THE ECONOMIC IMPACT OF NON-COMPLIANCE IN

THE CARBON-OFFSET MARKET

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ABSTRACT

Carbon offset markets have been suggested as a cost effective means of reducing GHG emissions. This paper develops a model of heterogeneous emitters and producers to examine the consequences of non-compliance on the performance of the carbon-offset market. The analysis begins with the derivation of demand and supply curves for carbon offsets based on perfect compliance. The paper then considers the impact of non-compliance by producers on the supply of carbon offsets. Results show that the extent of producers' non-compliance decreases with an increase in the audit probability and/or an increase in the penalty per unit of non-compliance. In addition, the number of producers participating in the carbon offsets market is shown to increase with an increase in the carbon-offset price. Based on the supply and demand curves, the analysis then considers the price and the quantity traded that are established by private firms that are engaged in carbon offset trading. The key role of the traders is to guarantee, based on the amount of monitoring that is undertaken, that the emitters purchase only carbon offsets that actually correspond to sequestered carbon. Both an oligopolistic and a monopolistic trading sector structure are considered. The analysis then examines two different organizational structures for the group that monitors producer compliance – a group owned by the firms and a government-run agency. The results of the analysis show that both monitoring groups always undertake sufficient monitoring to ensure that full compliance is achieved – thus, while non-compliance is possible, it does not occur in equilibrium. Since the level of monitoring effectively determines the amount of carbon that is sequestered and that can be traded, a monitoring group owned by the traders can achieve monopoly profits for the sector, even when it is oligopolistic. Although the formation of a government monitoring agency can potentially increase traded output and lower the price paid by emitters, these changes are likely to be small, particularly when the trading sector is monopolistic.

INTRODUCTION

The growing amount of greenhouse gases (GHG) in the atmosphere is regarded as responsible for global warming. Many countries, especially the industrialized ones, have been considering policy actions to address their net GHG emission reductions. Persistent climate policy negotiations over more than a decade were finalized with the Kyoto Protocol (KP), the first international and legally binding agreement on climate protection, which came into force on February 16, 2005. The Protocol requires Annex B countries to reduce their emissions of six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by at least 5 percent below 1990 levels over the first commitment period 2008-2012. A key feature of the KP is its use of market based instruments to deal with climate change in a cost-efficient way. The Protocol allows for the use of three flexible implementation mechanisms: international emissions trading (IET), Joint Implementation (JI) and the Clean Development Mechanism (CDM).

The treatment of sinks was left open during Kyoto negotiations. The negotiating parties reached a compromise on this issue during the Conference of Parties in Bonn (July 2001) by allowing a substantial credit to Australia, Canada, New Zealand, Japan and Russia for carbon dioxide sinks (Böhringer, 2004). The subsequent COP7 in Marrakech (November 2001) approved carbon sinks to be used as a means of carbon reduction within the Annex B countries.

A sink is defined as any process that removes CO_2 from the atmosphere (United Nations Framework Convention on Climate Change, 1992). Forests and agricultural soil have the potential to assist in decreasing the concentration of GHG in the atmosphere by storing CO_2 in soil or in the trees. Farmers can increase their soil sink potential by applying Best Management Practices (BMPs) that enhance carbon sequestration through improvements to soil, nutrient and livestock management practices (Fulton et. al., 2005), while forests managers can enhance carbon sequestration through afforestation, reforestation and forest management. Each unit of carbon stored in the soil or trees can be used to offset one unit of emission released from large final emitters (LFEs). If these

units can be verified and certified, they can be sold as carbon offsets or credits in a carbon-offset market.

Allowing trading of carbon offsets is one of the institutional innovations of Kyoto. Carbon-offset markets have been suggested as a cost effective means of reducing GHG emissions (Vercammen, 2002, Bloomfield et. al., 2003). An offset system can increase the efficiency of meeting emission targets by allowing entities with potential GHG reduction capabilities to supply offset credits to those that are required to reduce GHG emissions. This option offers greater flexibility in achieving emission reductions and hence the possibility of reaching environmental goals at a lower cost than would be possible if the countries did not have this alternative. The carbon offset system in Canada is still in the development stage. The decision whether Canada will elect to use sinks to meet a portion of its KP targets in the first commitment period is to be done by late 2006.

About half of Canada's total GHG emissions by 2010 is anticipated to be released from LFEs (Government of Canada, 2005). Based on their historical emissions, level of production and an emission intensity factor, the government will allocate a large portion of initial permits to LFEs. Each permit gives LFEs the right to emit one unit of emission; LFEs will be allowed to trade these permits. High cost companies can meet their additional permit requirements by purchasing permits from emitters with lower abatement costs. Permits will be traded until the point where the marginal abatement costs of all traders will be equalized. It is this cost equalization aspect that makes permit trading more cost-efficient than regulatory approaches. Provided that sinks will be elected from the government as an option, LFEs can use offset credits as well to address their emission potential. In the general discussion we talked about trading among LFEs but we are going to abstract away from it for the rest of the paper in order to concentrate on the issue of carbon offsets.

Even though both forests and agricultural soil can serve as a sink, the focus of this work will be on soil carbon offsets created as result of adapting BMPs under a contract. Whether or not the market for carbon offsets will emerge depends on a number of factors which mainly are related to the profitability of the BMPs and the costs of a carbon contract. BMPs build up organic matter in the soil. Adoption of these practices brings a number of environmental and economic benefits such as: improving soil quality and

increasing productivity, improving moisture retention and decreasing irrigation needs, and decreasing soil degradation and erosion. Because of the economic benefits, farmers have incentives to adopt BMPs voluntarily. In addition, they may find an incentive to adopt these practices in order to participate in carbon-offset market. Whether or not farmers will produce carbon offsets by applying BMPs under a sequestration contract depends on the net benefits of such an undertaking.

Provided that a market for carbon offsets emerges, the effectiveness of the market depends, in part, on the degree to which buyers and sellers in the market comply with the terms of the contracts they sign. Compliance, however, should not be presumed. Each tonne of emission reduced or offset created has a value that is equal to the price of a permit or a credit. This value can create an incentive for emitters to underreport their actual emissions and/or for sink generators to overreport the carbon offsets created from their emission reducing actions.

Non-compliance will be an issue as long as monitoring is imperfect. The possibility of non-compliance arises because it is costly to determine the actions of emitters or producers. Because of this cost, producers as well as emitters are in a position to misreport. The monitoring and verification costs vary depending on the frequency of monitoring and verification, accuracy of measurement, the quantification techniques employed and the size of the contract.

A number of studies have examined non-compliance and enforcement in transferable permit systems. Malik (1990) examines the consequences of non-compliance for a transferable discharge permits (TDP) market and analyses under which conditions markets will retain their efficiency. Keeler (1991) extends Malik's work by considering how a tradable permits' system performs relative to uniform standards system under different penalty structures faced by the firms. Work from Hahn (1984) considers the effects of market power and non-compliance in permits markets. Egtern and Weber (1996) show that, when a firm has market power in the permit market, the initial allocation is fundamental in determining prices and levels of compliance for all participants in the permit market. While these studies have explored TDP market when emitters violate their emission levels, attention has not been paid to compliance issues created when the producers of carbon offsets fail to comply. Thus, the purpose of this

paper is to examine overall cost effectiveness of the carbon-offset market when non-compliance on both the demand side (i.e., the LFEs) and the supply side (e.g., agricultural/forestry producers) of the offset market is introduced. Since compliance can be increased if more enforcement is undertaken, the paper explores the optimal amount of resources that should be allocated to enforcement.

In recent years, considerable attention has been paid to compliance by agricultural producers with the terms of the programs and policies in which they participate. Giannakas and Fulton (2000) introduce misrepresentation and cheating into the policy analysis of output quotas and subsidies. The paper analyses how the introduction of cheating and enforcement costs changes the welfare effects of the policy instruments. They show that a combination of policy instruments can result in a more efficient income transfer to producers than using policy instruments separately.

Recent work by Giannakas and Kaplan (2005) introduces farmers' non-compliance in the economic analysis of the highly erodible lands policy. They examine the economic determinants of producer non-compliance and the determinants of the equilibrium enforcement policy.

The analysis that will be performed in this paper is going to introduce non-compliance in the economic analysis of carbon-offset market. Monitoring and verification has the potential to reduce or deter non-compliance. One prospective approach to address monitoring and verification of the carbon-offsets is the involvement of a trader in the market with the responsibility of undertaking carbon offsets trading. Traders will buy carbon offsets offered from producers and sell verified carbon offsets to emitters. Even though traders can have different structures – e.g., for profit firm, governmental agency, an association of LFEs or an association of carbon offset suppliers, this paper will focus on trading undertaken by for profit firms. In this case, expect a monopoly or oligopoly structure because of the fixed costs involved in running a carbon trading scheme.

The analysis then examines two different organizational structures for the group that monitors producer compliance – a group owned by the firms and a government-run agency. The optimal amount of enforcement is likely to depend on the nature of the organization that undertakes the enforcement since they differ in their objective functions

and their access to information. Thus, an important part of the analysis will be an examination of the impact of organizational form on compliance and hence on the cost effectiveness of a carbon-offset market.

The rest of the paper is organized as follows. The second part develops a model of the emitter's choice of whether to purchase a carbon offset or to consider the emission reduction itself. The third section builds up a model of the producer's choice of whether to participate in the carbon-offset market or not. For each of these cases, the paper investigates the impact on the market of considering non-compliance. The paper also examines the role of policy instruments such as audit probabilities and penalties in promoting compliance. The fourth section of the paper investigates the pricing and output decisions of the traders involved in the market facilitate carbon offset trading. The analysis then examines the extent to which the different structures undertake monitoring, and the impact of this monitoring on the pricing behaviour. The last section summarizes the findings and concludes the paper.

