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# Carbon markets, transaction costs and bioenergy<sup>1</sup>

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Payment for carbon sequestration by agriculture and forestry can provide incentives for adoption of sustainable agricultural practices. However, a project involving contracts with farmers may face high transaction costs in showing that net emission reductions are real and attributable to the project. This paper presents a model of project participation that includes transaction and abatement costs. A project feasibility frontier (PFF) is derived, which shows the minimum project size that is feasible for any given market price of carbon. The PFF is used to analyse how the design of a climate mitigation program may affect the feasibility of actual projects.

Keywords: Climate Policy, Greenhouse Effect, Carbon Sequestration, Agroforestry, Transaction Costs

## Introduction

Since the Kyoto protocol entered into force in February 2005 the international carbon market has grown considerably. In 2006 carbon transactions amounted to 1.6 billion tonnes of carbon dioxide (CO<sub>2</sub>) with a value exceeding \$30 billion. This study was motivated by the possibility that markets for greenhouse gas emissions may benefit farmers, by compensating them for adopting farm forestry systems that capture more CO<sub>2</sub> from the atmosphere than traditional cropping systems. Tree-based systems are a convenient way of reducing net carbon emissions by sequestering CO<sub>2</sub> from the atmosphere through the process of photosynthesis. The CO<sub>2</sub> absorbed by trees remains fixed in wood and other organic matter in forests for long time periods.

The global warming problem creates a demand for carbon credits, and high oil prices and uncertain supply have increased the demand for biofuels. Farmers are in a position to supply both carbon credits and biofuels. Farmers would normally not be able participate directly in the international carbon market, but they could participate in projects that function as intermediaries.

Landholders who supply carbon credits will incur different abatement costs (the costs per unit of uncertified emission reductions) and transaction costs (the costs of converting those emission reductions into a tradeable commodity). Abatement costs can be estimated as the opportunity cost of undertaking a carbon-sequestration activity rather than the most profitable alternative activity, or the cost of switching from the previous land use (baseline) to the proposed land use. In order to participate in the carbon market, it is not enough for projects to cover their abatement costs; they also have to incur transaction costs to certify the abatement services they provide. Both abatement and transaction costs must be considered in order to evaluate the feasibility of farmers participation in carbon markets.

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This paper starts with a brief overview of the international carbon market. Followed by the development of a model of project participation. The model considers the necessary conditions for a buyer (project developer) and a group of sellers (farmers) to engage in a carbon-sequestration contract. Based on this model, a project feasibility frontier (PFF) is derived that defines the minimum feasible project size for any given carbon price. The model is later extended to incorporate bioenergy production in addition to carbon sequestration. This involves the application of a rental price on carbon stocks during tree growth and a purchase price on carbon flows when trees are used as sources of energy. Results indicate that combining sequestration and bioenergy can considerably enhance the feasibility of projects involving farmer contracts. Throughout the paper currency is measured in US Dollars unless otherwise specified.

## Overview of the carbon market

This section presents a brief overview of the carbon market largely based on reports produced by the World Bank (Capoor and Ambrosi, 2006, 2007; Lecocq, 2004; Lecocq and Capoor, 2003, 2005) and supplemented by price data from other sources.

The international carbon market has been likened to a currency market, rather than a commodity market, because there are several fragmented markets that coexist, with different degrees of interconnection (Capoor and Ambrosi 2006, 2007).

Carbon transactions are classified into two types: *allowance based* and *project based* (Capoor and Ambrosi 2006). Allowance-based transactions are based on a cap-and-trade mechanism, where emission allowances are allocated by regulators, and emitters trade these allowances based on their marginal abatement costs. Project-based transactions consist of a buyer who purchases emission credits from a project that has been independently certified. Project-based transactions can occur even in the absence of a regulatory regime; as long as two parties agree on the transaction (Lecocq 2004). In both types of markets, emission credits are measured in tonnes of CO<sub>2</sub> equivalents (CO<sub>2</sub>e). This unit of exchange allows trade of other greenhouse gases based on their global warming potential. Table 1 presents a summary of recent activity in carbon markets. The number of transactions more than doubled between 2005 and 2006. In 2006 the aggregated value of the international carbon market exceeded \$30 billion, representing 1.6 billion tCO<sub>2</sub>e.

[Table 1 Here]

### Allowance-Based Transactions

The largest allowance market by far is the European Union Emission Trading Scheme (EU-ETS), which trades in European Union Allowances (EUA). Of the \$30 billion worth of transactions in 2006, \$24 billion were EUAs with a volume of 1.1 billion tCO<sub>2</sub>e. EUA prices have exhibited high volatility (Figure 1). Spot prices for Phase I transactions (which expired in December 2007) reached a peak of €30/tCO<sub>2</sub>e in April 2006, followed by a fast collapse when large amounts of verified emission data were released and the market realised that too many allowances had been allocated. In the second half of 2007 the Phase II price (labelled Dec 08 in Figure 1) became the reference price. The discrepancy between Phase I and Phase II prices was caused by the inability to bank (carry forward) unused allowances from Phase I, which made these allowances worthless beyond the compliance year of 2007. The design of Phase

II allows banking, which should bring continuity to the market and encourage investors to undertake more long-term investments (Capoor and Ambrosi, 2007).

