	5,544
Crop Mgt. Foss. Fuel	1000TCE	-10,941	-10,759	-10,542	-9,694	-9,046	-8,482	-7,788
Total	1000TCE	123,648	129,352	139,983	173,832	198,987	212,155	218,614
Limited Eligibility no TC								
Afforestation	1000TCE	244	2,707	10,053	23,433	29,608	32,412	33,958
Forest Mgt.	1000TCE	58,873	59,097	58,642	60,608	64,845	65,672	65,072
Soil C Seq.	1000TCE	83,387	83,883	86,809	92,086	94,643	96,193	95,278
Biomass	1000TCE	9,164	10,045	12,294	17,143	24,763	28,487	36,054
Ag CH4&N2O	1000TCE	-17,080	-16,878	-16,465	-5,914	-911	519	2,870
Crop Mgt. Foss. Fuel	1000TCE	-10,941	-10,759	-10,542	-9,694	-9,046	-8,482	-7,788
Total	1000TCE	123,648	128,004	140,725	177,707	203,946	214,734	224,844
Limited Eligibility with TC								
Afforestation	1000TCE	244	2,707	10,053	23,434	29,608	32,412	33,958
Forest Mgt.	1000TCE	58,873	59,097	58,643	60,608	64,845	65,672	65,072
Soil C Seq.	1000TCE	83,387	83,891	86,817	92,086	94,643	96,236	95,239
Biomass	1000TCE	9,164	10,045	12,294	17,143	24,764	28,487	36,054
Ag CH4&N2O	1000TCE	-17,080	-16,878	-16,465	-5,914	-911	519	2,870
Crop Mgt. Foss. Fuel	1000TCE	-10,941	-10,759	-10,542	-9,694	-9,046	-8,482	-7,788
Total	1000TCE	123,648	128,013	140,734	177,708	203,947	214,777	224,804

TCE is Ton of Carbon Dioxide Equivalent.

Table 8 Results of Differences at Scenarios of Eligibilities with Same Condition of Transaction Costs Scenarios

		Carbon Dioxide Equivalent Price in $/metric ton					
Difference between Full Eligibility no TC and Limited Eligibility no TC	**Unit**	**$10**	**$20**	**$50**	**$100**	**$200**	**$500**
Afforestation	1000TCE	-1,168	-2,437	-4,150	-4,636	-4,875	-4,948
Forest Mgt.	1000TCE	2,988	4,352	1,652	-805	464	-222
Soil C Seq.	1000TCE	-349	-1,974	-1,125	1,128	2,252	3,525
Biomass	1000TCE	-218	-865	-394	-709	-2,036	-7,859
Ag CH4&N2O	1000TCE	2	117	187	111	1,546	2,674
Crop Mgt. Foss. Fuel	1000TCE	91	66	-45	-44	68	599
Total	1000TCE	1,347	-741	-3,876	-4,954	-2,581	-6,230
Difference between Full Eligibility with TC and Limited Eligibility with TC							
Afforestation	1000TCE	-1,168	-2,438	-4,151	-4,634	-4,875	-4,948
Forest Mgt.	1000TCE	2,988	4,349	1,652	-812	464	-222
Soil C Seq.	1000TCE	-357	-1,980	-1,126	1,128	2,209	3,565
Biomass	1000TCE	-218	-865	-393	-710	-2,035	-7,858
Ag CH4&N2O	1000TCE	2	117	187	112	1,546	2,674
Crop Mgt. Foss. Fuel	1000TCE	91	66	-45	-44	68	599
Total	1000TCE	1,339	-751	-3,876	-4,960	-2,622	-6,190

TCE is Ton of Carbon Dioxide Equivalent.
A positive value means that the amount of emission reductions is greater under full eligibility than under limited eligibility.
A negative value means that the amount of emission reductions is greater under limited eligibility than under full eligibility.

implying decreasing GHG emissions. The largest reduction of emissions occurs for soil carbon sequestration reaching 98 MMT under the scenario of full eligibility with transaction costs and with a carbon dioxide equivalent price of $500.

As shown in Table 7, under the scenarios of limited eligibility without transaction costs, most of the strategies show a reduction in net emissions as the carbon dioxide equivalent prices increase except for crop management fossil fuel. Similar results are found for the scenarios of limited eligibility without transaction costs. Also, note that significant increase in GHG emission reductions occur for the agricultural CH4& N2O and crop management fossil fuel strategies when carbon dioxide equivalent prices very high.

Table 8 presents the differences between full eligibility and limited eligibility scenarios both with and without transaction costs scenarios. Regardless of the presence of transaction costs, the implementation of afforestation and biomass strategies result in greater reductions in GHG emissions under scenarios of limited eligibility than under full eligibility. On the other hand, the strategies of agriculture CH4 & N2O appears to bring about more reductions in GHG emissions under full eligibility than under limited eligibility. The total difference between full and limited eligibility can be to over 6 MMT at $500 carbon dioxide equivalent price.

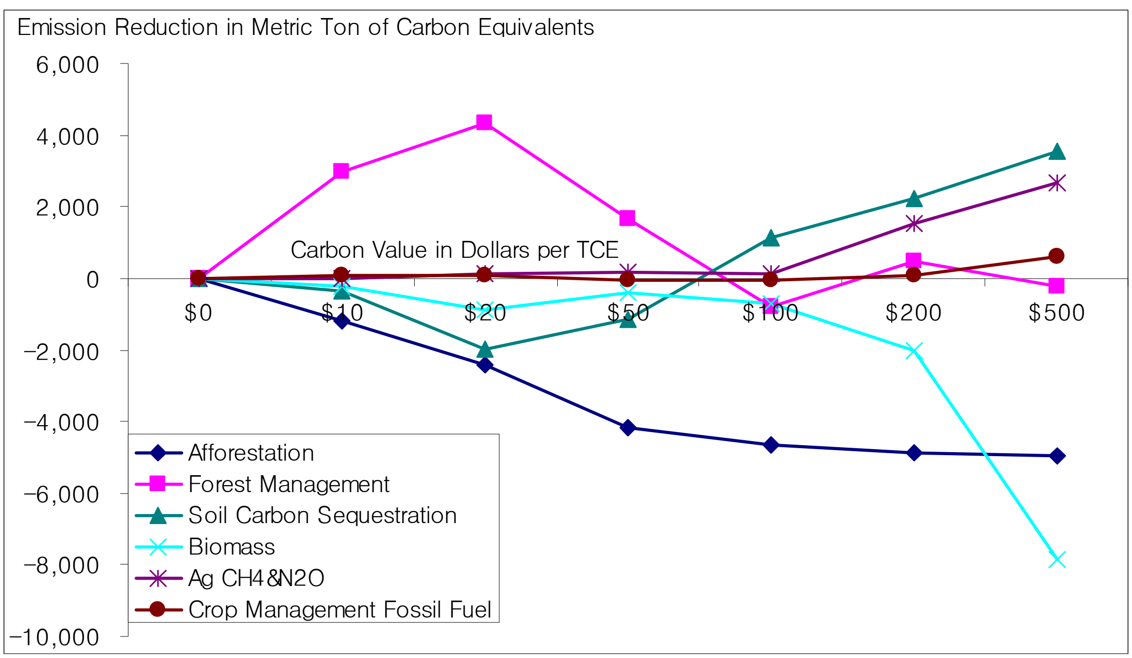

Figure 2 Difference between Full Eligibility without Transaction Costs and Limited Eligibility without Transaction Costs