THE MODEL

The model considers three sets of agents: LFEs, who generate a demand for carbon offsets as part of fulfilling their emission reduction requirements; producers, who supply carbon offsets; and third parties, who intermediate the trading of carbon offsets. Traders buy carbon offsets from producers and offer verified carbon offsets to emitters. Market price is determined by the interaction of genuine carbon offset supply and demand.

The model captures the heterogeneity of emitters and producers. We first examine the emitters' decision and the farmers' decision, followed by an examination of the traders' pricing decision. We consider four possibilities for monitoring agencies that can undertake monitoring and derive the optimal monitoring level in each case. Based on these optimal monitoring levels, we will conclude with a relative efficiency ranking of the regarded monitoring agencies.

THE EMITTERS' PROBLEM

Consider a group of emitters who produce an industrial product with carbon emissions as a by-product. Each emitter is required to reduce emissions by one unit. It is useful first to

analyse the emitters' decision in a perfect enforcement scenario. A key assumption of the analysis is that emitters differ in their cost of undertaking the emission reduction. This cost difference gives rise to a demand for carbon offsets. The analysis begins with the situation where perfect compliance is assumed; this assumption is then relaxed so that the more realistic situation where emitters have the potential to underreport their emissions can be explored.

The model captures emission reduction required over and above permits. LFE has two choices to address her emission reduction requirements: undertaking abatement or buying carbon offsets. Emitters are assumed to differ in such things as technology adopted, management abilities and experience and these differences affect their relative emission reduction costs. Let $e \in [0,1]$ be the attribute that differentiates the LFEs. An emitter with attribute e has the following costs of emission reduction:

$C_A = C^0 + \beta e$ if the emission requirement is met by abatement

$C_o = P_e$ if the emission requirement is met by the purchase of a carbon offset

where C_A and C_o are the costs associated with abating one unit of emission and buying one unit of carbon offset, respectively. The parameter C^0 denotes the per unit abatement cost of the emitter with differentiating attribute $e = 0$. The parameter β is a nonnegative cost enhancement factor that is constant across all emitters, while the term βe represents the additional cost incurred by emitters with $e > 0$. To ensure non-negativity of the portion of emitters that select the alternative of buying carbon offsets, it is assumed that $\beta \geq P_e - C^0$ (see equation 2). For tractability, the analysis assumes that emitters are uniformly distributed with respect to their differentiating attribute e.

An emitter's choice of whether to undertake abatement or to buy carbon offset is determined by the relationship between the costs associated with each option. Figure 1 illustrates the options available to emitters and the costs of these options. The horizontal axis depicts the differentiating attribute e. The upward sloping curve C_A graphs the cost associated with undertaking abatement for different values of the differentiating attribute (i.e., for different emitters), while the horizontal line C_o shows the cost of buying carbon offsets in the market. The intersection of the two cost curves determines the level of the

attribute corresponding to the emitter indifferent between the two options. Specifically, the emitter with differentiating attribute e_o given by:

$$(1) \quad e_o : C_A = C_o \Rightarrow e_o = \frac{P_e - C^0}{\beta}$$

is indifferent between undertaking abatement or buying carbon offsets since the cost associated with the two options are the same. Emitters located to the left of e_o (i.e., emitters with $e \in [0, e_o)$) find it less costly to undertake abatement, while emitters located to the right of e_o (i.e., emitters with $e \in (e_o, 1]$) find it more profitable to buy carbon offsets.

Recalling that emitters are uniformly distributed with respect to their differentiating characteristic e, the level of e corresponding to the indifferent emitter, e_o, also determines the fraction of emitters that decide to undertake abatement. The portion of emitters that choose to buy carbon offsets is given by $1 - e_o$. By normalizing the mass of emitters at unity, the proportion of emitters that select to buy carbon offsets gives the demand for carbon offsets, x^d, which is written as follows:

$$(2) \quad x^d = \frac{\beta - \left(P_e - C^0\right)}{\beta}$$

The inverse demand curve can be written as $D_0 : P_e = \left(C^0 + \beta\right) - \beta x^d$.

Comparative statics results can be easily derived from the graph. A reduction in P_e shifts the C^0 curve downwards, thus increasing the demand for carbon offsets (i.e., $\frac{\partial x^d}{\partial P_e} < 0$). A decrease in the cost enhancement factor β causes a rightward rotation of the C_A curve through the intercept at C^0, which in turn decreases the demand for carbon offsets (i.e., $\frac{\partial x^d}{\partial \beta} > 0$).
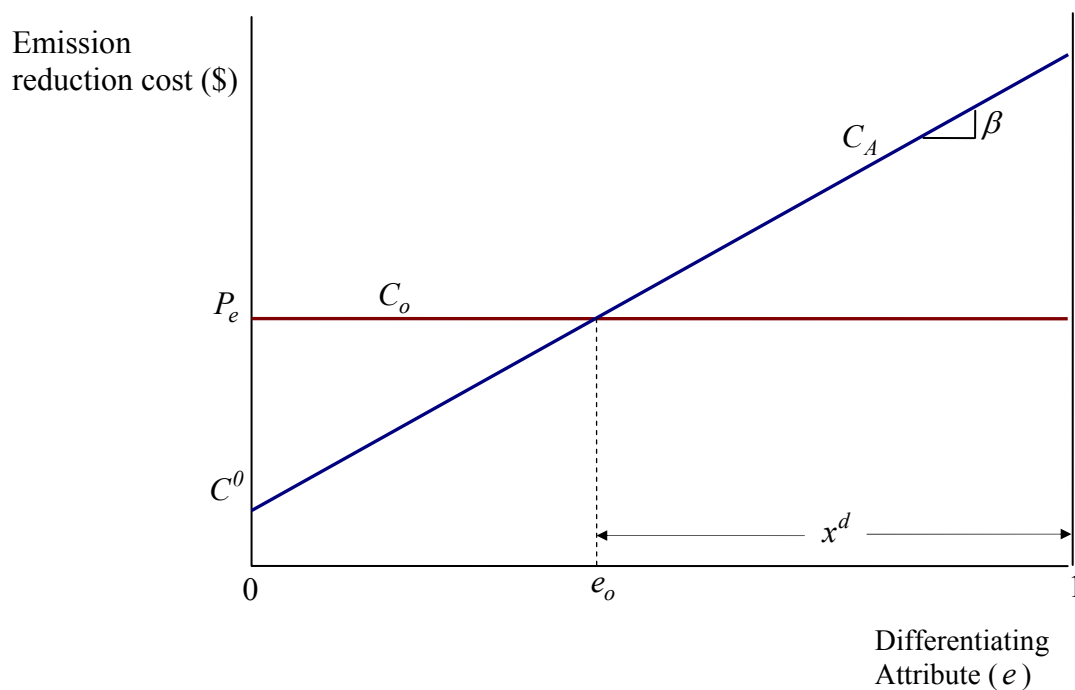
Figure 1. Emitters' decision under perfect compliance

Implicit in the above analysis is the assumption that either (1) emitters do not cheat when reporting their emission; or (2) enforcement is perfect and costless. Enforcement, however, requires resources. The consequence of the resource costs of monitoring and enforcement might be a lack of enforcement activity, which in turn creates economic incentives for emitters to underreport their emission levels. Under these circumstances, each emitter can meet her emission reduction target by the choice of one of three options: undertaking abatement; reporting abatement that was not undertaken (i.e., cheating); and buying carbon offsets in the offset market.

Assume that emitters know the probability $\delta \in [0,1]$ that they will be investigated, detected and punished, as well as the per-unit penalty ρ for detected non-compliance. In case an emitter violates the emission level, her expected cost will depend on her probability of being investigated, the penalty in case she is caught cheating and her personalized cost of engaging in cheating. This cost, which is denoted by τe, can be the result of trying to masquerade emission violation. The parameter τ is a non-negative cost enhancement factor which is constant across all emitters. Each emitter who cheats incurs

this cost regardless of being detected or not. If an LFE is not detected she saves the abatement cost of reducing her emission by one unit or the cost of buying one unit of carbon offset. The expected cost of cheating for an emitter with attribute e who reports abatement that is not undertaken (i.e., underreports emissions) is given as follows:

(**3**) $C_c = \delta\rho + \tau e$

Note that since emitters differ with respect to e, and as a result in their personalized cost of cheating, the expected costs of cheating differ across emitters.

      The emitter's decision of whether to undertake abatement, buy carbon offsets or cheat is determined by comparing the costs associated with each of the three options. A graphical illustration of the emitter's decision is given in Figure 2. The intersection of curves C_A and C_c determines the level of the differentiating characteristic e_1 :

(**4**) $e_1 : C_A = C_c \Rightarrow e_1 = \dfrac{\delta\rho - C^0}{\beta - \tau}$

corresponding to the emitter who is indifferent between undertaking abatement and cheating. Similarly, the intersection of curves C_o and C_c determines the level of the differentiating characteristic e_2 :

(**5**) $e_2 : C_c = C_o \Rightarrow e_2 = \dfrac{P_e - \delta\rho}{\tau}$

corresponding to the emitter indifferent between buying carbon offset and cheating.

      Emitters positioned to the left of e_1 (i.e., emitters with $e \in [0, e_1]$) choose to undertake abatement, while those positioned between e_1 and e_2 (i.e., emitters with $e \in (e_1, e_2)$) underreport their emissions; emitters located to the right of e_2 (i.e., emitters with $e \in [e_2, 1]$) select to buy carbon offsets.