**[Figure 1 Here]**

The New South Wales Greenhouse Gas Abatement Scheme (NSW GGAS) is small by world standards but represents an important development within Australia and it was one of the first carbon markets in the world. This is an allowance market (established in January 2003) that imposes mandatory emission benchmarks on all NSW electricity retailers and other parties. Participants are required to reduce their emissions to the level of the benchmark. Excess emissions can be offset by surrendering abatement certificates which can be traded (Lecocq 2004). These abatement certificates are created through project-based activities which may include capture of carbon through forestry, reductions in electricity demand by consumers and other options. Excess emissions that have not been offset at the end the compliance year attract a penalty. The current value of the penalty is A\$12. A total of 20 million certificates were traded in the NSW market in 2006, with an estimated value of \$225 million (Table 1). Between 2005 and early 2007, average weekly prices in the NSW market fluctuated between A\$10.70 and A\$14.75 (Figure 2); consistently above the penalty for non-compliance (Figure 3). Explanations for this seemingly irrational behaviour have included corporate image (firms do not want to be perceived as 'dirty') and expectations that fines will increase in the future (Capoor and Ambrosi 2006). Recently, prices have collapsed to just above AU\$5.10. Some analysts attribute this collapse to uncertainty regarding the attributes of the carbon market planned by the federal government.

**[Figure 2 Here]**

Other allowance markets include the Chicago Climate Exchange (CCX) and the UK emissions trading scheme. The former deals with voluntary emission reductions and reported \$38 million worth of transactions in 2006 (Table 1); the latter was the first country-wide emission-trading scheme (launched in March 2002), but it has reported only a small amount of transactions (not shown in Table 1).

### **Project-Based Transactions**

The largest representative of project-based markets is the Clean Development Mechanism (CDM) of the Kyoto Protocol, which trades on Certified Emission Reductions (CER). Within the CDM, 450 million tonnes of CO<sub>2</sub>e were traded in 2006, with a value of \$4.8 billion (Table 1). The secondary CDM represents financial institutions and funds that have engaged in secondary transactions of carbon portfolios with other banks or companies facing compliance obligations, these transactions amounted to a value of \$444 million in 2006 (Table 1).

The Joint Implementation (JI) Mechanism of the Kyoto Protocol deals in Emission Reduction Units (ERU). This market traded a total of 16 million tCO<sub>2</sub>e in (2006) with a value of \$141 million (Table 1). Most of these transactions came from projects in Russia, Eastern Europe and New Zealand. Other project-based transactions, which include the voluntary market, amounted to a value \$79 in 2006 (Table 1).

A disadvantage of project-based transactions is the time lag between signing of a contract and the time when emission credits are delivered. This, coupled with the fact that project performance is uncertain, means that CERs have certain risks not present

in allowance markets (Capoor and Ambrosi, 2006), and CER buyers in general have offered lower prices to compensate for these risks. Another factor that may lead to lower prices is that project-based exchanges tend to exhibit higher transaction costs than allowance exchanges. However Lecocq and Capoor (2003, p.20) state that prices for emission reductions from “small projects with a strong sustainable development contribution command premiums in the marketplace”, they also point out that “Retailers report a marked preference by customers for community-based agro-forestry and other forestry deals.”

Average CER prices in 2005 were approximately \$7.20 (range \$2.60 to \$14.90), increasing to \$10.95 (range \$6.70 to \$24.80) in 2006 (Figure 3). The secondary market exhibited higher average prices, but with a decrease between 2005 and 2006 (from \$22.20 to \$17.70). The prices of ERUs under Joint Implementation were the lowest, with averages of \$6.00 and \$8.60 in 2005 and 2006 respectively.

### [Figure 3 Here]

As of January 2008, a total of 901 projects had been registered with the CDM Executive Board, with an expected delivery of 1.15 billion CERs until the end of 2012. Of these, 53% are large-scale projects and 43% are small-scale<sup>2</sup>. In terms of regions, Asia dominates with 80% of emission reductions, followed by Latin America with 10% (Capoor and Ambrosi, 2007).

The land-use change and forestry (LUCF) sector accounted for only 1% by volume. LUCF assets face two disadvantages: they require complex methodologies, and the EU-ETS denies market access to LUCF projects<sup>3</sup> (Capoor and Ambrosi 2006). Thus, the current lack of LUCF projects has been caused by methodological complications rather than by any obvious lack of competitiveness of biological mitigation relative to energy efficiency.

## A model of project participation

This paper focuses on project-based transactions. The model of project participation of Cacho and Lipper (2006) provides the basis of this analysis. The original model was modified and extended to account for both temporary CERs associated with carbon accumulation during tree growth and permanent CERs associated with renewable energy production.

Consider a project composed of one buyer and many sellers. The buyer is a project developer and the sellers are farmers. The sellers are paid for adopting forestry land uses that sequester carbon above a baseline. The buyer purchases these carbon offsets and sells them in the CER market. So the buyer acts as an intermediary between the landholders and the international carbon market.