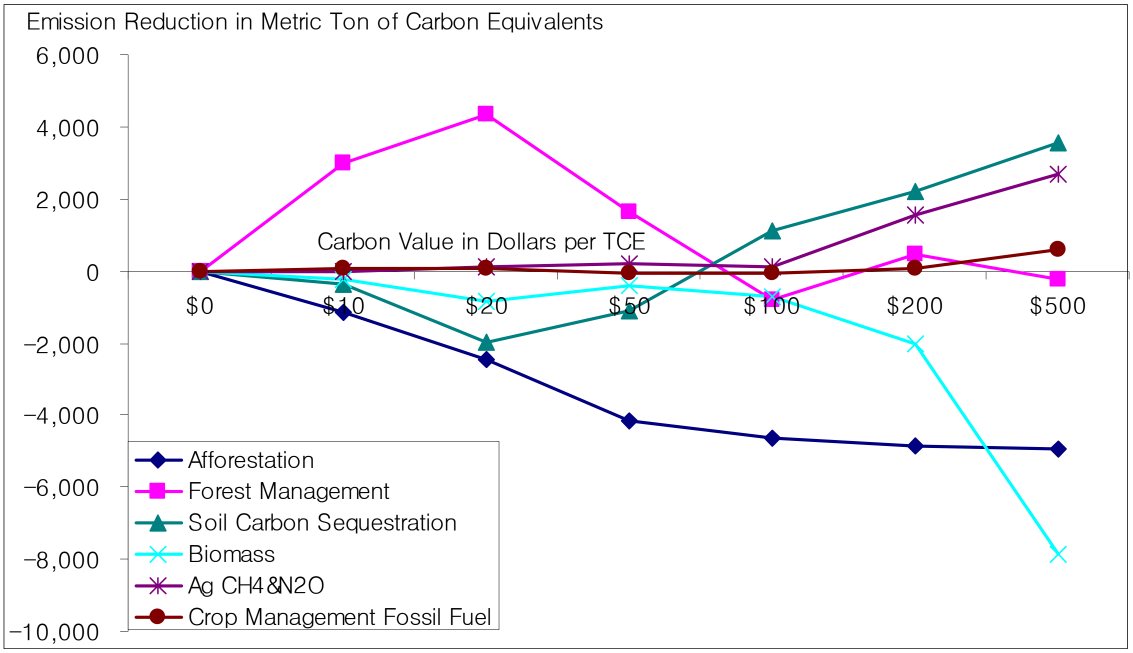

Figure 3 Difference between Full Eligibility with Transaction Costs and Limited Eligibility with Transaction Costs

Figure 2 and Figure 3 shows the response of difference GHG strategies under both eligibilities without transaction costs and with transaction costs over the various carbon dioxide equivalent price levels. Also, the strategy of forest management shows an advantage of transaction costs under full eligibility when carbon dioxide equivalent prices are lower.

Table 9 shows the differences between scenarios of eligibilities with and without transaction costs. For most of the strategies, the effect of transactions costs inclusion appears to be small. In the scenario of full eligibility, all mitigation options are impacted by transactions costs when the carbon dioxide equivalent prices are between $50 and $200. The strategy of the afforestation has the largest emission reductions with a carbon dioxide equivalent price of $100 under full eligibility. When the carbon dioxide equivalent price was $10, the effect of transactions costs was largest in full eligibility. When the carbon dioxide equivalent price was $100, the total amount of reductions of the full eligibility without transactions costs was larger than the full eligibility with transactions costs. For total reductions of emissions, when the carbon dioxide equivalent prices were $10, $50, $200, and $500, the supply of emission reductions was reduced with transaction costs. Graphically depicted, the emission reductions supply curve shifts to the left with a reduced quantity at each price level.

Table 9 Results of Differences at Scenarios of Eligibilities with Transaction Costs Scenarios

		Carbon Dioxide Equivalent Price in $/metric ton					
Difference Full Eligibility no TC between Full Eligibility with TC	**Unit**	**$10**	**$20**	**$50**	**$100**	**$200**	**$500**
Afforestation	1000TCE	-0.67	0.15	0.00	-1.92	-0.45	0.04
Forest Mgt.	1000TCE	-0.62	2.43	-0.05	6.39	-0.23	0.00
Soil C Seq.	1000TCE	-0.49	-1.58	-0.03	0.30	-0.22	-0.07
Biomass	1000TCE	-0.06	-0.07	-0.53	0.37	-0.32	-0.31
Ag CH4&N2O	1000TCE	0.09	0.15	-0.06	-0.32	-0.18	0.04
Crop Mgt. Foss. Fuel	1000TCE	0.13	0.12	-0.01	0.09	-0.06	-0.01
Total	1000TCE	-1.61	1.20	-0.68	4.90	-1.46	-0.31
Difference Limited Eligibility no TC between Limited Eligibility with TC							
Afforestation	1000TCE	-0.71	-0.42	-1.29	0.00	0.00	-0.25
Forest Mgt.	1000TCE	-0.36	-0.63	-0.25	-0.02	0.01	0.15
Soil C Seq.	1000TCE	-8.28	-7.80	-0.49	0.02	-42.58	39.26
Biomass	1000TCE	-0.18	0.06	0.46	-0.67	0.00	0.23
Ag CH4&N2O	1000TCE	-0.12	-0.03	0.08	0.00	0.00	0.01
Crop Mgt. Foss. Fuel	1000TCE	-0.03	-0.05	0.11	0.02	0.02	0.01
Total	1000TCE	-9.68	-8.87	-1.38	-0.65	-42.55	39.41

TCE is Ton of Carbon Dioxide Equivalent.
A positive value means that the amount of emission reductions is greater under scenarios without transaction costs than with transaction costs.
A negative means that the amount of emission reductions is greater under scenarios with transaction costs than without transaction costs.

Broadly speaking, under limited eligibility, the effect of transactions costs is larger than under full eligibility. Except for the carbon dioxide equivalent price of $500, the inclusion of transaction costs increase the total amount of GHG offsets produced. Note that when the carbon dioxide equivalent price is $200, the inclusion of transaction costs encourages the soil sequestration based GHG mitigation activities, however, when the carbon dioxide equivalent price is $500, the inclusion of transaction costs turns out to an impeding factor these activities.