      Assuming that emitters are uniformly distributed with respect to the differentiating attribute e, the level of e_1 determines the fraction of emitters who abate, $(e_2 - e_1)$ gives the fraction of emitters that engage in cheating, and $(1 - e_2)$ determines the portion of emitters that buy carbon offsets.
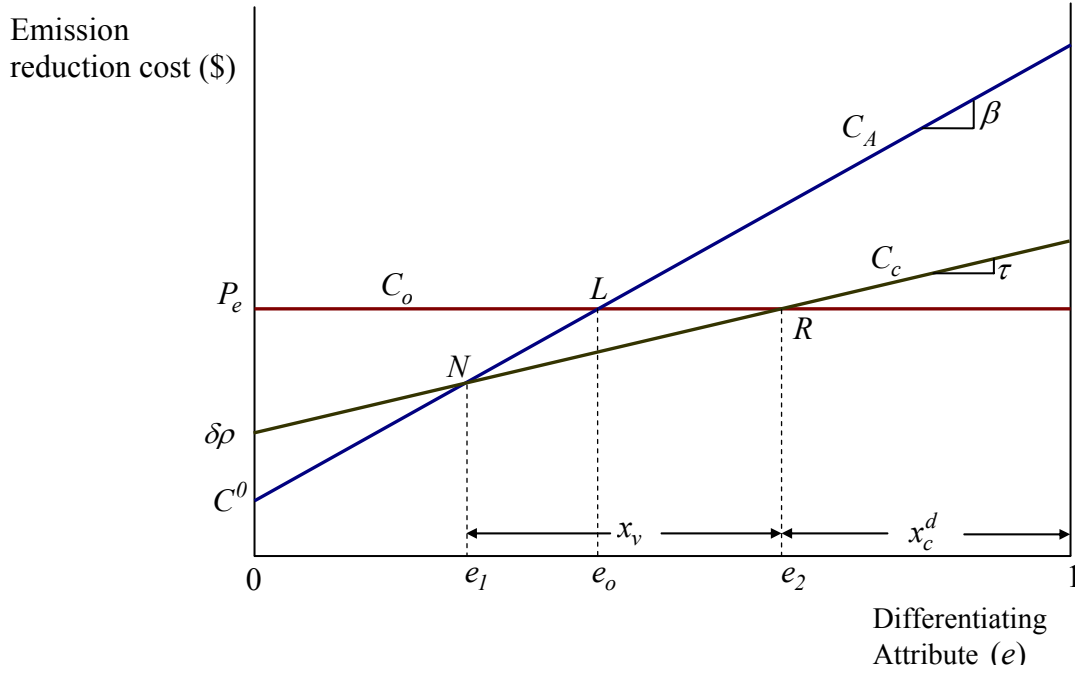
Figure 2. Emitters' decision under imperfect compliance

Since the mass of emitters is normalized at unity, the fraction of emitters that decide to buy carbon offsets gives the emitters' demand for carbon offsets, $x_c^d = 1 - e_2$, which can formally be written as follows:

(**6**) $x_c^d = \dfrac{\tau - (P_e - \delta\rho)}{\tau}.$

The inverse demand for carbon offsets can be written as $D_1 : P_e = (\tau + \delta\rho) - \tau x_c^d$.

The level of abatement undertaken is presented by $x_a = e_1$, which can be written as:

(**7**) $x_a = \dfrac{\delta\rho - C^0}{\beta - \tau}$

and the amount of abatement violations is given by $x_v = e_2 - e_1$, where x_v is given by:

(**8**) $x_v = \dfrac{P_e - \delta\rho}{\tau} - \dfrac{\delta\rho - C^0}{\beta - \tau} = \dfrac{(P_e - \delta\rho)\beta - (P_e - C^0)\tau}{\tau(\beta - \tau)}$

The model analyses the emitter's decision when all three choices are available. Assume we have an interior solution so that all three variables x_a, x_v, x_c^d are positive. This assumption needs the following conditions to hold: in order to have $x_a > 0$, $C^0 \le \delta\rho$ should hold (see equation 7); in order to have $x_v > 0$, $\beta > \frac{(P_e - C^0)}{(P_e - \delta\rho)}\tau$ should hold (see equation 8); and in order to have $x_c^d > 0$, $\tau \ge (P_e - \delta\rho)$ should hold (see equation 6). From equation 8 we can derive the critical audit probability value $\delta^{cr} = \frac{P_e\beta - (P_e - C^0)\tau}{\beta\rho}$, for which the full compliance holds (i.e., $x_v = 0$). For audit probabilities $\delta \ge \delta^{cr}$, non-compliance will be completely deterred. Each emitter selects either to undertake abatement or to buy carbon offsets; she does not find underreporting profitable since the probability of being detected is too high.

The inverse demand curves for a perfect compliance scenario as well as for the non-compliance case are illustrated in Figure 5 as curves D_0 and D_1, respectively. Referring to Figure 2, we can derive the condition under which $(e_2 - e_1) = 0$ (i.e. points N and R converge to L). This happens when carbon offset price is $P_e = \frac{(\delta\rho)\beta - C^0\tau}{\beta - \tau}$.

Thus, both demand curves join for prices less than $\frac{(\delta\rho)\beta - C^0\tau}{\beta - \tau}$.
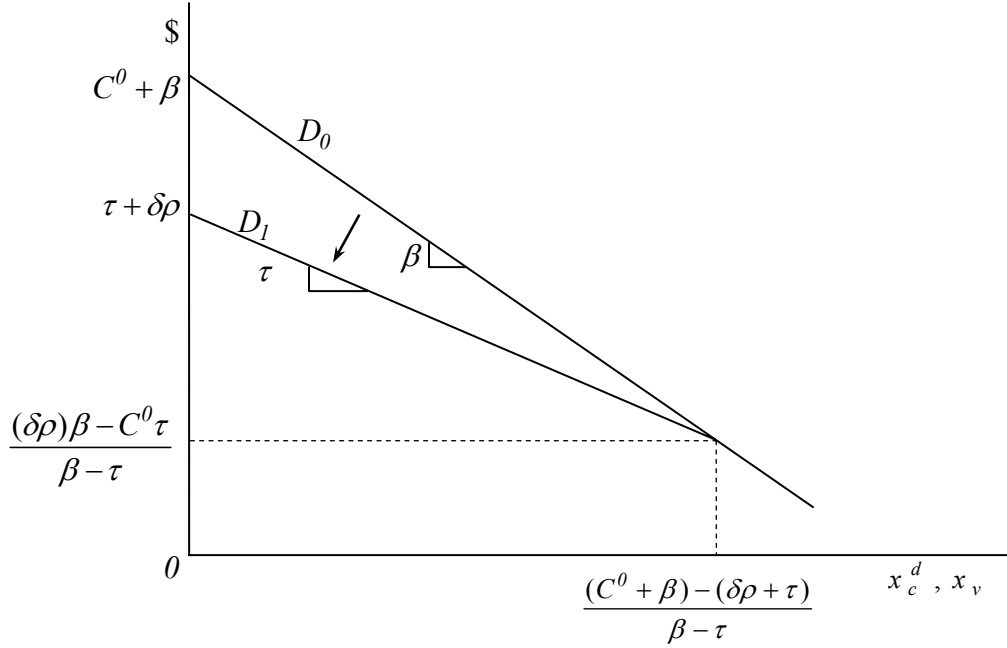
Figure 3. Demand curves under both scenarios

Comparative static results can be derived from Figure 2. For instance, an increase in the price of carbon offsets will influence the number of emitters that buy carbon offsets or engage in cheating behaviour. Specifically, the level of cheating will increase while, at the same time, the demand for carbon offsets will turn out to decrease (i.e., $\frac{\partial x_c^d}{\partial P_e} < 0, \frac{\partial x_v}{\partial P_e} > 0$).

An increase in the penalty per unit of violation causes an upward shift of the curve C_c that decreases the violation level and increases the fraction of emitters that purchase carbon offsets (i.e., $\frac{\partial x_c^d}{\partial \rho} > 0, \frac{\partial x_v}{\partial \rho} < 0$). Similarly, an increase in the audit probability δ shifts the curve C_c upward, thus decreasing the violation level and increasing the demand for carbon offsets (i.e., $\frac{\partial x_c^d}{\partial \delta} > 0, \frac{\partial x_v}{\partial \delta} < 0$).

THE PRODUCERS' PROBLEM

The producers' problem can be modeled similarly to the way emitters are modeled. Each producer cultivates product q under a certain land management practice, which can be either a BMP or a conventional land management practice. BMPs can be of many types such as: reducing tillage, planting permanent cover crops, undertaking agroforestry, reducing summerfallow, implementing good grazing management and fertilization practices (Agriculture and Agri-food Canada, 2003). Each practice gives rise to different rates of carbon accumulation and to different streams of net profits. Due to the economic benefits related to the BMPs many farmers have already adapted these practices. However, a fraction of producers still produce under the conventional land management practices because of the new investment required, part of which is sunk, and a lack of experience to undertake change in their practices. In addition to these direct economic benefits, farmers may have an incentive to adopt BMPs in order to participate in the carbon-offset market. However, there are some important considerations for the farmer when he comes to signing the carbon offset contract.

Farmers adopt BMPs to a greater or a lesser degree. They may capture carbon in their soil, but none of this sequestered carbon is available for trading if they don't sign a carbon-offset contract. Producers are reluctant to sign the contract for three reasons: the transaction costs, uncertainty, and the risk associated with signing the contract. Examples of transaction costs would be: administrative costs of keeping records and reporting carbon offsets, the costs of undertaking the transaction to sell the carbon offsets, and costs associated with the signing process. These transaction costs can reduce the attractiveness of participating in the carbon-offset market. In a study performed by Marbeck Resource Consultants (2004), the transaction costs for GHG offset system were estimated to range between $0.4 and $2 per tonne of CO_2.

Other issue for producers considering participating in the carbon-offset market is the uncertainty issue. There is a lot of uncertainty surrounding climate change policies so the producers have to sign the contract under the condition of uncertainty - e.g., about the rate of soil carbon accumulation and about the market price of sequestered carbon. The carbon price can be affected by changes in demand and supply conditions which are not known at the time of signing. An example of a change in the demand conditions can be a

new emission reduction technology that becomes available to emitters. If emitters find it more profitable to invest in adopting this technology than to continue buying carbon offsets, the demand for carbon credits will decrease. Uncertainty, combined with the irreversibility of the decision, implies that delaying the signing decision has an option value. Producers will enter to a contract relation only if the net present value of their investment exceeds this option value (Vercammen, 2002).