Let sellers be identified by an index  $j = 1, 2, \dots, n$ . A seller  $j$  will participate in the project if the reward received for carbon sequestration ( $v_{Cj}$ ) is larger than the opportunity cost of switching land uses (the abatement cost,  $v_{Aj}$ ) plus the transaction cost of participating in the project ( $v_{Tj}$ ). The condition for seller participation is:

<sup>2</sup> Data from CDM web site at <http://cdm.unfccc.int/Statistics/index.html>

<sup>3</sup> A linking directive approved by the European Parliament in 2004, allows participants in the EU-ETS market to use emission-reduction credits from the CDM, but this does not include projects in the LUCF sectors.

$$v_{Cj} > v_{Aj} + v_{Tj} \quad (1)$$

with the three variables measured in terms of present value. The buyer will implement a project if the present value of carbon payments received in the CER market ( $V_C$ ) is at least equal to the present value of payments to smallholders (the abatement cost to the buyer,  $V_A$ ) plus the transaction costs of designing and implementing the project ( $V_T$ ). The condition for buyer participation is:

$$V_C \geq V_A + V_T \quad (2)$$

### Carbon Payments and Abatement Costs

The present value of carbon payments received by seller  $j$  is:

$$v_{Cj} = a_j \sum_t p_F (C_{jt} - C_{0t}) (1 + \delta_s)^{-t} \quad (3)$$

where  $a_j$  is the area of land converted to forestry in year zero;  $(C_{jt} - C_{0t})$  represents the stock of carbon above the baseline per hectare of land in year  $t$ ;  $p_F$  is the farm price of carbon and  $\delta_s$  is the seller's discount rate.

For the buyer, carbon payments are given by the discounted sum of payments obtained by accumulating the carbon offsets produced by all landholders in the project, certifying them and selling them in the CER market:

$$V_C = \sum_j a_j \left[ \sum_t p_C (C_{jt} - C_{0t}) (1 + \delta_B)^{-t} \right] \quad (4)$$

where  $p_C$  is the rental price per tonne of carbon and  $\delta_B$  is the buyer's discount rate.

Abatement costs are the costs of producing one unit of uncertified carbon sequestration services. For sellers abatement costs are measured as the opportunity cost of not undertaking the most profitable land-use activity as a result of adopting a prescribed activity that stores additional carbon. This opportunity cost is the present value of the stream of net revenues foregone as a result of participating in the project. The abatement cost to seller  $j$  is:

$$v_{Aj} = a_j \sum_t (r_{0t} - r_{jt}) (1 + \delta_s)^{-t} \quad (5)$$

where  $r_{0t}$  and  $r_{jt}$  represent the net revenues per hectare in year  $t$  for the baseline and the proposed land use respectively.

The abatement cost to the buyer is the present value of the stream of payments to landholders for carbon-sequestration services:

$$V_A = \sum_j a_j \left[ \sum_t p_F (C_{jt} - C_{0t}) (1 + \delta_B)^{-t} \right] \quad (6)$$

In order to implement these equations we require information on carbon sequestration rates and net revenue streams for the baseline and the forestry activity.

Carbon trajectories for the baseline and the project activity,  $C_0(t)$  and  $C_j(t)$  used below do not consider soil carbon, which is more expensive to measure than biomass carbon.

For projects that are known to have non-decreasing effects on soil carbon it may not be necessary to measure this pool after the baseline is established. As a general rule, reforestation projects in agricultural lands tend to increase soil carbon and, if the marginal cost of measuring this carbon pool is greater than the marginal benefit of the carbon credits obtained, the project developer would prefer not to measure this pool (see Cacho et al 2004).

Net revenue streams for the baseline and the project activity,  $r_{0t}$  and  $r_{jt}$ , are calculated based on inputs (labour, fertiliser and seedlings etc.) and outputs (fruit, timber, resin etc.) for the region of interest. In this case we selected a fast-growing tree used for pulp and timber (*Acacia mangium*) which is popular in Indonesia and represents one of the main plantation trees in Sumatra.

The expected amount of carbon sequestered in aboveground biomass was estimated using a Gompertz function:

$$C_t = \beta_1 \left( \frac{\beta_2}{\beta_1} \right)^{\exp(\beta_3 t)} \quad (7)$$

The parameter values ( $\beta_1, \beta_2, \beta_3$ ) were set to (282.3, 1.216, 0.517). The mean carbon stock of this system (130 tC/ha) is of similar magnitude to the systems used in the *Scolet Te* smallholder project in Mexico ( $128 \pm 25.6$  tC/ha) reported by de Jong et al. (2004).

The baseline is assumed to be an annual cassava crop (NPV = \$2,705/ha) and the project activity is an *A. mangium* plantation harvested every 8 years (NPV = \$2,367/ha). Based on equation (5), the seller abatement cost for this project, under the assumption of identical sellers, is therefore:  $v_A = a(2,705 - 2,367) = a 338$ . The discount rates were set at  $\delta_B = 0.06$  and  $\delta_S = 0.15$  to reflect the high cost of credit faced by smallholders in Indonesia.

## Transaction Costs

Cacho, Marshall and Milne (2003, 2005) present a typology of transaction costs applicable to carbon-sink projects. In this study we aggregate their seven categories into five and distinguish between the costs borne by buyers and sellers.

Transaction cost assumptions are presented in Table 2. These values are based on estimates from the literature (see Cacho and Lipper, 2006 for details). The original five transaction-cost categories are disaggregated to account for variation in the units of measurement. The expanded classification is presented in the ‘sub-type’ column (Table 2), where number subscripts denote the different cost types. For example, there are three types of monitoring costs;  $W_{M1}$  (\$/ha/y),  $W_{M2}$  (\$/y), and  $W_{M3}$  (CER/y). Transaction costs for sellers were calculated based on the time required for different activities multiplied by the wage rate.