Figure 4 and Figure 5 show the differences between scenarios with and without transaction costs, for both full and limited eligibility. In the full eligibility case, the strategy of the forest management without transactions costs has largest emission reductions with a carbon dioxide equivalent price of $100 as do afforestation with

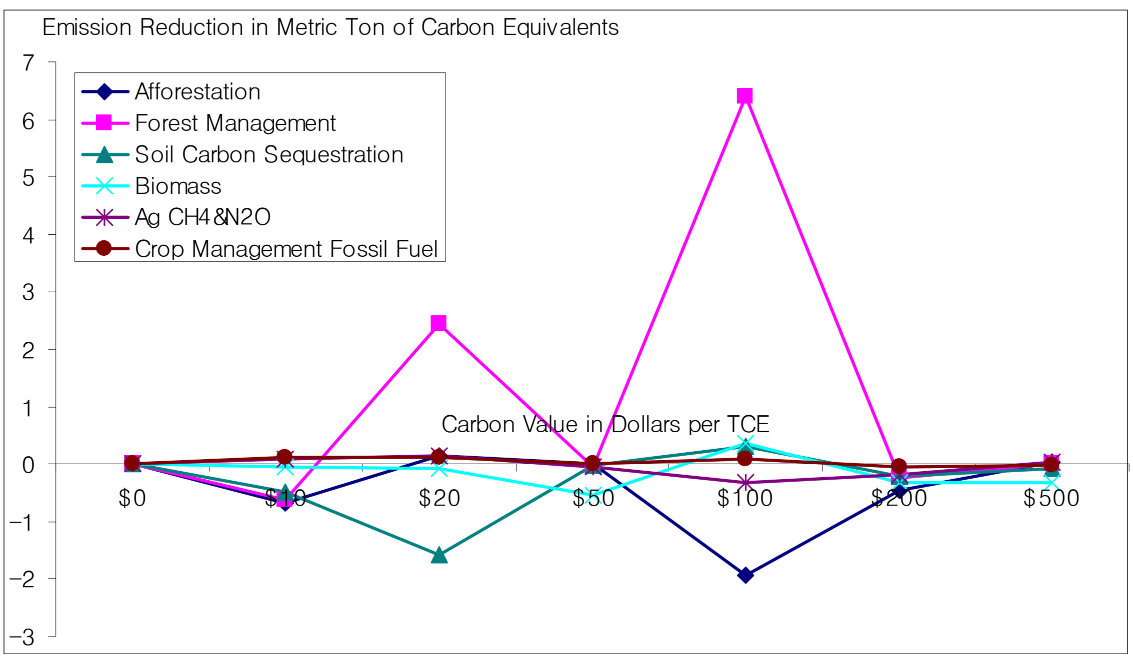

Figure 4 Difference between Full Eligibility without Transaction Costs and Full Eligibility with Transaction Costs

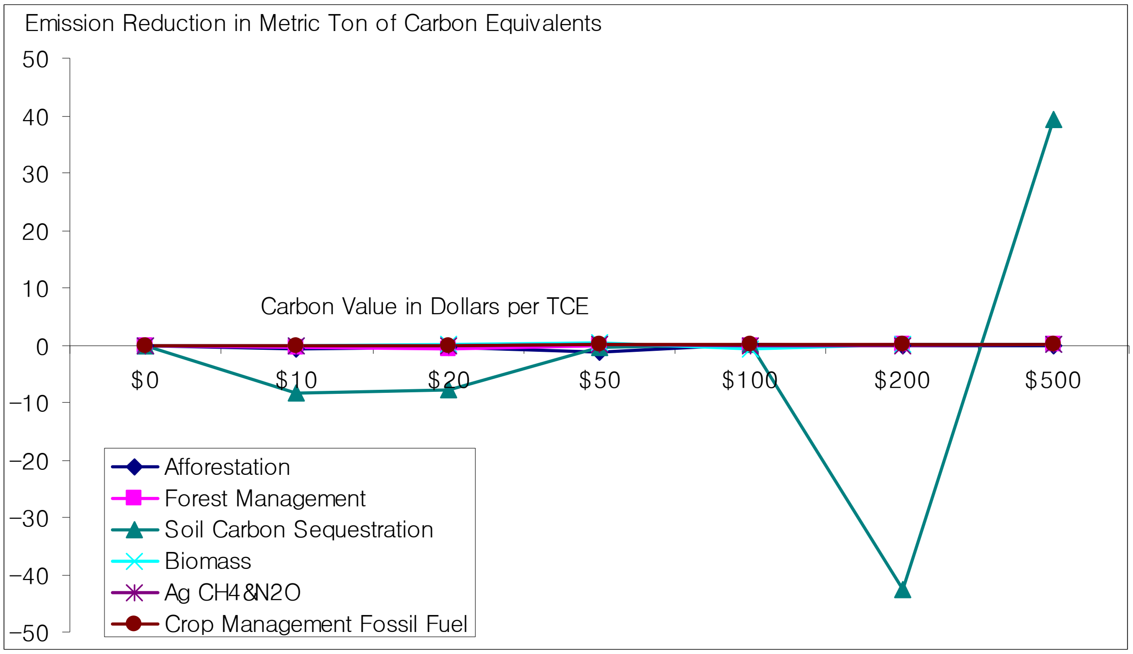

Figure 5 Difference between Limited Eligibility without Transaction Costs and Limited Eligibility with Transaction Costs

transactions costs. In the limited eligibility scenarios, the strategy of the soil carbon sequestration with a carbon dioxide equivalent price of $200 increase because of the effect of transactions costs. When the carbon dioxide equivalent price is $500, the eligibility without transactions costs has much more emission reductions than the eligibility without transactions costs.

The results demonstrate that how GHG mitigation strategies are employed depend upon the carbon dioxide equivalent prices. Also, the reduction of emissions occurred more as transaction costs were applied for both full eligibility and limited eligibility. At $100 and $20, afforestation in full eligibility and soil carbon sequestration in limited eligibility appear highly responsive to transaction costs.

Conclusion

The implications of transactions costs in determining optimal agricultural and forestry based GHG mitigation strategies for providing GHG offsets was examined. The inclusion of transactions costs in analysis reduces the role of agriculture and forestry GHG mitigation strategies as the effective price received by GHG offset producers is lowered. Also the degree to which the spectrum of GHG mitigation options is limited has implications. Under limited eligibility there are larger GHG emission reductions for afforestation than under full eligibility when transactions costs are included. In both cases, the forest management portfolio share in limited eligibility has more reductions than other mitigation strategies. The effect of including transactions costs is not large for overall mitigation but fairly significant for the portfolio composition of GHG mitigation option under scenarios of full eligibility with the carbon dioxide equivalent price of $100 when transaction costs are not included. The effect of transaction costs also appears to be large for the portfolio share of the afforestation and the soil carbon sequestration strategies. In general, the inclusion of transaction costs shifts the supply curve of GHG emission reductions to the left. Theses findings may inform policymakers about how transaction costs influence GHG offsets provided by the agriculture and forestry sector, thus, helping them make better decisions regarding the treatment of GHG mitigation options portfolio in national climate policy.