Apart from this, producers incur additional risk if they decide to sequester carbon under a contract and to sell carbon credits in an emission market. Since producers are believed to be risk averse, they will require a risk premium in order to participate in a carbon sequestration scheme. The option value, the risk premium, as well as the transaction costs associated with signing the contract constitute the contract costs. Under the above considerations, each farmer will sign the contract only if the benefit from participating in the carbon-offset market exceeds the cost of signing the contract.

Producers have the choices of: (1) signing the carbon contract; or (2) not signing the contract. They are postulated to differ in the returns they get from their activities as a result of differences in such things as soil type, experience, location, education and management skills. Let α denote the attribute that differentiates them. Producer heterogeneity is critical in generating the supply of carbon offsets.

Before investigating the producers' compliance decision, it is helpful to analyze their economic behaviour under a perfect enforcement scenario. The assumption is relaxed latter with the intention that the more realistic situation where producers have the potential to overreport their carbon offsets can be explored.

The per unit profit for a farmer with differentiating attribute $\alpha \in [0,1]$ is given as follows:

$$\pi^{ns} = P^q - \mu\alpha \qquad \text{if he does not sign the sequestration contract}$$

$$\pi^s = P^q + P^e - \lambda\alpha \qquad \text{if he does sign the contract}$$

where P_e and P^q are the prices for carbon offset and product q, respectively. The parameters μ and λ are non-negative cost enhancement factors that are constant across all producers. It is assumed that $\lambda > \mu > 0$; the difference between λ and μ is denoted as $\omega = \lambda - \mu$. The term $\mu\alpha$ represents the cost incurred by producer with $\alpha > 0$ who

does not sign a contract, while term $\lambda\alpha$ symbolizes the cost incurred by producer with $\alpha > 0$ who does sign a contract. The term $\lambda\alpha$ embodies the production cost that the product incurs as well as the carbon offset contract cost which includes the transaction costs associated with signing the contract, the risk premium that farmers require to take on the risk of signing the contract, and the option value that farmers attach to the potential to wait to sign the contract at a latter date (see Fulton et. al., 2005). Whether or not producer participates in carbon sequestration under a contract depends on the profitability of such involvement. Each producer makes his choice based on which alternative operates the highest per unit profit.

The downward sloping curve π^{nc} drawn in Figure 1 represents the net returns associated with the production of product q for different values of α (i.e., for different producers). The curve, π^c, shows the net returns associated with production of product q and the sequestration of carbon under contract for different values of the differentiating attribute. The intersection of π^{nc} and π^c determines the level of the differentiating characteristic corresponding to the farmer that is indifferent between signing the contract to sequester carbon and not signing the sequestration contract. This farmer has attribute α^c given by:

(**9**) $\alpha^c : \pi^{nc} = \pi^c \Rightarrow \alpha^c = \dfrac{P_e}{\omega}.$

To the left of α_c, (i.e., for $\alpha \in \left[0, \alpha^c\right]$) all producers select to sign a contract, while to the right of α^c, (i.e., for $\alpha \in \left(\alpha^c, 1\right]$) all producers choose not to sign the contract, no matter what land management practice they are applying. Given that α is uniformly distributed between zero and one, α^c represents the portion of producers that produce carbon offsets under a contract, while $\alpha^{nc} = \left(1 - \alpha^c\right)$ is the fraction of producers that do not choose to sign the carbon offset contract. By normalizing the mass of producers at unity, the fraction of producers that sign the contract gives the supply of carbon offsets in the market, which is written as follows:

(**10**) $x^c = \dfrac{P_e}{\omega}.$

The inverse supply function is represented by equation: $S_0 : P_e = \omega x^c$.

Comparative static results can be obtained form Figure 4. The price of carbon offsets is a key factor in determining how many producers sign the contract. An increase in the price of carbon offsets results in an increase of the benefits from signing the contract, ceteris paribus. More specifically, an increase in P_e leads to an upward shift in the π^c line. This upward shift results in a larger portion of producers signing the sequestration contract (i.e., $\frac{\partial x^c}{\partial P_e} > 0$). As shown in Figure 4, decreasing the cost enhancement factor λ causes a rightward rotation of the π^c curve through the intercept at $P^q + P_e$, thus increasing the number of contracts signed by producers (i.e., $\frac{\partial x^c}{\partial \lambda} < 0$). A decrease in the cost enhancement factor μ results in a rightward rotation of the π^{nc} curve through the intercept at P^q, which in turn decreases the supply of carbon offsets (i.e., $\frac{\partial x^c}{\partial \mu} > 0$).
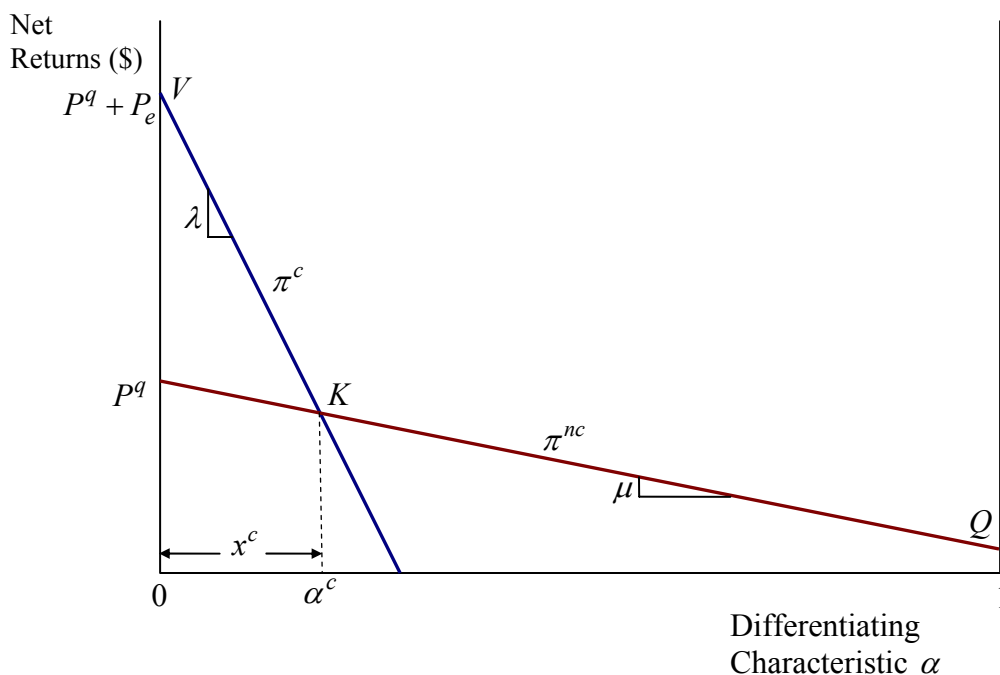
Figure 4. Producers' decision under perfect compliance.

The previous analysis was performed under the assumption of perfect compliance. But in the real world, monitoring and enforcement activities required to ensure compliance with a contract are costly. Producers need to be monitored in order to ensure that the carbon offsets that are claimed actually represent a reduction of carbon. However, the resource costs of monitoring and enforcement might result in insufficient enforcement activity. The lack of enforcement creates economic incentives for producers to overreport the amount of carbon offsets they are supplying under a contract. Each producer now has a choice of: (1) signing a carbon offset contract; (2) signing the contract but not complying with its terms (i.e., cheating); and (3) not signing the contract.

Suppose producers are audited with a probability $\theta \in [0,1]$ which is known to them and they face a per unit penalty γ if they are caught cheating on the contract. If a producer cheats, his expected net return depends on the likelihood of his being audited, the penalty paid if he is caught cheating, as well as his individualized costs. If he does not get detected he can enjoy the benefit $P^q + P_e - \sigma\alpha$, where σ is a cost enhancement factor that is constant across all producers. The term $\sigma\alpha$ represents the costs incurred by

producer with $\alpha > 0$ in the case when he signs the sequestration contract but does not comply with its terms. Thus this term comprises the production costs as well as the costs associated with cheating. Following Cule and Fulton, these costs might represent the cost of keeping contract records. It is assumed that $\lambda > \sigma > \mu > 0$; the difference between λ and σ is denoted as $\varphi = \lambda - \sigma$, while the difference between σ and μ is denoted as $\eta = \sigma - \mu$. If the producer is caught cheating, he gets the benefit $P^q + P_e - \gamma - \sigma\alpha$. As a result, the expected return from cheating for a producer with characteristic α will be given as:

$$\pi^{ch} = P^q + P_e - \theta\gamma - \sigma\alpha$$

Note that, since producers differ with respect to α, and as a result in their individualized costs $\sigma\alpha$, the expected profits from cheating differ across producers. The producer's decision of whether to participate in the carbon-offset market and, if so, whether to comply with the provisions of the sequestration contract depends on the profits received or expected to be received from these alternatives. A graphical illustration of the producer's decision is given in Figure 5. The intersection of curves π^c and π^{ch} determines the level of the differentiating attribute α_1 corresponding to the producer who signs the carbon offset contract but is indifferent between complying with the terms of the contract and cheating:

(11) $\alpha_1 : \pi^c = \pi^{ch} \Rightarrow \alpha_1 = \dfrac{\theta\gamma}{\varphi}.$

In a similar way, the intersection of curves π^{ch} and π^{nc} determines the level of the differentiating attribute α_2 corresponding to the producer who is indifferent between not participating in the carbon-offset market (i.e., not signing the contract) and signing the sequestration contract but not satisfying its terms:

(12) $\alpha_2 : \pi^{ch} = \pi^{nc} \Rightarrow \alpha_2 = \dfrac{P_e - \theta\gamma}{\eta}.$

Producers located to the left of α_1 (i.e., producers with differentiating attribute $\alpha \in [0, \alpha_1]$) choose to participate in the carbon-offset market; producers located between α_1 and α_2 (i.e., producers with characteristic $\alpha \in (\alpha_1, \alpha_2)$ choose to sign the contract

but not to comply with all the provisions; and producers positioned to the right of α_2 (i.e., those with attribute $\alpha \in [\alpha_2, 1]$) choose not to sign the sequestration contract no matter what land management practice they are applying.
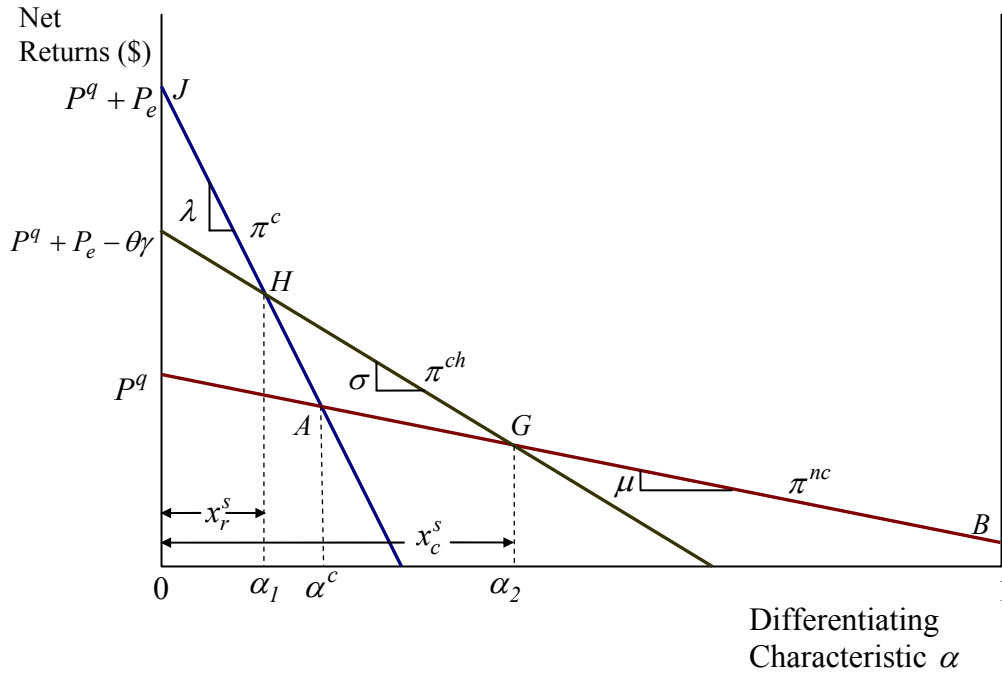

Figure 5. Producers' decision under non-compliance

Since producers are uniformly distributed with respect to differentiating characteristic α, α_2 determines the portion of producers that sign the sequestration contract; α_1 gives the portion of producers who sign the carbon contract and do honour the provisions; $(\alpha_2 - \alpha_1)$ gives the portion of producers that sign the contract but do not comply with its terms; and $(1 - \alpha_2)$ determines the portion of producers that do not sign the contract. In a formal way $(\alpha_2 - \alpha_1)$ can be written as follows:

$$\alpha_2 - \alpha_1 = \frac{P_e \varphi - \theta \gamma \omega}{\eta \varphi}.$$

The portion of producers who sign the contract, but do not comply with the provisions, $(\alpha_2 - \alpha_1)$, will equal zero when all three curves π^c, π^{ch} and π^{nc} meet at the same point. This happens when carbon offset price $P_e = \dfrac{\omega\theta\gamma}{\varphi}$.

By normalizing the mass of producers at unity, the portion of producers that choose to sign the contract gives the total supply of carbon offsets in the market, $x_c^s = \alpha_2$, which can be written as follows:

(13) $x_c^s = \dfrac{P_e - \theta\gamma}{\eta}$.

Having introduced cheating in the model, the inverse supply equation of the total carbon offsets offered from producers is the following:

(14) $S_2 : P_e = \theta\gamma + \eta x_c^s$.

When cheating is not considered, aggregate producers' welfare is given by the area *0VKQ1*, while, when cheating is introduced into the analysis, the aggregate producers' welfare is increased by the area *HAG*.

The carbon offsets offered in the market can come from producers who actually undertake sequestration or from those who engage in cheating activity. Put in a simple way, carbon offsets supplied in the market can be genuine or bogus. Only producers positioned to the left of α_1 contribute with real carbon offsets. As a result, the supply of real carbon offsets in the market $x_r^s = \alpha_1$, is given as follows:

(15) $x_r^s = \dfrac{\theta\gamma}{\varphi}$,

while the amount of bogus carbon offsets in the market, $x_c^s - x_r^s = \alpha_2 - \alpha_1$, is given by:

(16) $x_c^s - x_r^s = \dfrac{P_e\varphi - \theta\gamma\omega}{\eta\varphi}$,

The number of producers that choose not to sign the sequestration contract, $x_{nc}^s = 1 - x_c^s$, is presented by:

(17) $x_{nc}^s = \dfrac{\eta - P_e + \theta\gamma}{\eta}$.

The previous analysis shows that the number of total contracts signed, the amount of real carbon offsets and the amount of bogus carbon offsets offered in the market depends on the audit probability as well as the penalty applied per unit of non-compliance. In addition to these factors, the total number of contracts signed is influenced by the price of carbon offsets and η; the amount of genuine carbon offsets is impacted by φ; and the amount of bogus carbon offsets is influenced by the price of carbon offsets as well as by the three parameters φ, ω and η.

This model analyses the producer's decision when all three choices are available. The relation $P^q + P_e > P^q + P_e - \theta\gamma$ guarantees that a positive number of producers, $x_r^s > 0$, select to sign the carbon offset contract and to comply with its terms. Assume we have an interior solution so that all three variables x_r^s, x_{nc}^s, and $(x_c^s - x_r^s)$ are positive. This assumption needs the following conditions to hold: in order to have $x_{nc}^s > 0$, $\eta > P_e - \theta\gamma$ should hold (see equation 17); and in order to have $(x_c^s - x_r^s) > 0$, $P_e\varphi > \theta\gamma\omega$ should hold (see equation 16). From equation 16 can derive the critical audit probability value $\theta^{cr} = \dfrac{P_e\varphi}{\gamma\omega}$ for which the full compliance holds (i.e., $(x_c^s - x_r^s) = 0$). For audit probabilities $\theta \geq \theta^{cr}$, non-compliance (i.e., overreporting) will be completely deterred. Each producer chooses either to sign the carbon offset contract and honour it or to decline the sequestration contract. He does not find overreporting profitable since the probability of being detected is too high.

Figure 6 illustrates three supply curves S_0, S_1 and S_2, where: S_0 represents the inverse supply curve under a full-compliance scenario; S_1 represents the supply of genuine carbon offsets; and S_2 represents the total supply of carbon offsets after we have introduced cheating in the model. For prices $P_e < \dfrac{\omega\theta\gamma}{\varphi}$ they converge on segment $0T$.
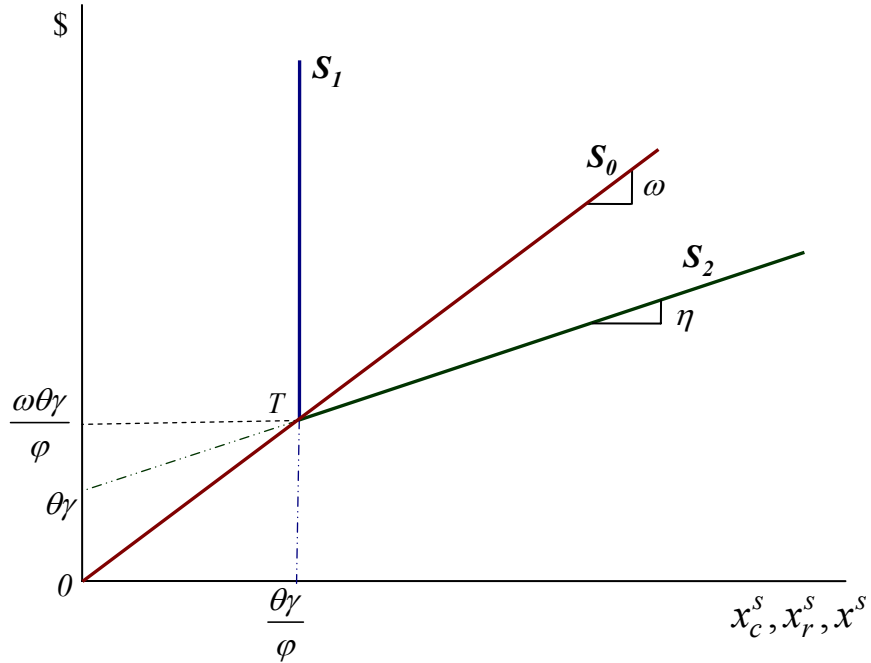
Figure 6. Supply curves under both scenarios

Comparative statics results can be derived diagrammatically from Figure 5. An increase in the penalty per unit of non-compliance causes a downward shift in the π^c curve, which in turn results in a decrease in the number of contracts signed as well as in the non-compliance level (i.e., $\dfrac{\partial x_c^s}{\partial \gamma} < 0, \dfrac{\partial \left(x_c^s - x_r^s \right)}{\partial \gamma} < 0$), ceteris paribus. In a similar way, a higher audit probability causes an increase in the expected penalty and shifts the π^c curve downwards, thus decreasing the amount of bogus carbon offsets as well as the total amount of carbon offsets offered in the market from producers (i.e., $\dfrac{\partial x_c^s}{\partial \theta} < 0, \dfrac{\partial \left(x_c^s - x_r^s \right)}{\partial \theta} < 0$), ceteris paribus.