[Table 2 here]

*Search and negotiation* costs for the buyer include consultation and negotiation sessions with farmers, establishment of the baseline and estimation of carbon flows of the project, design of a monitoring plan, establishment of permanent sampling plots and preparation of a Project Design Document (PDD) for submission to the CDM Executive Board ( $W_{S1}$ ); they also include the design of individual farm plans and

contracts ( $W_{S2}$ ). For sellers these costs include attendance to information sessions, undertaking training and participating in the design of farm plans and contracts ( $w_S$ )

*Approval costs* for the buyer include approval of the project by the host government, validation of the project proposal by a Designated Operational Entity (DOE) and a registration fee upon submission of the PDD to the CDM Executive Board ( $W_A$ ). The approval cost for sellers consists of obtaining local government permission to participate in the project ( $w_A$ ).

*Project management costs* for the buyer include purchase of IT infrastructure and establishment of a local office ( $W_{P1}$ ); as well as maintaining databases and software, administering payments to farmers, coordinating field crews and paying salaries ( $W_{P2}$ ). For sellers these represent the annual costs of attending project meetings ( $w_P$ ).

*Monitoring costs* for the buyer include randomly checking carbon stocks reported by farmers ( $W_{M1}$ ); verification and certification of carbon stocks by a DOE ( $W_{M2}$ ); and an adaptation fee payable to the CDM Executive Board to help poor countries adapt to climate change ( $W_{M3}$ ). For sellers they consist on measuring trees, filling in report forms and delivering them to the project office ( $w_M$ ).

*Enforcement and insurance costs* for the buyer include an allowance per farm for settlement of disputes ( $W_{E1}$ ); and the cost of maintaining a buffer of carbon stocks that are not sold ( $W_{E2}$ ) to cover for the eventuality that the project will under-perform. For sellers they include an allowance for the costs of protecting their plots from fire and the cost of participating in dispute resolution ( $w_E$ ).

Using the expanded notation introduced in Table 2, transaction costs are calculated as:

$$V_T = W_{S1} + W_A + W_{P1} + nW_{S2} + \sum_t \left[ \frac{W_{P2} + W_{M2} + n(W_{E2} + aW_{M1})}{(W_{M3} + W_{E1})(C_{jt} - C_{0t})p_C} \right] (1 + \delta_B)^{-t} \quad (8)$$

$$v_{jT} = w_S + w_A + \sum_t [w_P + w_E + a w_M] (1 + \delta_S)^{-t} \quad (9)$$

## Carbon Prices

The farm price of carbon ( $p_F$ ) must be set at a level that satisfies conditions (1) and (2). The feasible range of farm prices is influenced by the market price of carbon ( $p_C$ ). Here we express both these variables as annual rental prices per unit of biomass carbon stored in trees. This avoids the need of dealing with the permanence problem (see Cacho et al 2003) by imposing arbitrary carbon accounting procedures or constraining the duration of temporary CERs<sup>4</sup>. To estimate rental prices consider the present value ( $PV$ ) of an asset that yields a perpetual stream of annual payments  $Y$  discounted at rate  $i$ :

<sup>4</sup> A temporary CER or 'tCER' is a CER issued for an AR project activity which expires at the end of the commitment period following the one during which it was issued (UNFCCC document FCCC/CP/2003/6/Add.2).



$$PV = \frac{Y}{1 - e^{-i}} \quad (10)$$

In a perfect market the ratio  $Y/PV$  is equivalent to the rental price of the asset expressed as a proportion of the asset's value. If we let the asset be a CER (expressed as a tonne of CO<sub>2</sub>e) valued at price  $p_{CER}$ , and consider that the process of photosynthesis converts 3.67 units of CO<sub>2</sub> into one unit of biomass carbon, then the rental price of biomass carbon is:

$$p_C = 3.67(1 - e^{-i})p_{CER} \quad (11)$$

Clearly, the CER price places an upper limit on the feasible farm price, because the buyer would set  $p_F \leq p_C$  even in the absence of transaction costs.

## Analysis of Project Feasibility

In the analysis presented here we assume that the project developer establishes individual contracts whereby farmers agree to change their land use from cropping to forestry and receive payments for the carbon captured in their trees. For simplicity the project is assumed to consist of  $n$  identical farms each consisting of  $a$  hectares. In designing the project the buyer decides on the number of participants ( $n$ ), the carbon price paid to farmers ( $p_F$ ) and other features such as monitoring and risk-mitigation strategies.

Based on conditions for project participation (1) and (2) and dropping the  $j$  subscripts for simplicity, the project is feasible if the following two conditions are satisfied:

$$v_C(a, p_F, C(t), \delta_S) - v_A(a, r(t), \delta_S) \geq v_T(w, \delta_S) \quad (12)$$

$$V_C(a, p_C, C(t), \delta_B) - V_A(a, p_F, C(t), \delta_B) \geq V_T(a, n, p_C, C(t), W, \delta_B) \quad (13)$$

Where  $C(t)$  is the eligible carbon trajectory ( $C_{jt} - C_{0t}$ ),  $r(t)$  is the trajectory of opportunity costs ( $r_{0t} - r_{jt}$ ), and  $w$  and  $W$  are vectors of transaction costs for seller and buyer respectively (based on Table 2). The expressions on the left of the inequalities are the carbon margins (carbon payments minus abatement costs) and the expressions on the right are the transaction costs. Now we can solve the model for any set of values of the arguments in the functions above and determine when both conditions (12) and (13) are satisfied.

