THE ECONOMICS OF FOREST CARBON OFFSET TRADING:

THE DESIGN OF AN ECONOMIC EXPERIMENT

by

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ABSTRACT

The proposed Domestic Emission Trading System in Canada included an offset market that was expected to provide cost-efficient carbon offsets to the Large Final Emitters. The objective of this thesis was to design an economic experiment that incorporated this institutional design. The experimental design included both regulated and non-regulated sectors and is based on a "cap and trade" carbon emission model. Three markets are included in the experimental design; timber, carbon, and electricity. The electricity sector represents the regulated sectors with a carbon emission cap while the forestry sector represents the non-regulated sectors, i.e. they do not have a carbon emission cap. The decision making framework of the forestry sector is based on a joint-product model; i.e. timber and carbon. The price of carbon offset credits impacts both timber and electricity supply.

RÉSUMÉ

Le système d’échange de droits d’émission envisagé au Canada incluait un marché compensatoire qui devait fournir aux grands émetteurs finaux des crédits compensatoires pour le carbone rentables. L'objectif de cette thèse était de concevoir une expérience économique qui incluait cette conception institutionnelle. L'expérience a été conçue pour inclure des marchés réglementés et non-réglementés et elle est basée sur un modèle “cap and trade” d’échange d’émissions de carbone. Elle a été menée sur trois marchés : celui du bois, celui du carbone et celui de l’électricité. Le marché de l’électricité représente les marchés réglementés avec un cap sur émissions de carbone tandis que le secteur forestier représente les marchés non-réglementés, c.-à-d. il n’y a pas de cap sur émissions de carbone. Les décisions de production dans le secteur forestier sont basées sur un modèle de production conjoint ; c.-à-d. celui du bois et du carbone. Le prix des crédits compensatoires pour le carbone ont une influence sur l’offre de bois et d’électricité. La réglementation de l’émission du carbone est incorporée dans l’expérience en utilisant une courbe de l’offre coudée pour l’électricité. Les prévisions de la théorie et du comportement ont été faites en se basant sur les incitatifs proposés dans l’expérience ainsi que sur l’expérience d’expériences antérieures.

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TO MY FAMILY

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CHAPTER 1: Introduction

1.1 Background on Forest Carbon Offsets Trading

The Kyoto Protocol (KP) is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC), initially negotiated in Kyoto, Japan in December 1997. It came into force in February 2005, with the objective "to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"(UNFCCC 1992, Article 2). Three flexible mechanisms were proposed in the KP to reduce GHG emissions: the Clean Development Mechanism (CDM), Joint Implementation (JI), and international emission trading.

The CDM is a mechanism that allows an industrial country (called Annex 1 countries) to invest in GHG abatement in a developing country and receive the emission reductions from that investment. JI allows industrial countries with emission targets to jointly implement emission reduction projects with the country making the investment receiving the reductions. Emission trading allows carbon credits to be traded between firms within and between countries. Each of these mechanisms is based on the economic concept that differences in the marginal cost of abatement for firms or countries provide an opportunity for trade that will result in emission reductions at the lowest costs.

For emission trading, high-cost abaters would buy credits from low-cost abaters since it is more economical for them to buy the credits than to reduce their emissions directly. While the low-cost abaters can sell their surplus credits for profit, providing an incentive to abate more. This will occur until the marginal abatement cost equalizes among them by letting the emission trading market allocate the resources.

In 2002 Canada ratified the KP and committed to reduce its GHG emissions by 6% below its 1990 level, during the first commitment period of 2008-2012. This is a reduction of 270 megatonnes (Mt) carbon dioxide equivalent (CO2e) below its business-as-usual (BAU) projected baseline for 2010 (Lowey 2005). The KP was signed by the Federal Liberal Party under Prime Minister Jean Chretien when they were in power. As part of the government's initial plan to meet its international commitment, they proposed a domestic carbon emission trading system based on emissions intensity targets incorporating an offsets market.

Canada's Domestic Emission Trading System was based on regulating the intensity of GHG emission from the country's large final emitters (LFEs). The LFEs included: the thermal electricity, oil and gas, mining and manufacturing sectors. The plan was to have the LFEs reduce their emissions by 45 Mt through a covenant/back stop system (Government of Canada, 2005b). There were several ways for the LFEs to meet their target. They could reduce their emission directly, trade emission credits among other LFEs through the domestic emission trading system, purchase Kyoto compliance units, and/or purchase domestic offsets credits through the offset market

By 2006, the Canadian total emission was 721 Mt. Fossil Fuel Production sector emitted 158Mt, accounting for 22% of the total national emissions; electricity sector emits 118Mt, 16%