An increase in the carbon offset price P_e causes an upward parallel shift of the curves π^s and π^c by the same amount. These shifts result in a higher number of the contracts signed (i.e., $\dfrac{\partial x_c^s}{\partial P_e} > 0$); the amount of carbon sequestered under contract remains constant however.

By examining the supply curves in Figure 6 we draw some implications. An increase in price of carbon offsets from zero to $\dfrac{\omega\theta\gamma}{\varphi}$ increases the number of producers who sign contracts with full compliance, since nobody who signs a sequestration contract finds it profitable to cheat along section $0T$ of the supply curve.

An increase in the penalty per unit or in the auditing probability causes an upward shift in the S_2 curve as well as a rightward parallel shift in the S_1 curve, thus extending the section $0T$ where the three supply curves converge. As a result, the amount of genuine carbon offsets supplied in the market increases.

TRADERS' INVOLVEMENT IN THE MARKET

Carbon offsets trading will be undertaken by traders that buy carbon offsets from producers and sell verified carbon offsets to emitters. This section of the paper considers two structures for the trading sector: monopolistic structure and oligopolistic structure. If trading is undertaken by profit maximizing firms, we expect a monopolistic or oligopolistic structure to emerge because of the fixed costs involved in running a trading scheme. For each of these cases, we consider that monitoring can be undertaken by a monitoring group which can be either a governmental agency or a monitoring group operating in behalf of the traders. Even though other structures can be used for the trading sector or the monitoring group, we concentrate the work of this paper only on the above-mentioned structures.

The amount of monitoring performed by the monitoring agency defines the total supply of carbon offsets as well as the supply of genuine carbon offsets in the market. This section examines the trader's price and output decision as well as the monitoring agency's decision of the choice of θ; the consideration of the last element means the audit probability is endogenized. The optimal amount of enforcement is likely to depend on the nature of the organization that undertakes the enforcement since they might have different objective functions. The section examines the extent to which these different monitoring agencies undertake monitoring, and the impact of this monitoring on the pricing behaviour.

The supply and the demand equations for the carbon offset market are determined from the producers' and the emitters' problem, respectively. Emitters are aware that producers will be monitored and that carbon offsets traded by third parties will represent actual sequestration, hence the carbon offsets demand emerging from emitters will be represented by D_1 (see Figure 3). Given this demand and the supply, the amount of carbon offsets trading and the endogenous auditing probability are determined in a two stage game. In the first stage of the game, the monitoring agency chooses the level of auditing that it will undertake, knowing the producers' response to this choice of auditing as well as the impact of the chosen θ on the pricing decisions. In the second stage of the game, traders make their decision on how much carbon offsets to buy from producers and how much to sell to emitters based on the degree of auditing that has been undertaken. The game is solved using backward induction (Kreps, 1990).

The monopoly and oligopoly cases

First we consider the case when the trader is a profit maximizing monopolist-monopsonist. The firm is thus the sole buyer of carbon from producers and the exclusive provider of verified carbon offsets to emitters. The profit maximization problem for the trader would be:

$$Max_Y PY - P_e(Y + X)$$
(**18**) $$st \quad Y \leq \bar{Y}$$

where P_e is the price at which the trader buys the amount $(Y + X)$ of carbon offsets, P is the price at which he is selling the Y verified units, while $\bar{Y}$ is defined from the auditing probability $\bar{\theta}$ determined by the monitoring group (i.e., $\bar{Y} = \dfrac{\bar{\theta}\gamma}{\phi}$). The solution to this problem is presented in Appendix A. The analysis shows that the output is the lesser of Y^* and $\bar{Y}$, where Y^* is determined where $MR = MO$, and marginal revenue and marginal outlay are derived from the demand curve D_1 and the supply curve S_0, respectively. The familiar "marginal revenue equal to marginal outlay" solution for the trader's problem will serve as a starting point in analysing the monitoring group problem.

With knowledge of the behaviour of the trading firm, the decision of the monitoring group can be considered. Since the monitoring group operates on behalf of the firm, it chooses the audit probability θ that maximizes the profit of the firm minus the monitoring cost. The auditing probability defines the position of the genuine carbon offsets supply curve S_1. Since the trading firm will never trade more than Y^*, the monitoring group will always find it optimal to make $\bar{Y}$ no larger than Y^*, thus the constraint is binding. The reason is because of the extra cost of monitoring that could be saved by cutting back in monitoring. In order to cover the monitoring costs C_m, the monitoring group will reduce $\bar{Y}$ to Y_1, where Y_1 is below Y^* and is determined by $MR = MC + C'_m$. Appendix A shows that amount Y_1 corresponds to the output traded.
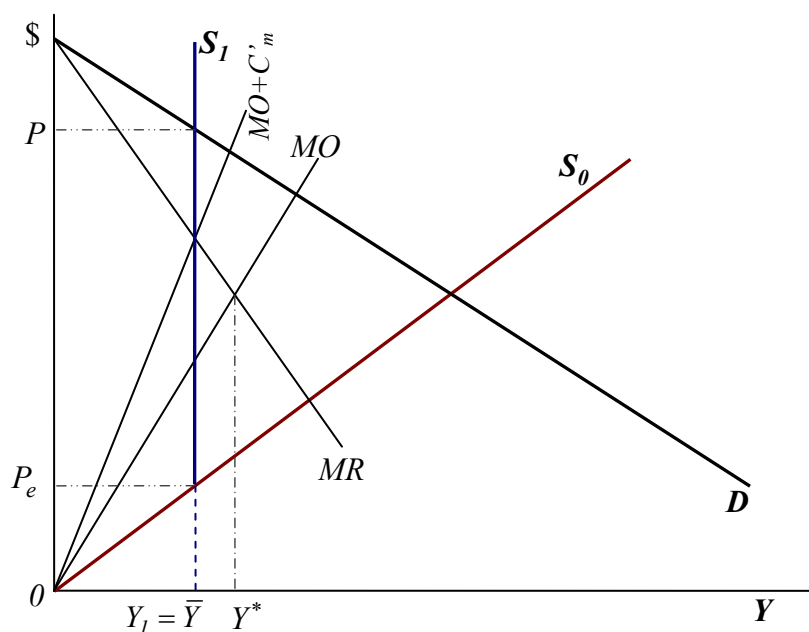

Figure 7. Monitoring group decision (monopoly or oligopoly case)

Formally, the maximization problem of the monitoring group can be written as:

$$Max_\theta \ P\frac{\theta\gamma}{\varphi} - P_e\frac{\theta\gamma}{\varphi} - \frac{1}{2}\xi\theta^2$$

where monitoring cost, $C_m = \frac{1}{2}\xi\theta^2$, is assumed to be an increasing and convex function of the auditing intensity θ, and ξ is a positive scalar that depends on factors such as the total number of producers and the effort required to perform monitoring.

The first order condition equalizes the marginal revenue with the sum of the marginal outlay and the marginal cost of monitoring $MR = MO + C'_m$. The optimal amount of monitoring, which is defined by the auditing probability, is given by the formula:

$$(19) \quad \theta^* = \frac{(\tau + \delta\rho)\varphi\gamma}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

while the amount of carbon offsets that will be traded by the firm is given by:

$$(20) \quad Y^* = \frac{(\tau + \delta\rho)\gamma^2}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

Now consider the case when oligopolistic-oligopsonistic firms undertake the carbon offsets trading. Representatives from these firms form the monitoring group. As with monopoly, the output will be the lesser of Y^* and $\bar{Y}$. Traders will never trade more than Y^*, therefore the monitoring group will always find it optimal to make $\bar{Y}$ no larger than Y^* in order to save the extra costs of monitoring. As a result, the constraint is binding. In order to cover the monitoring costs, the monitoring group will reduce $\bar{Y}$ to Y_1, which is the same as defined earlier.

From the monitoring group perspective, the group behaves on behalf of all oligopolistic firms, thus chooses the audit probability θ that maximizes the profit of all traders minus the monitoring cost. Since the objective function is the same with the one corresponding to the monopoly case, the optimal amount of monitoring will be given by the same formulas (19). Monitoring probability define the supply of the genuine carbon offsets, which in this case is the same with the one in the monopoly case. Knowing that the firms trade only the genuine carbon offsets ($x_i = 0$, see Appendix B), the total

amount of carbon offsets that oligopolistic firms trade will be $\overline{Y}$, which is the same with the amount that a monopolistic firm would trade (see formula 20). Both monopoly and oligopoly scenarios lead to the same solution because of the vertical supply. The oligopoly solution is presented in Appendix B. The amount of carbon offsets traded by each oligopolistic firm will be given by:

$$y_i^* = \frac{(\tau + \delta\rho)\gamma^2}{N\left[2(\tau + \omega)\gamma^2 + \xi\varphi^2\right]}$$

The governmental monitoring group case

This part examines the case of carbon offsets' trading performed by per-profit firms with monitoring services undertaken by the government. The analysis considers first the monopolistic structure for the trader followed after by the case of an oligopolistic structure.