The first step in the analysis is to determine bounds for the farm price for any set of values of other arguments in (12) and (13). This involves finding the minimum price acceptable to the average seller ( $p_S$ ) and the maximum price the buyer is willing to pay ( $p_B$ ). Let  $p_S$  be the value of  $p_F$  which makes  $v_C - v_A = v_T$ , and let  $p_B$  be the value of  $p_F$  which makes  $V_C - V_A = V_T$ . The project is feasible only if  $p_B \geq p_S$ , and the farm price falls within the range  $p_S \leq p_F \leq p_B$ . The actual value of  $p_F$  depends on the market power of the participants and the outcome of negotiations between buyer and sellers.

### Minimum feasible project size

Now consider the effect of project size (or the number of farmer contracts) on the seller price ( $p_S$ ) and the buyer price ( $p_B$ ). Given our assumptions that each farmer engages in an individual contract with the buyer and that all farms are represented by the "average" farm, this analysis involves solving for  $p_S$  and  $p_B$  for any given value of

$n$  (Figure 4). The buyer's price increases at a decreasing rate as the number of farms under contract increases; whereas the seller's price remains constant, because individual farm costs are independent of the number of farms under contract.

[Figure 4 here]

In Figure 4, the minimum number of contracts (farms) is that at which  $p_B = p_S$ . For the base parameter values, any project size larger than 242 farms will yield a surplus ( $p_B - p_S$ ).

### Project Feasibility Frontier

The breakeven point at which  $p_B = p_S$  will shift as the values of the arguments in equations (12) and (13) change. It is of particular interest to determine how the position of this point is affected by the market price of CERs ( $p_{CER}$ ). This is illustrated in Figure 5. The curve in Figure 5 forms a frontier, because projects falling below or to the left of this curve are not feasible under the given transaction and abatement costs, whereas projects that fall above or to the right of the frontier are feasible. We call this curve the project feasibility frontier (PFF).

[Figure 5 here]

In essence, the PFF is the set of points at which the carbon margins just cover the transaction costs for both parties. The breakeven value of  $n$  for any given  $p_{CER}$  can then be converted to CER units based on the carbon-sequestration rate per unit area, thus allowing comparison with projects in the energy sector (see below). The PFF is a convenient way of exploring the influence of land productivity, individual transaction costs, or any other exogenous variable on the viability of a project. A new PFF can be derived by changing any exogenous variable and repeating the process; thus providing a useful tool for sensitivity analysis.

### Introducing Biomass Energy (Fuel Switching)

Now assume that the biomass harvested every eight years is used to produce biofuel, so it is possible to claim CERs on the reduced emissions caused by replacing a fossil fuel, such as diesel or coal, with biomass fuel. The biomass fuel emissions receive carbon credits because they represent CO<sub>2</sub> recently absorbed from the atmosphere, rather than CO<sub>2</sub> absorbed millions of years ago as is the case with fossil fuels. Therefore biomass fuel emissions are said to be greenhouse neutral. The number of CERs that can be claimed by the project depend on the fuel that is being replaced. The following assumptions are made:

- Wood biomass contains 50% carbon;
- only 70% of biomass is usable as a fuel;
- the net calorific values (NCV) of wood, diesel and coal are as shown in Table 3;
- the carbon content factors (CCF) of diesel and coal are as shown in Table 3.

[Table 3 here]

To estimate the number of CERs that can be claimed by the project for fuel substitution we need to obtain a wood-replacement factor for the fossil fuel in

question. These factors (t of CO<sub>2</sub> fossil-fuel emissions avoided per t of carbon harvested from trees) are  $\gamma_1 = 1.425$  for diesel and  $\gamma_2 = 1.829$  for coal. The required calculations are shown in Table 3. The present value of the fuel-substitution activity can then be calculated as:

$$V_k = \sum_{\tau \in t_H} \gamma_k H_\tau p_{CER} (1 + \delta_B)^{-\tau} \quad (14)$$

where  $H_\tau$  is the amount of carbon harvested in year  $\tau$ ,  $t_H$  is the set of harvest years and the subscript  $k$  represents either diesel (1) or coal (2). The value of  $V_k$  is then added to the present value of rental carbon ( $V_C$ ) to obtain the total value of carbon when a biofuel component is included in the project. The critical project-design variables can then be calculated following the same process as before.

The introduction of biofuel in the project complicates the measurement of CERs because now there are two components: (1) annual rental payments on carbon stocks above the land-use baseline and (2) purchase payments on the flows of CO<sub>2</sub> emissions replaced every harvest year relative to a baseline given by the fossil fuel being replaced (diesel or coal). Thus it is now more appropriate to report the project size in terms of carbon flows rather than number of farms. Average CER flows per unit area (t CO<sub>2</sub>/ha/y) are calculated for every eight-year rotation as consisting of 118 t CO<sub>2</sub>/ha/y during tree growth plus either 46.1 t CO<sub>2</sub>/ha/y or 59.2 t CO<sub>2</sub>/ha/y for diesel or coal, based on the replacement factors  $\gamma_k$ . CER flows per unit area are then multiplied by the project area to calculate the (CER) size of the project in terms of t CO<sub>2</sub>/y. For reference, the production of 200,000 CERs, requires 1,129 farmer contracts under the base assumptions.