CHAPTER IV

ECONOMIC CONSIDERATION OF STORAGE COST IN BIOENERGY PRODUCTION

Introduction

Biomass energy can be produced from the agricultural or forest production. Assessment of energy crops in the U.S. agricultural sector shows that although biomass based electricity is expensive, it has considerable potential to offset carbon emissions (McCarl et al., 2001).

Even though a biomass fired power plant emits CO2 into the atmosphere, plant growth absorbs it through the photosynthesis process. Using agricultural products to generate energy in a power plant generally involves recycling of CO2 as opposed to traditional fossil fuels that only emit CO2 (McCarl, 1998). Moreover, the emissions from combustion and extraction of an equivalent amount of fossil fuels are saved with the emissions from biomass amounting to approximately 95 percent CO_2 emitted when burning the biomass (Kline et al., 1998).

Currently, biomass conversion into forms of energy is receiving largely attention because of environmental, energy supply and agricultural concerns although it is an old idea (McCarl and Schneider, 2001). Specifically, using biomass for fuels, power, and products can make important contributions to U.S. energy security, agricultural economy, and environmental quality (Schneider and McCarl, 2005).

Biomass has to be stored from the time of harvest to its use by a power plant or biorefinery. Thus, biomass must be accumulated during harvest periods so that feedstocks are available for year-round bioenergy production. A biomass storage system should be designed to minimize dry matter loss, and protect and enhance, when possible, the quality of biomass until it is utilized (Turhollow et al., 2009).

Biomass from dry matter losses occur in various ways. Leaves and other parts of the plants are lost and broken in the wind or mixed with soil during collection processes. Some of the losses occur during storage due to fermentation and breakdown of plant carbohydrates. Weather is another factor that creates biomass losses, primarily by precipitation and/or water absorption from the ground. Sokhansanj et al. (2006) developed a logistics model for estimating storage dry matter losses based on a seasonal bioenergy feedstocks. They found that the dry matter loss is significantly affected by the moisture content of stalks with an inverted U-shape relationship. Richardson et al (2002) found that an increase in dry matter losses reduces overall energy content and increases the ash content of the biomass.

Richey et al. (1982) reported that dry matter losses in round bales of corn stover stored outdoors ranged from 10 to 23 percent of total biomass depending on initial stover moisture. Shinners et al. (2007) evaluated the costs of ensiling corn stover. Turhollow and Sokhansanj (2007) performed an extensive economic analysis of storing high moisture corn stover in large piles similar to a bagasse storage method used by the pulping industry.

The total cost of biomass storage can be calculated by summing the cost generated from storage site or materials and the cost of dry matter losses during storage (Turhollow et al., 2009)

Table 10 gives the estimated dry matter loss for stored round bales of hay. The enclosed shed and plastic wrap on ground storage methods have the smallest amount of dry matter losses. The uncovered on gravel pad method has a significant amount of the dry matter loss ranging from 13 ~ 17 percent. It is worth noting that storage losses in rectangular bales could vary significantly from these estimates depending on ambient weather conditions. Moreover, dry matter losses from other biomass crops such as corn stover and switchgrass may differ from the above findings.

Shinners et al. (2007) founded that, for the inside storage, the value of the dry matter loss of large round bales is generally greater than that of large square bales. The value of dry matter losses from the outside storage on the ground for different types of bale tying (sisal twine, plastic twine, and net wrap) is generally greater than that from outside storage on pallets. On average, the percentage of the dry matter losses from the

Table 10 Estimated Dry Matter Loss in Round Bales of Hay from Various Storage Methods

Storage Method	Estimated Annual Dry Matter Loss, %
Enclosed shed	2~5
Open-sided pole structure	3~10
Reusable tarp on gravel pad	5~10
Plastic wrap on ground	4~7
Uncovered on gravel pad	13~17

Sources: Collins et al. (1997), Huhnke (2006)

Table 11 Percentage of Dry Matter Loss in Storage Characteristics of Dry Corn Stover Bale

Storage Location	Wrap and/or Bale Type	Dry Matter Loss (% of total)		
		2002	2003	Average
Inside	Large round	4.9	2.2	3.6
	Large square	4.8	1.1	3.0
Inside Total Average				**3.3**
Outside on ground	Sisal twine	29.1	38.5	33.8
	Plastic twine	14.3	19.0	16.7
	Net wrap	10.7	14.2	12.5
Outside on pallets	Sisal twine	17.7	36.1	26.9
	Plastic twine	11.4	11.0	11.2
	Net wrap	7.0	8.2	7.6
Outside Total Average				**18.1**

Source: Shinners et al. (2007)

inside storage (3.3%) is less than that from the outside storage (18.1%) based on the data in Table 11.

Table 12 Average Percentages of Reported Dry Matter Losses from Inside and Outside Storage

Studies	Dry Matter Losses (% of total biomass)	
	Inside storage	Outside storage
Turhollow et al. (2009)	2.0	15.5
Shinners et al. (2007)	3.3	18.1
Collins et al. (1997), Huhnke (2006)	3.5	8.6
Average	2.9	14.1

A comparison of the average dry matter losses from the above mentioned studied for both inside and outside storage is in Table 12. The average percentage of the dry matter losses across all studies is 2.9 and 14.1 percent for inside and outside storage, respectively.

Turhollow et al. (2009) analyzed the cost of storage options for swicthgrass bales. They assumed the storage system was a barn built on agricultural land that would hold 110 bales and would occupy 2.47 acres. In forming their estimates, they determined land cost, annualized construction cost, rent, insurance and taxes. The components of the total cost estimates are shown in Table 13. Their annual cost of inside storage was $2,464 while the cost of outside storage was $1,020. The primary reason inside storage costs are higher than those of outside storage is the barn's construction cost which was annualized over the life of the structure.

The costs of repair, taxes, and insurance from Gay and Grisso (2002) were 0.7 percent, 1.0 percent, and 0.3 percent of the initial investment, respectively. Using these costs, 2 percent of the initial investment is $443 and $72 for inside and outside storage, respectively, for repair taxes and insurance costs.

The annual cost is equal to $22.4/dry ton ($2,464/110 dry ton) and $9.3/dry ton ($1,020/110 dry ton) for inside and outside storage, respectively. By incorporating the dry matter loss (2.9 percent for inside and 14.1 percent for outside) into annual cost, the adjusted annual storage cost is $23.1 and 10.8 per dry ton for inside and outside storage, respectively, as show in Table 14.

Table 13 Estimated Annual Cost of a Biomass Storage System*

	Inside	Outside	
Land[1)]	\$85/ac (\$210/ha)	\$85/ac (\$210/ha)	
Construction Cost	\$22,155[2)]	Tarp	Gravel Pad
		\$1,298[3)]	\$2,308[4)]
Useful Life	20 yr	5 yr	10 yr
Interest Rate[5)]	0.06		
Annualized construction cost of Building	\$1,936[6)]	\$308[7)]	\$314[8)]
Insurance, taxes & Repair	\$443[9)]	\$72[10)]	
Annual Cost	\$2,464[11)]	\$1,020[12)]	

* 110 dry ton capacity.