Monopoly trader/ governmental agency monitoring group

The profit-maximization problem of the monopolist determines $Y_m^* : MR = MO$. The monopolistic firm will not trade more than $Y_m^* = \dfrac{(\tau + \delta\rho)}{2(\tau + \omega)}$. On the other side, the governmental agency chooses the audit probability θ such that to maximize the total welfare, which is the sum of the producers surplus, consumer surplus, and trader's profit minus the monitoring costs. The total level of the genuine carbon offsets, Y_{uc}^*, is obtained in Appendix C by solving the unconstrained problem for the monitoring agency.

$$Y_{uc}^* = \frac{(\tau + \delta\rho)\gamma^2}{(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

This level of output, which is determined by $S_0 + C_m = D_1$, is presented in Figure 8 as well. Since the monopoly firm will never trade more than Y_m^*, the governmental agency will find it optimal to make $\overline{Y}^g$ equal to Y_m^*. Governmental agency cuts back in monitoring in order to save the extra costs of monitoring. As a result, the supply of genuine carbon offsets, S_1, will be located as illustrated in Figure 8. We recall from the

previous analysis that the monitoring agency that was operating on behalf of the monopoly undertakes as much monitoring as to position the supply of genuine carbon offsets at $\overline{Y}^m$. Even though government agency is constrained in its choice from the monopolist's selection of the trading level, the amount of genuine carbon offset $\overline{Y}^g$ supplied in this case is higher than $\overline{Y}^m$. The price that emitters are paying for verified carbon offsets decreases to P^g. Hence; the structure of a governmental monitoring agency has potential to increase the traded output and lower the price paid by emitters.
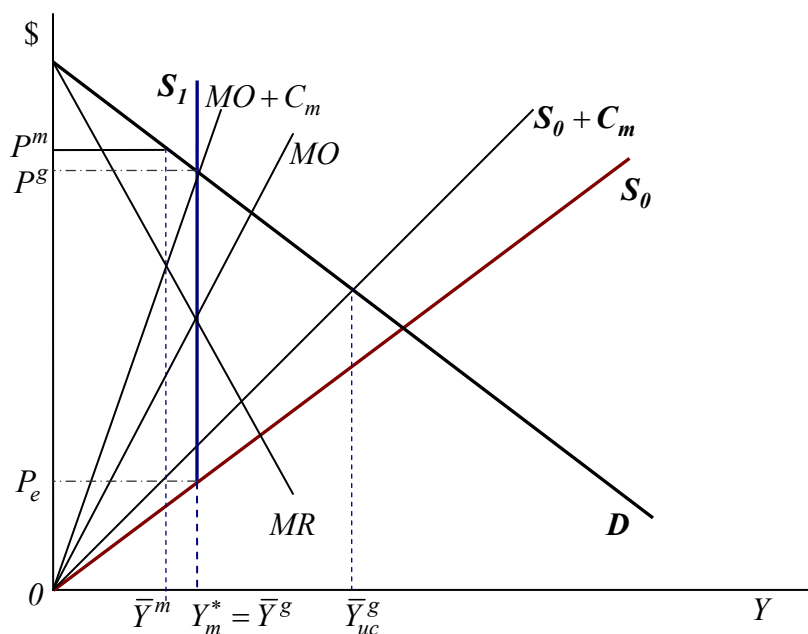

Figure 8. Governmental agency monitoring (Case of a monopoly trader)

Oligopoly traders/ governmental agency monitoring group

The total amount of carbon offsets that oligopolistic traders find optimal to trade is determined by equating marginal revenue of the industry with the marginal outlay of the industry (i.e., $MR^o = MO^0$). Given the supply and demand parameters of our case, this total amount Y_o^* is given by:

$$Y_o^* = \frac{(\tau + \delta\rho)N}{(\tau + \omega)(N+1)} > Y_m^*$$

The unconstrained governmental agency problem provides us the solution:

$$Y_{uc}^* = \frac{(\tau + \delta\rho)\gamma^2}{(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

Since the oligopolistic firms will never trade more than Y_o^*, the monitoring agency will find it optimal to make $\overline{Y}^g$ equal to Y_o^*, otherwise it will waste resources with extra monitoring. The supply of genuine carbon offsets, S_1, will be located as illustrated in Figure 9.

From the previous analysis, the monitoring agency that was operating on behalf of the oligopoly was choosing as optimal the level of monitoring that positions the supply of genuine carbon offsets at $\overline{Y}^o = \overline{Y}^m$. On the other side, government agency, being constrained from the maximum level of trading that oligopolistic firms can undertake, selects the optimal audit probability such that $\overline{Y}^g$ amount of genuine carbon offsets to be supplied in the market. The price emitters are paying in this case decreases further more to $P^{g'}$. The structure of a governmental monitoring agency can potentially increase the carbon offsets amount traded as well as lowers the price emitters are paying for the verified carbon offsets. .
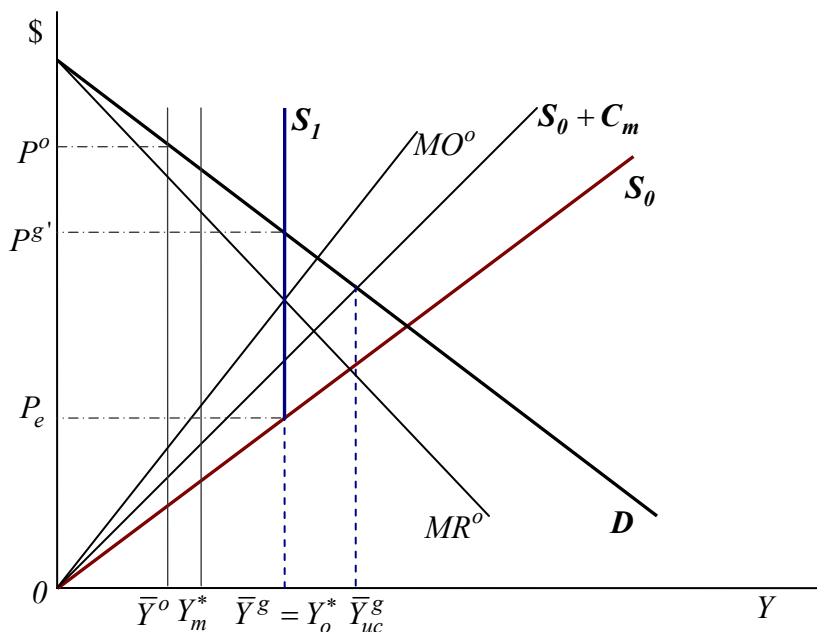
Figure 9. Governmental agency monitoring (Case of oligopoly traders)

While there is enough monitoring in each case to deter cheating, the optimal level of auditing probability is different for different structures of the monitoring group. A governmental agency will undertake more monitoring than a monitoring group owned by the firms. The more monitoring is undertaken from the monitoring group, the greater is the amount of the genuine carbon offsets in the market; hence the greater is the quantity traded from the traders in the carbon-offset market.

SUMMARY AND CONCLUDING REMARKS

This paper develops a model of heterogeneous emitters and producers to examine the performance of the market when the assumption of non-compliance is relaxed for both actors of the carbon market. Besides this, the paper examines what impact has the involvement of the traders in carbon-offset market on non-compliance, as well as how the structure of the monitoring group affects non-compliance and the amount of carbon offsets traded in the market by determining the extend of auditing.

The analysis suggests that the extent of producers' participation in the carbon market and the share of producers in non-compliance depend on the price of carbon offsets and the enforcement policy of the government. More specifically: the extent of non-compliance is shown to decrease with an increase in the audit probability and /or an increase in the penalty per unit of non-compliance; the number of producers participating in the carbon offsets market is shown to increase with an increase in the carbon-offset price.

Similarly with the producers' side, the comparative statics results show that the extend of emitters non-compliance increases with an increase in the price of carbon offsets and decreases with an increase in the audit frequency and/or an increase in the penalty per unit of cheating.

Based on the supply and demand curves, the analysis then considers the price and the quantity traded that are established by private firms that are engaged in carbon offset trading. The key role of the traders is to guarantee, based on the amount of monitoring that is undertaken, that the emitters purchase only carbon offsets that actually correspond to sequestered carbon. Both an oligopolistic and a monopolistic trading sector structure are considered.

The analysis then examines two different organizational structures for the group that monitors producer compliance – a group owned by the firms and a government-run agency. The results of the analysis show that both monitoring groups always undertake sufficient monitoring to ensure that full compliance is achieved – thus, while non-compliance is possible, it does not occur in equilibrium. Since the level of monitoring effectively determines the amount of carbon that is sequestered and that can be traded, a monitoring group owned by the traders can achieve monopoly profits for the sector, even when it is oligopolistic. Although the formation of a government monitoring agency can potentially increase traded output and lower the price paid by emitters, these changes are likely to be small, particularly when the trading sector is monopolistic. As we were expecting, the optimal amount of enforcement, and as a result the cost effectiveness of a carbon-offset market, depends on the nature of the organization that undertakes the enforcement.

References

Agriculture and Agri-Food Canada. 2003. Greenhouse Gas Mitigation Program for Canadian Agriculture. Background. March 2003. http://www.agr.gc.ca/progser/ghgm_e.phtml

Bloomfield, J., R. Bonnie, M. Carey, J. Goffman, and Z. Willey. 2003. A bridge to Climate Protection. Slowing global warming by marketing carbon stored in farms and forests. Downloaded from: http://www.environmentaldefense.org/documents/2638_bridge_carbon.pdf

Böhringer, C. 2003. The Kyoto Protocol: A review and perspectives. *Oxford Review of Economic Policy* 19 (3): 451-466.

Cule, M, and M. Fulton. Forthcoming. Some implications of the unofficial economy-bureocratic corruption relationship in transition countries. *Economics Letters*.

Fulton, M., M. Cule, and A. Weersink. 2005. Greenhouse gas policy and Canadian agriculture. *Current Agriculture, Food and Resource Issues*. 6: 1-11.

Giannakas, K., and J. D. Kaplan. 2005. Policy design and conservation compliance on highly erodible lands. *Land Economics* 81 (1): 20-33.

Government of Canada. 2005. *Moving Forward on Climate Change. A Plan for Honouring our Kyoto Commitment.* Downloaded from: http://www.climatechange.gc.ca/english/newsroom/2005/plan05.asp

Keeler, A.G. 1991. *Noncompliant Firms in Transferable Discharge Permit Markets: Some Extensions.* Journal of Environmental Economics and Management. 21: 180-189.