The effect of CER price ( $p_{CER}$ ) on minimum project size flattens out at  $p_{CER}$  values beyond about \$10 or \$20/tCO<sub>2</sub>e depending on whether the project includes a biofuel component (Figure 6). There is a considerable gap between the base case and the biofuel cases, but the actual gap may not be as large if the costs of establishing a biofuel plant have to be covered by the project.

[Figure 6 here]

## Concluding Comments

In this study we have assumed that farms participating in a project are homogeneous and are willing to supply carbon offsets at a fixed price, as long as abatement and transaction costs are covered. Essentially this assumption implies that the supply of carbon-sequestration services is perfectly elastic. This simplifies the analysis by allowing us to calculate transaction costs, abatements costs and carbon payments for the average farm, and then multiply the results by the number of farms to obtain project-level results. This simplification also makes it computationally feasible to derive the project-feasibility frontier (PFF) for a large number of scenarios, thus helping us understand the influence of different types of transaction costs and other assumptions on the feasibility of a project. In deriving the PFF we implicitly assume that there are as many farms available as needed by the project to cover transaction costs. In reality, a limited number of farms is available in a region and there can be considerable variability between farms in terms of size and productive capacity. Antle and Valdivia (2006) observed this variability in US agriculture and pointed out that it may have important implications for policy analysis of payments for environmental

services. Their minimum-data approach to the derivation of supply functions offers interesting possibilities for extension of the present study.

The analysis of bioenergy presented above implicitly assumes either that there is an existing plant in the region which can take the harvested wood and produce a fuel such as biodiesel or ethanol, or that local power demand can switch from fossil fuel to woodfuel at no cost. This replacement, however, may require an investment in new equipment and this investment would become part of the buyer's abatement cost. Different types of investments could be evaluated, one option would be the replacement of a diesel or coal generator with a wood-fired generator, another option would be the construction of lignocellulosic ethanol plant that can convert wood into liquid fuel. It is also possible that the introduction of a biofuel component into the project will change transaction costs by, for example, reducing monitoring and enforcement costs because farmers have to supply their harvest to the biofuel plant, thus providing a cheap audit on carbon outputs. These are interesting topics for future research.

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**Table 1. Summary of carbon transactions in 2005-2006. Source: Capoor and Ambrosi (2007).**

	Volume Mt CO <sub>2</sub> e		Value Million \$US	
	2005	2006	2005	2006
Allowance markets				
EU-ETS	321	1,101	7,908	24,357
NSW GGAS	6	20	59	225
CCX	1	10	3	38
Project-based markets				
Primary CDM	341	450	2,417	4,813
Secondary CDM	10	25	221	444
JI	11	16	68	141
Other	20	17	187	79
Total	710	1,639	10,863	30,097

**Table 2. Transaction cost assumptions for base case.**

Cost type	sub-type	Cost	Units
<b>Buyer (project manager)</b>			
Search and Negotiation	$W_{S1}$	84,500	\$
	$W_{S2}$	500	\$/farm
Approval	$W_A$	7,000*	\$
Project Management	$W_{P1}$	20,000	\$
	$W_{P2}$	70,000	\$/y
Monitoring	$W_{M1}$	8	\$/ha/y
	$W_{M2}$	15,000	\$/y
	$W_{M3}$	0.02	CERs/y
Enforcement and Insurance	$W_{E1}$	0.1	CERs/y
	$W_{E2}$	100	\$/farm/y
<b>Sellers (farmers)</b>			
Search and Negotiation	$w_S$	34.40	\$
Approval	$w_A$	6.88	\$
Project Management	$w_P$	8.60	\$/y
Monitoring	$w_M$	5.16	\$/ha/y
Enforcement and Insurance	$w_E$	20.64	\$/y

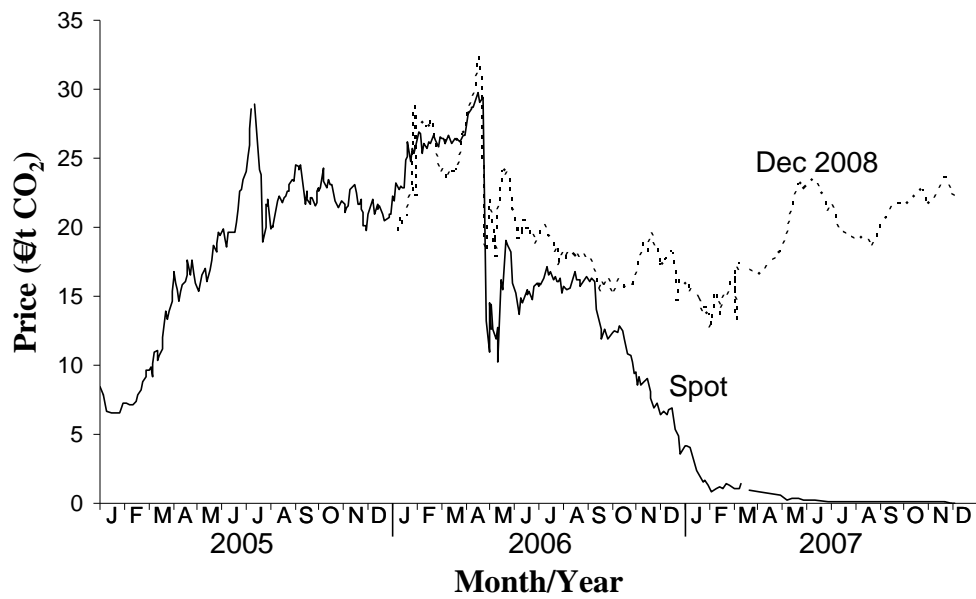
\* Plus a registration fee that varies with project size <15,000 CERs=\$5,000; 15,000 to <50,000 CERs=\$10,000; 50,000 to <100,000 CERs=\$15,000; 100,000 to <200,000=\$20,000; >200,000 CERs = \$30,000