1) US average annual cash rent for cropland with state average in 2007 assuming total land area assigned to storage was 0.99 aces are used.

2) The building cost was \$99.35/m^2 and the size of the building was determined using the same procedure as the gravel pad as 223.4m^2 (\$99.35/m^2 $\times$223.4m^2 = \$22,155).

3) The tarp area required was 446m^2 and the estimated cost of a hay tarp was \$2.37/m^2. Assuming a labor rate is \$10/h, \$0.54/m^2 of tarp area ((\$2.37/m^2 + \$0.54/m^2) $\times$ 446m^2 = \$1,298).

4) The gravel pad was sized for all sides of the stack for a total area of 223 m^2 and cost of constructing gravel pad is \$10.33/m^2 (\$10.33/m^2$\times$223 m^2 = \$2,308).

5) Assumed an interest rate of 6%.

6) C_{0_inside} = (\$22,155)(0.06/(1-(1+0.06)$^{-20}$)) = \$1,936

7) C_{0_tarp} = (\$1,298)(0.06/(1-(1+0.06)$^{-5}$)) = \$308

8) C_{0_gravel} = (\$2,308)(0.06/(1-(1+0.06)$^{-10}$)) = \$314

9) The annual costs of repair and insurance were \$443 (2% of the \$22,155 initial investment).

10) The annual costs of repair and insurance were \$72 (2% of the (\$1,298 + \$2,308) initial investment).

11) The total annual cost of storing biomass indoors included the building (\$1,936), land (\$85), and insurance and repair (\$443) is \$2,464.

12) The total annual cost of storing biomass on a gravel pad and covered with a tarp which included the tarp (\$308), gravel pad (\$314), land (\$85), labor to place and remove the tarp each year is \$241 (\$0.54/ m^2 $\times$ 446 m^2), and insurance and repair (\$72) is \$1,020.

Source: Turhollow et al. (2009)

Table 14   Adjusted Annual Costs of Two Options of Biomass Storage

	Inside	Outside
Average of dry matter loss	2.9%	14.1%
Annual cost	$22.4/dry ton	$9.3/dry ton
Adjusted annual cost	$23.1/dry ton	$10.8/dry ton

Another factor that affects storage costs is that more than one set of bales can be stored per year. For example, if bales are stored for six months and utilized, then a new group of bales can be stored for the last six months of the same year. In this case, the storage cost per ton should be reduced by half for that year. Also, one producer may take their biomass bales immediately after harvest to the bioenergy plant, while another producer may have to keep their bales in storage for future delivery to the bioenergy plant. Three potential schemes for storage premiums exist. First, the producer could be paid a set per ton per month premium for each month (from one to twelve) that the bales are kept in his possession. Second, the producer could agree to a maximum of six months of storage and be paid for each month beyond six that he still has the bales. Finally, the producer could be paid a flat per ton premium only if they keep the bales for six months or more. This would be payment for the opportunity cost of the land on which the bales are stored. If bales are kept on the edge of the field for more than six months, that land will not be available for planting a crop or producing more switchgrass in the year after harvest.

Although biomass storage costs are parts of the cost of a GHG offset trading system, researchers have often ignored these costs. The storage cost occurs between harvest at the farm and use by the bioenergy plant and could be classified as a transaction cost. The objective of this chapter is to examine the emission reductions impact of storage costs adjusted for the dry matter losses for both inside and outside storage on the portfolio of biomass commodity options in an emission reductions program.

Methodology and Assumptions

FASOMGHG was used to estimate the GHG mitigation potential for U.S. agricultural and forest sector for this storage cost analysis. The list of all biomass commodities in FASOMGHG that could be stored is in Table 15.

Table 16 contains the data for determining the storage costs of FASOMGHG biomass commodities. This data includes the number of months of peak storage, the number of months an average ton is stored, the amortized cost of building and keeping storage for one unit of feedstock, the cost of moving one unit of feedstock in and out of storage, and the cost of maintaining one unit of the feedstock for one month. Also, it is assumed that the annual cost of the biomass storage system is fixed for both indoor and outdoor storage costs because the costs have already been paid. For this study, dry matter losses were assumed for both indoor and outdoor storage to be 2.9 and 14.1 percent, respectively, following the discussion above.

Table 15 FASOMGHG Biomass Commodities That Could Be Stored

Biomass Commodities	Context
cornres	Corn crop residues in tons
wheatres	Wheat crop residues in tons
sorghumres	Sorghum crop residues in tons
barleyres	Barley crop residues in tons
oatsres	Oat crop residues in tons
riceres	Rice crop residues in tons
sspulp	Sweet Sorghum Pulp in US tons
switchgrass	SwitchGrass in US tons
willow	Willow in US tons
hybrdpoplar	Hybrid Poplar in US tons
energysorghum	Energy Sorghum for biofuels
miscanthus	Miscanthus in US tons
bagasse	Sugarcane bagasse in tons
biomanure	Manure for use in bioprocesses in tons
beefbiomanure	Manure for use in bioprocesses in tons
dairybiomanure	Manure for use in bioprocesses in tons
Lignin	Lignin produced from cellulosic non-wood ethanol process in tons
LigninHardwood	Lignin produced from cellulosic hardwood ethanol process in tons
LigninSoftwood	Lignin produced from cellulosic softwood ethanol process in tons
SoftwoodRes	Soft wood logging residues in tons
HardwoodRes	Hard wood logging residues in tons
SoftwoodPulp	Soft wood pulp in tons
HardwoodPulp	Hard wood pulp in tons
SoftMillRes	Soft wood milling residues in tons
HardMillRes	Hard wood milling residues in tons

Table 16 FASOMGHG Biomass Commodities Storage Cost Data

Biomass Commodities	Peak months[1)]	Avg months[2)]	Fixedcost peak[3)]	Pertonin andout[4)]	Costper month[5)]
cornres	10	4.58	7.15	4.59	2.72
wheatres	10	4.58	7.15	4.59	2.72
sorghumres	10	4.58	7.15	4.59	2.72
barleyres	10	4.58	7.15	4.59	2.72
oatsres	10	4.58	7.15	4.59	2.72
riceres	10	4.58	7.15	4.59	2.72
sspulp	5	4.58	7.15	4.59	2.72
switchgrass	9	3.75	7.15	4.59	2.72
willow	4	0.83	7.15	4.59	2.72
hybrdpoplar	4	0.83	7.15	4.59	2.72
energysorghum	6	1.75	7.15	4.59	2.72
miscanthus	6	1.75	7.15	4.59	2.72
bagasse	10	4.58	7.15	4.59	2.72
biomanure	0	0	7.15	4.59	2.72
beefbiomanure	0	0	7.15	4.59	2.72
dairybiomanure	0	0	7.15	4.59	2.72
Lignin	0	0	7.15	4.59	2.72
LigninHardwood	0	0	7.15	4.59	2.72
LigninSoftwood	0	0	7.15	4.59	2.72
SoftwoodRes	0	0	7.15	4.59	2.72
HardwoodRes	0	0	7.15	4.59	2.72
SoftwoodPulp	0	0	7.15	4.59	2.72
HardwoodPulp	0	0	7.15	4.59	2.72
SoftMillRes	0	0	7.15	4.59	2.72
HardMillRes	0	0	7.15	4.59	2.72