Kreps, D.M. 1990. *A Course in Microeconomic Theory*. Princeton University Press, Princeton, NJ.

Malik, A. 1990. *Markets for pollution control when firms are noncompliant*. Journal of Environmental Economics and Management. 18: 97-106.

Marbeck Resource Consultants. 2004. Administration and transaction cost estimates for a greenhouse gas offset system. A final report submitted to Strategic Policy Branch, Agriculture and Agri-food Canada. http://www.climatechange.gc.ca/english/publications/offset_costs/

United Nations Framework Convention on Climate Change. 1992. FCCC Convention Text. http://www.globelaw.com/Climate/fcc.htm

van Egteren, H., M. Weber. 1996. *Marketable Permits, Market Power, and Cheating.* Journal of Environmental Economics and Management. 30: 161-173.

Vercammen, J. 2002. Dynamic economic modelling of soil carbon. Technical Report # 1-02 (March). Ottawa: AAFC.

APPENDIX A

Monopoly Case:

Stage 2: The maximization problem for the trader:

The objective function:
$$Max_Y PY - P_e(Y + X)$$
$$st \quad Y \leq \overline{Y}$$

Lagrangean function:
$$L = PY - P_e(Y + X) + \kappa(\overline{Y} - Y)$$

The first-order Kuhn-Tucker conditions with respect to the choice variables Y, X and the Lagrangean multiplier κ for this problem are:

$$(\textbf{A1}) \quad L_Y = \frac{\partial L}{\partial Y} = P + \frac{\partial P}{\partial Y}Y - P_e - \frac{\partial P_e}{\partial Z}(Y + X) - \kappa \leq 0 \qquad Y \geq 0 \rightarrow L_Y Y = 0$$

$$(\textbf{A2}) \quad L_X = \frac{\partial L}{\partial X} = -P_e - \frac{\partial P_e}{\partial Z}(Y + X) \leq 0 \qquad\qquad X \geq 0 \rightarrow L_X X = 0$$

$$(\textbf{A3}) \quad L_\kappa = \frac{\partial L}{\partial \kappa} = \overline{Y} - Y \geq 0 \qquad\qquad\qquad \kappa \geq 0 \rightarrow L_\kappa \kappa = 0$$

The second inequality holds as a strict inequality, hence $X = 0$.

We argue in the paper (in the monopoly case) that the constraint is binding. Hence $Y = \frac{\theta\gamma}{\varphi}$, while $\kappa = (\tau + \delta\rho) - 2(\omega + \tau)\frac{\theta\gamma}{\varphi}$.

Solving maximization problem of the monitoring group will provide us the optimal auditing probability θ^*. We are going to substitute the optimal monitoring probability into the formula that we just derived for Y in order to find the amount of carbon offsets Y^* that will be traded in the market.

For the sake of completeness we report the optimal lagrangean multiplier κ^* as well.

Stage 1:   Maximization problem for the monitoring group that operates on trader's behalf

The objective function: $\qquad Max_\theta \ P\dfrac{\theta\gamma}{\varphi} - P_e\dfrac{\theta\gamma}{\varphi} - \dfrac{1}{2}\xi\theta^2$

where P is given by: $D_1 : P = (\tau + \delta\rho) - \tau Y = (\tau + \delta\rho) - \tau\dfrac{\theta\gamma}{\varphi}$

and P_e is given by: $S_0 : P_e = \omega Y = \omega\dfrac{\theta\gamma}{\varphi}$.

The First Order Condition with respect to θ is as follows:

$$\dfrac{\partial(\pi - MC)}{\partial\theta} = (\tau + \delta\rho) - 2\tau\left(\dfrac{\gamma}{\varphi}\right)^2\theta - 2\omega\left(\dfrac{\gamma}{\varphi}\right)^2\theta - \xi\theta = 0$$

The optimal monitoring amount is: $\qquad \theta^* = \dfrac{(\tau + \delta\rho)\varphi\gamma}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}.$

After substituting this to the formulas we derived for Y and κ, we get the optimal amount of carbon offsets that will be traded in the market as well as the optimal value for the Lagrangean multiplier as follows:

$$Y^* = \dfrac{(\tau + \delta\rho)\gamma^2}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

$$\kappa^* = (\tau + \delta\rho) - 2(\omega + \tau)\dfrac{(\tau + \delta\rho)\gamma^2}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

APPENDIX B

Oligopoly Case

Stage 2: Maximization problem for each trader:

$$\underset{y_i,x_i}{Max}\ \pi_i = P(y_i + y_{-i})y_i - P_e\underbrace{(y_i + x_i + y_{-i} + x_{-i})}_{Z}(y_i + x_i)$$

$$st\quad y_i + y_{-i} \le \overline{Y}\qquad\qquad i \in \{1,...,N\}$$

The Lagrangean function can be written as:

$$L = P(y_i + y_{-i})y_i - P_e(y_i + x_i + y_{-i} + x_{-i})(y_i + x_i) + \kappa_i(\overline{Y} - y_i - y_{-i})$$

The first-order Kuhn-Tucker conditions with respect to the choice variables y_i, x_i and the Lagrangean multiplier κ_i for this problem are:

(**B1**) $\quad L_{y_i} = \dfrac{\partial L}{\partial y_i} = P + \dfrac{\partial P}{\partial Y}y_i - P_e - \dfrac{\partial P_e}{\partial Z}y_i - \dfrac{\partial P_e}{\partial Z}x_i - \kappa_i \le 0 \qquad\qquad y_i \ge 0 \rightarrow L_{y_i}y_i = 0$

(**B2**) $\quad L_{x_i} = \dfrac{\partial L}{\partial x_i} = -P_e - \dfrac{\partial P_e}{\partial Z}x_i - \dfrac{\partial P_e}{\partial Z}y_i \le 0 \qquad\qquad x_i \ge 0 \rightarrow L_{x_i}x_i = 0$

(**B3**) $\quad L_{\kappa_i} = \dfrac{\partial L}{\partial \kappa_i} = \overline{Y} - y_i - y_{-i} \ge 0 \qquad\qquad \kappa_i \ge 0 \rightarrow L_{\kappa_i}\kappa_i = 0$

All terms in condition (B2) are negative therefore it turns out to be a strict inequality implying as a result $x_i = 0$. This finding suggests that, when buying carbon offsets, traders find it profitable to operate only in the component $0T$ of the producers' supply.

We have argued on the main body of the paper that the constraint will be binding, which means that $Y = \dfrac{\theta\gamma}{\varphi}$ and $\kappa_i > 0$. As a result, we will proceed to find the solution when:

$\kappa_i > 0,\ x_i = 0,$ and $y_i > 0.$ As derived from equation (B1), the reaction function for the ith firm would be:

$$y_i = \frac{(\tau + \delta\rho) - \kappa_i - (\tau + \omega)y_{-i}}{2(\tau + \omega)}$$

and after considering the symmetry of the firms we obtain:

$$y_i = \frac{(\tau + \delta\rho) - \kappa_i}{(N+1)(\tau + \omega)}$$

By using the above equation and equation (B3), we get the formula for the shadow value:

$$\kappa_i = (\tau + \delta\rho) - \frac{\theta\gamma(\tau + \omega)(N+1)}{\varphi N}$$

and by substituting this back to the equation for y_i, we get the level of the amount of carbon offsets purchased from producers and sold to emitters from the trader identified

by i:
$$y_i = \frac{\theta\gamma}{N\varphi}.$$

Stage 1: Maximization problem for the monitoring group tha operates on traders' behalf:

It is exactly the same as in the monopoly case. Thus:

$$\theta^* = \frac{(\tau + \delta\rho)\varphi\gamma}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

Substituting this to the formulas for y_i and κ_i, we get:

$$y_i^* = \frac{(\tau + \delta\rho)\gamma^2}{N\left[2(\tau + \omega)\gamma^2 + \xi\varphi^2\right]}$$

$$\kappa_i^* = (\tau + \delta\rho) - \frac{(\tau + \delta\rho)\gamma^2(\tau + \omega)}{2(\tau + \omega)\gamma^2 + \xi\varphi^2}\frac{(N+1)}{N}$$

APPENDIX C

Governmental Agency

Stage 1: Unconstrained maximization problem for the monitoring group:

Monitoring group maximizes the social welfare minus the monitoring cost. The objective function will be:

$$Max_\theta \ \pi + CS + PS - C_m$$

$$= Max_\theta \int_0^\theta \left[\left((\tau + \delta\rho) - \tau \frac{\theta\gamma}{\varphi} \right) d\left(\frac{\theta\gamma}{\varphi} \right) \right] - \int_0^\theta \omega \frac{\theta\gamma}{\varphi} d\left(\frac{\theta\gamma}{\varphi} \right) - \frac{1}{2}\xi\theta^2$$

The First Order Condition for this problem specification is:

$$\frac{\partial(\pi + CS + PS - MC)}{\partial\theta} = \underbrace{(\tau + \delta\rho)\frac{\gamma}{\varphi} - \tau\left(\frac{\gamma}{\varphi} \right)^2 \theta}_{from \ D} = \underbrace{\omega\left(\frac{\gamma}{\varphi} \right)^2 \theta}_{from S_0} + \underbrace{\xi\theta}_{C'_m}$$

The optimal auditing probability is given as:

$$\theta^* = \frac{(\tau + \delta\rho)\varphi\gamma}{(\tau + \omega)\gamma^2 + \xi\varphi^2}$$

By substituting the optimal θ^* in the formula for $\overline{Y}$, we find the amount of carbon genuine carbon offsets that will be offered in the market for this level of monitoring.

$$Y_{uc}^* = \frac{(\tau + \delta\rho)\gamma^2}{(\tau + \omega)\gamma^2 + \xi\varphi^2}$$