**Table 3. Energy and carbon content of alternative fuels.**

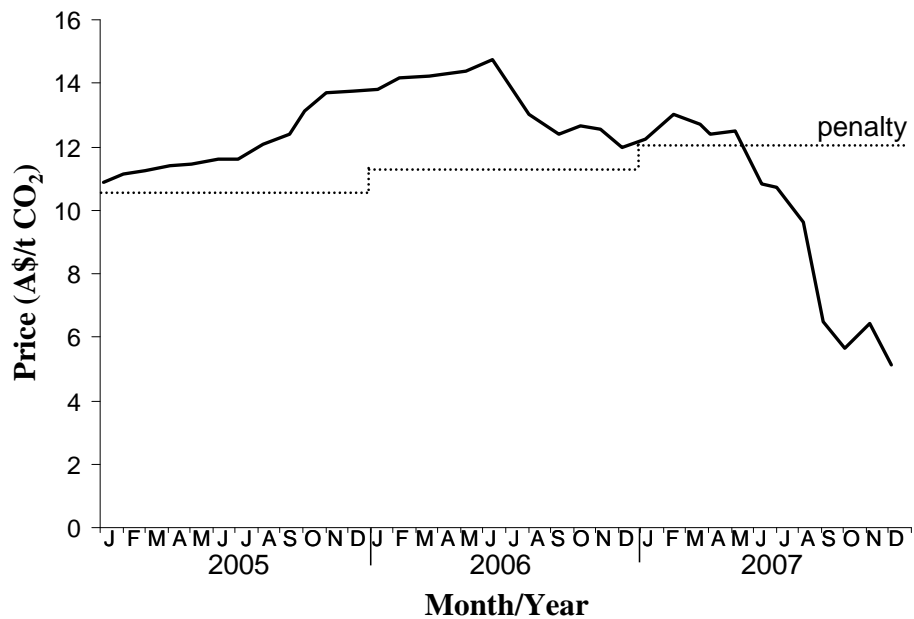
Variable	Fuel			Units
	Wood	Diesel	Coal	
NCV - Net calorific value	13.8 <sup>a</sup>	43 <sup>b</sup>	28.2 <sup>b</sup>	MJ / kg fuel
CCF - Carbon content factor <sup>b</sup>		0.0201	0.0258	kg C / MJ
Calculations				
a Carbon produced by burning fuel = NCV × CCF		0.864	0.728	kg C / kg fuel
b Wood required to replace fuel = NCV wood / NCV fuel		3.116	2.043	kg wood / kg fuel
c Equivalent carbon produced by wood = a/b		0.277	0.356	kg C / kg wood
d CO <sub>2</sub> replaced by wood = 3.67 × c		1.018	1.307	kg CO <sub>2</sub> / kg wood
e CO <sub>2</sub> emissions replaced by biomass carbon ( $\gamma_k$ ) <sup>c</sup> = 0.7 × d / 0.5		1.425	1.829	kg CO <sub>2</sub> / kg biomass C

Sources: <sup>a</sup> FAO 2004; <sup>b</sup> Kazunari (2005) coal values are for coking coal;

<sup>c</sup> assumes biomass contains 0.5 carbon and only 0.7 of biomass is usable for fuel

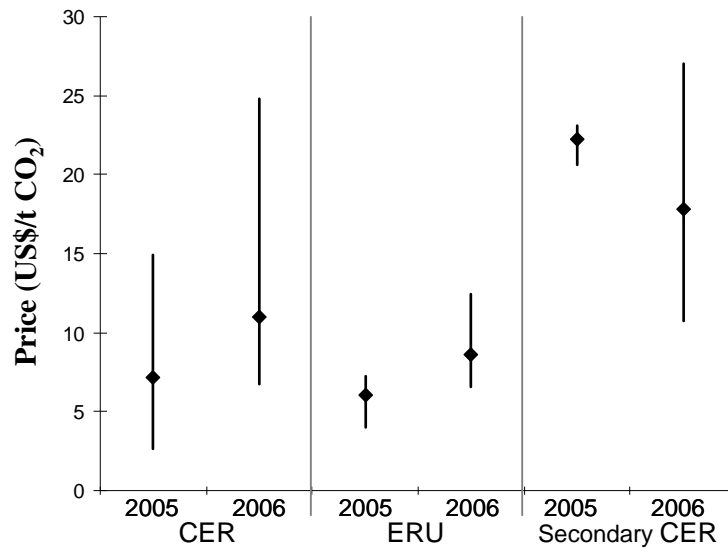


**Figure 1. Prices of European Emission Allowances (2005-2007); spot prices are for Phase I allowances (which expired in December 2007); December 2008 prices represent phase II contracts. Sources: The Economist (2005), Capoor and Ambrosi (2006, 2007), Katoomba Group (2007).**