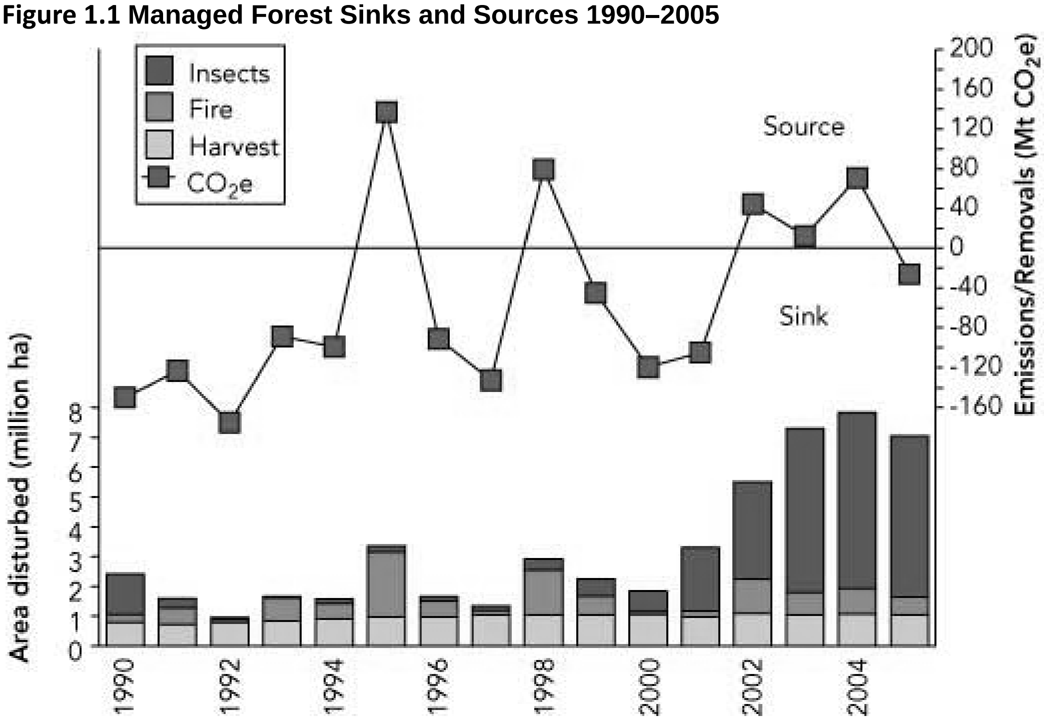
of the total emissions; heavy industry and manufacture sector emits 113Mt, 15.6% of the total emissions. The sectors involving LFEs were responsible for over half of the national emissions. In 2006, approximately 60% of the electricity generated in Canada was from hydro, while 16% was generated from nuclear fuel, 22% was from fossil fuels, and the remainder was generated from renewable such as wind and biomass (Environment Canada, 2008). According to the 2003 data, among the fossil fuels used to generate electricity, natural gas accounted for 6% of the total electricity output; oil-fired power took part of 3%, while coal-fired generated 19% of electricity (Canadian Electricity Association 2006). By far, nevertheless, coal-fired electricity represents generally 18 percent of Canada's current emissions, and eight of the country's top ten GHG emitters are coal-fired power plants (McCarthy 2009).

Complementary to the LFE regulatory system, the government proposed the development of an offset system. Offset system "awards offset credits for verified emission reductions or removals by eligible projects. Participation in the offset system is voluntary" (Government of Canada 2005a, 39). An offset credit is granted to a non-regulated sector or firm when there is a reduction or removal of 1 tonne of CO_2e from the atmosphere by a registered offset project. The sectors that have been identified as having the greatest potential for supplying offset reductions or removals are the agriculture, forestry, and landfill sectors. According to the KP, carbon can be sequestered in sinks. Potential sinks for carbon include afforestation, reforestation, avoided deforestation and potential forest management along with land use management. It is estimated that the agricultural sector can reduce or remove approximately 10 Mt CO2e, the forestry sector 20Mt CO2e and land fill gas sector 7 Mt. It is roughly estimated that, the potential for forests would be a minimum of 4Mt CO2e per year from sequestered beyond BAU over 2008-2012, assuming afforestation and reforestation projects with a carbon price of \$10/t CO2e. Agriculture could potentially provide a sink of approximately 10Mt CO2e per year beyond BAU over 2008-12, at a price range of \$10-15/t CO2e. Landfill gas management could generate reductions of 8-10 Mt CO2e per year beyond BAU over 2008-12 at a carbon price less than \$15/t CO2e (Government of Canada 2003).

Forests can contribute to mitigating climate change with a "double benefit", storing the carbon in their above ground woody biomass, below ground with their root, which results in benefits to the soil system. This also helps to conserve biodiversity by preserving old grown forests, wilderness, and improves environmental quality. These results are based on sound science and do not depend on the KP for their validity. The KP, however, could contribute by providing incentives to encourage, promote and implement forest carbon sequestration (von Mirbach 2003). In the first commitment period, the KP limits eligible forest carbon sequestration under certain categories. Although forests provide a variety of carbon sinks, only the activities of afforestation, reforestation and deforestation (ARD) (KP Article 3.3) and forest management (KP Article 3.4) can generate tradable forest carbon offsets.