Note: See Table 15 for definitions.
1) Number of months of supply stored at peak based on harvest window of crop
2) Number of months average ton is stored calculated assuming a uniform drawdown of storage
3) Amortized cost of building and keeping storage for one unit of feedstock and assumed to be $7.15 based on preliminary results from Searcy.
4) Amortized cost of moving 1unit of feedstock in and out of storage and assumed $4.59 based on Rose.
5) Cost of maintaining one unit of the feedstock for one month and assumed $2.72 based on opportunity cost of money.
6) Crop residues assume 2 month harvest window so must store 10 months
7) Crop residues assume annual average is 10/12+9/12+8/12+...+1/12
8) Switchgrass assume 3 month harvest window so must store 9 months
9) Switchgrass assume annual average is 9/12+8/12+...+1/12
10) Wood items assume 12 month harvest window so must store 0 months
11) Energy sorghum assume 6 month harvest window so must store 6 months
12) Energy sorghum assume annual average is 6/12+5/12+...+1/12
13) Miscanthus assume 6 month harvest window so must store 6 months
14) Miscanthus assume annual average is 6/12+5/12+...+1/12

Results

FASOMGHG was used to see how the storage cost including dry matter losses affects the GHG mitigation portfolio.

Table 17 shows the amount of estimated emission reductions and welfare changes from dry matter loss of biomass arising due to both indoor and outdoor storage between a case with and without the dry matter loss of biomass under different carbon dioxide equivalent prices. It was found that the total amount of emission reductions from both indoor and outdoor storage was positively correlated to the carbon dioxide equivalent price. In the case of biomass, at $500 of carbon dioxide equivalent price, the amount of emission reductions from both storage methods reaches about 28 MMT.

The difference between the amount of emission reductions from indoor and outdoor storage under different carbon dioxide equivalent prices is also shown in Table 17. A negative (positive) sign in this table means that the amount of emission reductions from biomass indoor storage is smaller (larger) than that from outdoor storage. The difference between these two storage methods is very small for all levels of carbon prices. When carbon dioxide equivalent price are in the range from $20 to $200, the amount of emission reductions in biomass from outdoor storage exceed those from indoor storage implying the outdoor storage method is more competitive in emission reductions than indoor storage over that carbon price range. When the price is very large the outdoor storage included emission reductions are smaller than that from indoor storage indicating that indoor storage may be more effective carbon dioxide equivalent.

The emission reductions of biomass with dry matter loss both indoor and outdoor reach a maximum of about 75 MMT.

Table 17 contains the value of the slope of the “Difference between Indoor and Outdoor” line of Figure 6. The slope has a negative value from $10 ~ $50 carbon price, while it is positive after the $50 carbon price. The amount of emission reductions for indoor storage relative to outdoor storage decreases 0.1171 metric tons and 0.0048 metric tons as the carbon dioxide equivalent price increases by a dollar in the range of carbon dioxide equivalent price of $10 ~ $20 and $20 ~ $50, respectively. On the other hand, if the carbon dioxide equivalent price is above $50 dollar per metric ton, the amount of emission reductions for indoor storage relative to outdoor storage will increase as the price of carbon dioxide equivalent price increases with the amount of the increase equal to 0.0044, 0.0087, and 0.0004 metric tons in the range of carbon dioxide equivalent price of $50 ~ $100, $100 ~ $200, and $200 ~ $500, respectively. This is demonstrated in Figure 6.

The overall societal welfare results from storage loss consideration are also shown in Table 17. The data in the table are calculated as the change from a no storage case or loss case to one where storage cost and either indoor and outdoor dry matter losses are included for a given carbon dioxide equivalent price. These results show that total societal welfare is raised by considering dry matter loss with the loss positively correlated to the carbon dioxide equivalent price. At a $500 carbon dioxide equivalent price, the total societal welfare loss reaches a maximum of about $7,100 billion. When the carbon dioxide equivalent prices were $10 and $100, the welfare of indoor storage

Table 17 Estimated Biomass Emission Reductions and Welfare from Dry Matter Loss for Indoor and for Outdoor Storage Methods under Different Carbon Dioxide Equivalent Prices

Reduction of Emissions	**Carbon Dioxide Equivalent Price in $/metric ton**					
Biomass (1000TCE)	**$10**	**$20**	**$50**	**$100**	**$200**	**$500**
DML for Indoor Storage	9,844	11,437	16,824	24,101	26,444	28,205
DML for Outdoor Storage	9,843	11,437	16,824	24,102	26,444	28,205
Without DML	9,827	11,429	16,749	24,054	26,452	28,195
Difference between						
Indoor and Outdoor[1)]	-0.58	0.59	0.73	0.52	0.07	-0.03
Indoor and without DML[2)]	-16.10	-8.32	-74.91	-46.98	7.17	-9.99
Outdoor and without DML[2)]	-15.52	-8.91	-75.64	-47.49	7.09	-9.95
Slope of difference between indoor and outdoor	**-**	**-0.1171**	**-0.0048**	**0.0044**	**0.0087**	**0.0004**
Welfare (billion dollar)						
Indoor	5,857	5,884	5,852	6,038	6,271	7,077
Outdoor	5,698	5,885	5,900	5,891	6,271	7,077
Difference between Indoor and Outdoor[3)]	-159.66	0.18	47.38	-146.87	0.03	0.07

TCE is Ton of Carbon Dioxide Equivalent.
1) A positive (negative) value means that the reductions of emissions of indoor storage are greater (smaller) than the reductions of emissions of outdoor storage.
2) A positive (negative) value means that the reductions of emissions without dry matter loss storage are greater (smaller) than the reductions of emissions of indoor or outdoor storage.
3) A positive (negative) value means that the welfare with outdoor with dry matter loss storage are greater (smaller) than the welfare with indoor with dry matter loss storage.

with dry matter loss was greater than outdoor storage with dry matter loss. The welfare of outdoor storage was greater than the welfare of indoor storage when the carbon dioxide equivalent price $50. At the carbon dioxide equivalent prices $20, $200, and $500, the welfare both indoor and outdoor were similar. At a $10 price, the amount of the emission reductions and the welfare of the indoor storage with dry matter loss were greater than the amount of the emission reductions and welfare of the outdoor storage