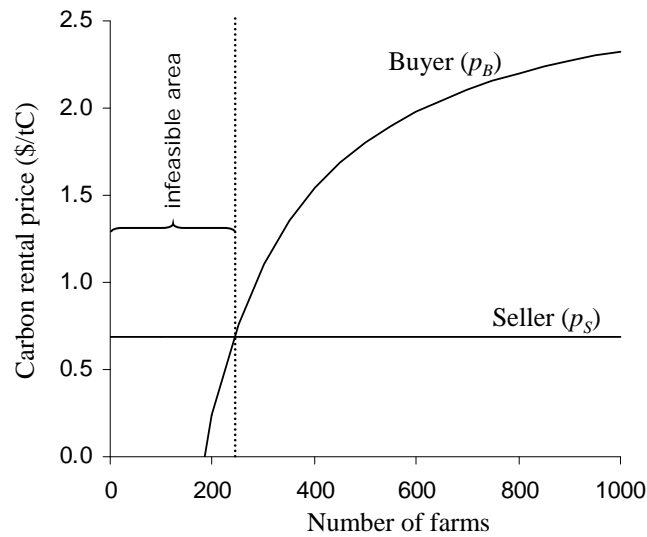


**Figure 2. Average weekly prices of NSW Greenhouse Gas Abatement Certificates (2005-2007); the dotted line represents the penalty for excess emissions not covered by certificates. Source: Katoomba Group, Ecosystem Marketplace, average weekly prices.**





**Figure 3. Average prices and ranges of project-based carbon transactions for 2005 and 2006.**  
Source: Capoor and Ambrosi (2007).



**Figure 4. The breakeven number of farms, indicated by the dotted line, is calculated as the point at which the maximum price the buyer is willing to pay ( $p_B$ ) equals the minimum price the seller is willing to accept ( $p_S$ ).**

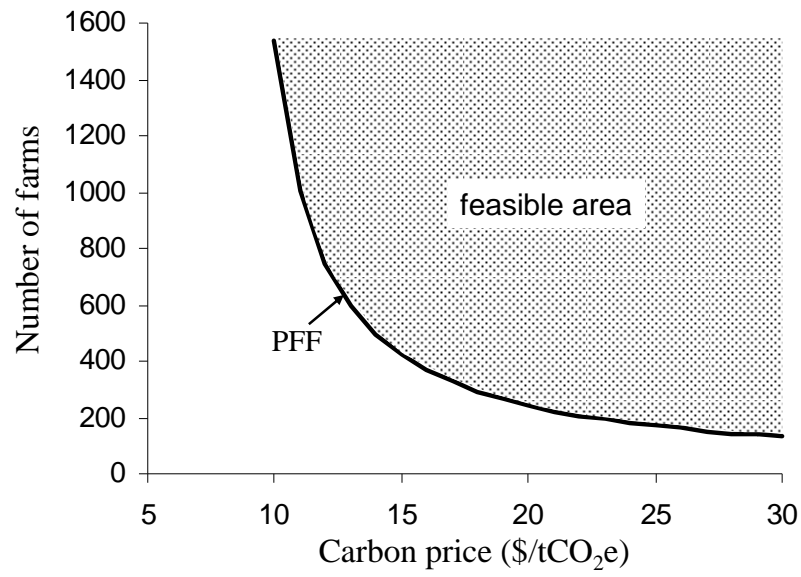


Figure 5. Project Feasibility Frontier for the base parameter values.

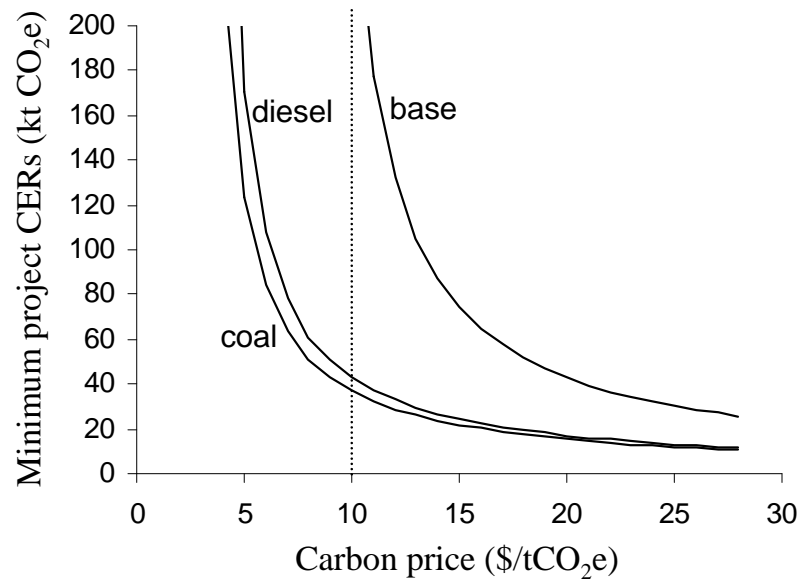


Figure 6. The project feasibility frontier for the base project and two alternative bioenergy projects replacing either diesel or coal. The dotted line indicates the approximate CER price (\$10) in 2006.