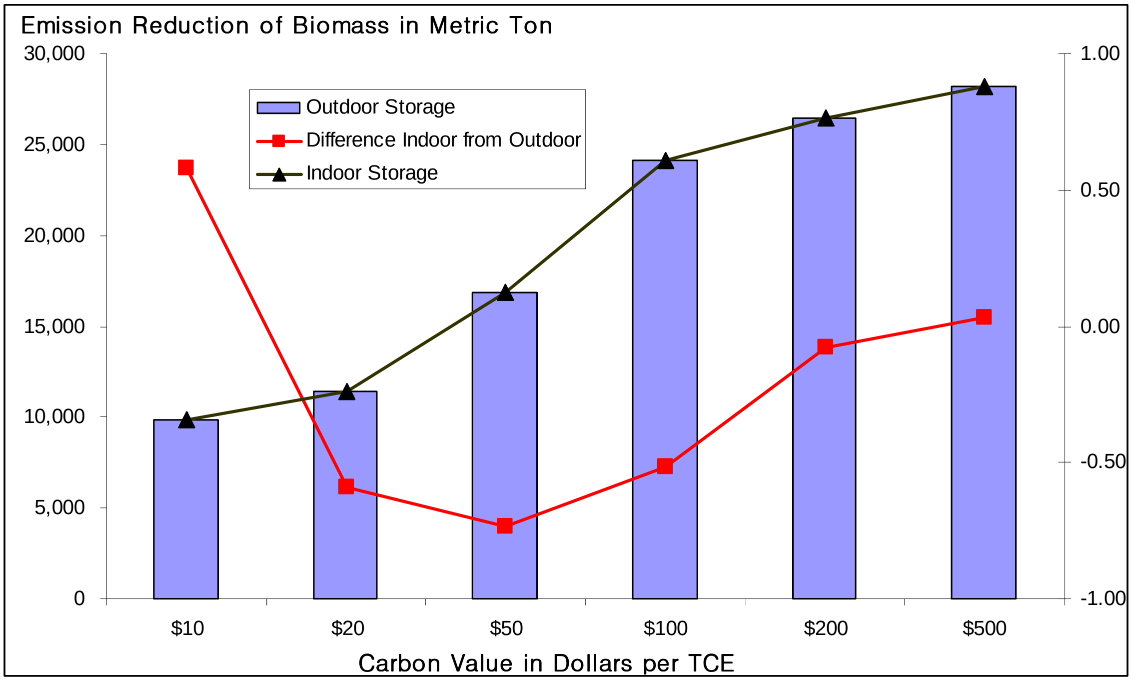

Figure 6 Results of Differences at Storage Costs Scenario between Indoor and Outdoor in Biomass

with dry matter loss so indoor storage would be preferred. However, carbon dioxide equivalent price at a price of $50, $200, and $500, the amount of emission reduction and the welfare loss with outdoor storage is greater than that with indoor storage.

Table 18 shows the amount of estimated emission reductions from the total of all GHG mitigation strategies by dry matter loss both indoor and outdoor storage and from total GHG account under different carbon dioxide equivalent prices.

These results show that the total amount of emission reduction from all mitigation strategies with dry matter loss for indoor and outdoor storage and without dry matter loss was positively correlated to the carbon dioxide equivalent price. In table 18 for the difference between indoor and outdoor storage both with and without dry matter loss, the

Table 18 Estimated Total Emission Reductions from Dry Matter Loss for Indoor and for Outdoor Storage Methods under Different Carbon Dioxide Equivalent Prices in 1000 Metric tones Carbon Dioxide Equivalent

Reduction of Emissions	**Carbon Dioxide Equivalent Price in $/metric ton**					
Total	**$10**	**$20**	**$50**	**$100**	**$200**	**$500**
Total DML for Indoor	129,457	139,911	174,022	199,098	212,196	218,650
Total DML for Outdoor	129,458	139,906	174,022	199,098	212,196	218,650
Total without DML	129,351	139,984	173,831	198,992	212,153	218,614
Difference between						
Indoor and Outdoor[1)]	1.00	-4.80	0.45	-0.15	0.25	0.08
Indoor and Total w/o DML[2)]	-106.00	73.49	-190.96	-106.05	-42.55	-35.51
Outdoor and Total w/o DML[2)]	-107.00	78.29	-191.41	-105.91	-42.80	-35.59

TCE is Ton of Carbon Dioxide Equivalent.
1) A positive (negative) value means that the reductions of emissions of indoor storage are greater (smaller) than the reductions of emissions of outdoor storage.
2) A positive (negative) value means that the reductions of emissions indoor or outdoor storage system are greater (smaller) than the reductions of emissions of total without dry matter loss.

negative (positive) sign means that the amount of emission reductions from all mitigation strategies without dry matter loss is smaller (larger) than that from both indoor and outdoor storage. If the carbon dioxide equivalent price is between $20 and $100, the emission reductions of outdoor storage are larger than indoor storage. In the case of the difference between indoor or outdoor storage and no dry matter loss, the amount of emission reductions from indoor or outdoor storage are larger than the amount without dry matter loss except for carbon dioxide equivalent price $20. This implies that the indoor or outdoor storage with dry matter loss produces more emission reductions than without dry matter loss at that carbon dioxide equivalent price. At a $50 carbon dioxide equivalent price, the difference in emission reductions between indoor or outdoor storage with dry matter loss and without dry matter loss reaches about 191 MMT.

Conclusion

In this chapter, the implications of storage cost including dry matter loss were explored for agricultural and forestry based GHG mitigation alternatives. By reviewing previous studies, it was found that the average dry matter losses for indoor and outdoor storage can be estimated at 2.9 and 14.1 percent of total biomass, respectively. Incorporating the dry matter loss in the storage cost increases the total storage cost. In general, the study found that the total amount of emission reductions from both indoor and outdoor storage is positively correlated to the carbon dioxide equivalent price. Although the percentage of dry matter losses from the indoor storage is generally lower than that from the outdoor storage, the amount of the emission reductions from both indoor and outdoor storage methods varies depending on the level of carbon dioxide equivalent price. The outdoor storage method is more competitive than the indoor storage method, if the carbon dioxide equivalent price ranges from \$20 ~ \$200. Otherwise, the indoor storage method is more advantageous than the outdoor storage method. The amount of emission reductions of biomass from dry matter loss of indoor or outdoor storage is larger than the amount of emission reductions without dry matter loss under all carbon dioxide equivalent prices except for \$200. Considering the slope of the difference between the amount of the emission reductions from indoor and outdoor storage, the competiveness of the indoor storage method tends to increase as carbon dioxide equivalent price increases. Although the costs of the indoor storage are higher than the outdoor storage, incorporating the dry matter loss as a storage cost increases the competiveness of indoor storage (lower dry matter loss) versus the outdoor storage (higher dry matter loss) as the carbon dioxide equivalent price increases. For the total emission reductions from all mitigation strategies from dry matter loss, except for $50, the amount of emission reductions of indoor or outdoor storage is larger than total emission reductions without dry matter loss. If policy makers are making decisions only on a biomass mitigation strategy, they should consider how much the carbon dioxide equivalent price affects emission reductions related to storage systems. Also, by considering the total emission reductions from all strategies when storage systems are used, they could identify the carbon dioxide equivalent price that reduces emissions. These findings could provide valuable information for policy makers regarding the reduction of GHG using biomass.

CHAPTER V

CONCLUSIONS AND IMPLICATIONS

Transaction costs are typically ignored when assessing the greenhouse gas marginal abatement curve as well as the associated role of alternative mitigation strategies. These costs are difficult to estimate and have not been a major focus of many studies. In the last ten years, some papers have done some estimates of transaction costs on a project-basis. These papers show significant levels of costs. However, there are no papers that analyze the impact of transaction costs directly on the sectoral wide marginal abatement curve or the choice of greenhouse gas mitigation strategies.

This dissertation examines how transaction costs including storage costs affect agriculture and forestry levels of greenhouse gas mitigation. In this analysis, the following are examined; 1) the general economics of how marginal abatement curves are impacted by transactions costs plus the estimates of these costs by research teams; 2) the empirical their role that transactions costs play in estimates of the marginal abatement curve for agricultural and forestry based GHG emission offsets plus the role of alternative strategies; 3) the reasons for including storage costs; and 4) their impacts of including storage costs on estimates of the marginal abatement curve for agricultural and forestry based GHG emission offsets.

The transaction costs reported by many researchers were reviewed and the cost components identified, that is, assembly costs, measurement and monitoring, certification, enforcement, additional adoption cost incentive estimates, and procedures for and cost of risk/liability for adverse outcomes. By graphical analysis, when transaction costs are considered in a GHG offset trading market, the emission reductions supply curve will be shifted to the left. The transaction costs effectively lower carbon dioxide equivalent prices to the GHG offset supplier which decreases the quantity of GHG offsets supplied.

The effect of differential transactions costs across alternative strategies was also examined with the finding that the relative shares of abatement are likely to shift with increases in those with the least transactions cost and decreases in those with the highest.

The effect of transaction costs on the optimal level and portfolio composition of GHG emission reductions by agriculture and forestry was then examined. Four scenarios were analyzed:

- full eligibility of all GHG mitigation strategies without transaction costs,
- full eligibility with transaction costs,
- limited eligibility of GHG mitigation strategies without transaction costs, and
- limited eligibility with transaction costs.

The eligibility scenarios cover the extent to which GHG offset possibilities are eligible for payment. The limited eligibility scenarios only allow fossil fuel, bioenergy, sequestration, and manure emissions capture as GHG offset alternatives that receive carbon dioxide equivalent prices.

Each of these scenarios was run under a range of carbon dioxide equivalent prices. The transaction costs expressed as percentages of the carbon dioxide equivalent price were developed based on the expert opinion of members of the FASOMGHG team. The percentage of transaction costs ranged across four cases; low (5%), medium (15%), high (35%), and very high (40%).

The emission reductions are not greatly affected by transactions costs varying at most by 6 MMT. The limited eligibility versus full eligibility has large implications with the limited emissions reducing the volume of offsets generated. In particular, the emission reductions from afforestation are substantially smaller because the other gains from fertilizer reductions etc are not credited under limited eligibility.

There are relatively large differences in the optimal portfolio of GHG mitigation alternatives when transaction costs are considered. The results indicate that transaction costs are an important factor in determining the emission reductions strategies to pursue. The portfolio of mitigation alternatives is different for each carbon dioxide equivalent price for both eligibility scenarios. Finally, policymakers should be aware of which GHG mitigation alternatives under the various scenarios are most significantly affected by transactions costs, so that, they can use this information to make decisions about GHG mitigation portfolios for national climate policy legislation and the strategies found to be most affected here are afforestation, soil carbon sequestration, forest management, and biomass with the first two shrinking and the latter growing.

Storage costs are another commonly omitted factor when considering bioenergy related GHG mitigation strategies. The use of crop residues or energy crops as bioenergy feedstocks is likely to require substantial storage activities due to seasonality of supply and the bulkiness of commodities. In recent years, some studies have examined storage losses and costs.

In this study, the effect of storage costs was examined with estimates developed based on the literature. In this case were calculated including an adjustment for dry matter losses. The average dry matter loss for indoor and outdoor storage was estimated to be 2.9 and 14.1 percent of total biomass, respectively. The total storage cost amounts to $23.1/dry ton/year and $10.8/dry ton/year for inside and outside storage, respectively including dry matter loss.

The FASOMGHG was then used to examine the effects of storage costs. In turn, it was found that storage cost consideration reduces marginal abatement with levels that vary depending on the level of the carbon dioxide equivalent price although the results were generally small. The cheaper outdoor storage method is slightly more competitive than the indoor storage method for lower carbon dioxide equivalent price ranges from $20 to $200. At higher prices, the lower storage loss dominates and indoor storage method is more advantageous. The storage cost inclusion change the portfolio shares of the strategies with feedstocks with lower storage requirements or dry matter losses increasing relative to those with higher costs/dry matter losses. However, as the price increases, the dry matter loss affects the price more. For the biomass mitigation strategy, except for $200 carbon dioxide equivalent price, the amount of emission reductions when considering dry matter loss for both indoor and outdoor systems is larger than that when not considering dry matter loss implying the storage systems with dry matter loss are more competitive than the storage systems without dry matter loss. For the total of all mitigation strategies, except for $20 carbon dioxide equivalent price, the total amount of emission reductions when considering dry matter loss in both indoor and outdoor storage systems is larger than the total amount of emission reductions without dry matter loss implying storage systems with dry matter loss were slightly more advantageous than without dry matter loss.

These findings could provide information for policy makers regarding to the desirableness of pursuing reductions in GHGs by using biomass for bioenergy.

The results of this study illustrate the need to include all costs of the mitigation of GHG emissions when designing policies or promoting mitigation alternatives. The changes to total GHG emissions when the effects of transaction and storage costs are included are small. However, the portfolio of optimal GHG mitigation alternatives is significantly affected, especially, under limited eligibility. Also, biomass dry matter losses during storage affect emission reductions as the carbon dioxide equivalent price changes.

A limitation of this study is that transaction costs were assumed to be a percentage of carbon dioxide equivalent prices. If the carbon dioxide equivalent price goes up and then transaction costs increase as well. However, there are many reasons for carbon dioxide equivalent prices to increase that are unrelated to transaction costs. Thus, the assumption of transaction costs as a percentage of carbon dioxide equivalent prices could over or under estimate these costs. Also, dry matter losses of biomass can easily be affected by weather; rainfall, temperature, and wind, etc. The weather is different from state to state in U.S. Thus, a consideration of the weather impacts on dry matter storage losses as they vary across states would be useful.

Future research needs to assess detailed estimates of the transactions costs for each of the GHG mitigation alternatives. Then all transactions costs could be more accurately modeled. Additionally, the reason why the transactions and storage costs and losses had such small effects needs further investigation. Finally future research should consider geographically specific weather effects on biomass dry matter storage because of the potential impact on the level of emission reductions.

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