Forests can store and accumulate carbon in their wood and soil; however, the stored carbon can be released back into the atmosphere slowly by decaying trees or rapidly by natural disasters. When a forest emits more GHGs than it removes from the atmosphere over certain period, it is consider a source; while it is a sink when it removes more than it emits. These emissions and removals are not only impacted by natural processes, but also forest management activities such as harvesting method, tree planting, rotation length, and efforts to fight fires and insects. Forests in Canada cover approximately 310 million hectors, 76% of which is the managed forest where human activities have direct effect on forest as either a carbon source or sink. The following graph illustrates that between 1990 and 2005 Canada's managed forest was an overall sink except in 1995, 1998, 2002, 2003, and 2004. The main causes for the forests to become sources were fires and insect attacks. During most of this period, the harvested area each year remained fairly steady (Natural Resource Canada 2007).

Figure 1.1 Managed Forest Sinks and Sources 1990–2005



Source: Natural Resource Canada, 2007

The government can use three approaches to influence forests to be managed as a carbon sinks. The first is through direct regulation. This could be done by requiring or prohibiting certain activities or by requiring them to be responsible for any reduction of carbon sinks by purchasing credits etc. The second method would be to have targeted measures. Programmes could be initiated to provide incentives such as subsidies or tax breaks to encourage forest manager to sequester additional carbon. For example, plantations could be encouraged. The third method would be to include reduced or removed carbon from the forest sector into the carbon emission trading system through an offset program. Forest managers could voluntarily undertake activities such as carbon sequestration which could produce “carbon credits” or “offsets credits”. The holders of the offsets credits could sell or trade them to entities that are required to meet certain targets (i.e. the LFEs referred above).

The Liberal Party lost the federal election in 2006 to the Conservative Party who had a minority government. The Conservatives abandoned Canada’s KP commitment for the first commitment period. Instead, they have presented new legislation focusing on air quality. This was done with the Clean Air Act. This legislation does not set regulatory reductions for the LFEs in the 2008-2012 periods, but it does recognize the potential for carbon emission trading. In addition, the Province of Alberta has introduced a carbon emission trading system for LFEs in the province. Carbon credits from the offset sectors are acceptable in this system. Québec and Ontario are also contemplating a “Cap and Trade” system for carbon. The Liberal government’s proposed domestic emission trading system included some unique institutional design characteristics by incorporating the offset market. Forests have been recognized as a potential carbon sink and thus could supply sequestered carbon into the market.

Canada has shown a keen interest in creating a possible market for carbon offset credits. The process is similar to implementing CDM projects between developed and developing countries. Canada’s concept of the offset market is similar to the application of the international CDM process. Forest producers or land owners are able to interact with LFEs that need to purchase offset credits so as to meet the imposed emission regulations. Examples of emission trading systems that have been successful in the past include the SO_2 market in the US. However, a comprehensive trading regime covering GHGs would be significantly more complex due to the nature of the emissions.

The initial institutional design for the emission trading market and the offset system can be investigated in a controllable observable laboratory environment. Using a controlled laboratory setting can be beneficial when the existing theory offers little guidance on how different institutions will affect information interactions and price discovery. Experiments can be designed and conducted to test bed trading institutions or evaluate alternative trading policy proposals to determine those optimal for a particular application. Defects in proposed designs can also be revealed and rectified before field application, where such modifications may be impossible or highly costly. Simulating the market environment in the lab in a simplified, controlled, and repeatable manner allows observable lab experiments to contribute to the design of the emission trading market and offset system, including forest carbon offsets (Smith 1976, 1994; Davis and Holt 1993). These contributions can include: (1) the type of market instrument traded (for example whether temporary credits or offset credits), (2) the suitable market institution (how the instruments are traded, for example, posted-offer auction versus double auction), (3) the market power under different institutional designs, and how it can impact the market (for example, if there is monopoly power or monopsony power, and whether there is collusion between the buyers and seller before they make their bids and asks) (Muller and Mestelman 1998; Muller 1999). The test bedding of these different institutional designs in the controlled lab environment is able to provide some policy implications on developing an efficient and practical emission trading market for public decision makers.

1.2 Problem Statement

The Federal and provincial governments are considering carbon emission trading systems and the possibility of integrating offsets trading into them. Since carbon emission trading and offset credit trading in particular, is a new mechanism, there are several questions concerning the institutional design of the trading system. The offsets trading system could include carbon credits for removals or sequestration from the forestry, agriculture, and the landfill gas sectors. The development of the offset trading system is being proposed because it is expected that they could produce cost-efficient carbon credits. Including offset trading in the design of the domestic emission trading system provides a mechanism for pricing discovery among the regulated and non-regulated industries. Experimental economics can be used to test the price discovery design, the market outcome, and the behavioural changes for both the regulated and non-regulated sectors in the offset market by running a preliminary market mechanism for offsets trading. Since no actual experiments were conducted, this research was to design an experiment that could be used to test bed how carbon offset credits might be traded in a controlled lab environment. In the design, by using the forestry sector was used as a model to address unique production decisions and the probable behavioural impact of forestry producers and LFE participants in the carbon emission market. This could illustrate potential market interactions and behavioural predictions that could be useful for policy makers designing the carbon trading market.

The objective of this research was to design an experiment that would include both offset and carbon credit trading between regulated and non-regulated firms. The contribution of this research was: first, to design an experiment that had three markets for two types of producers;

forest producers and electricity producers (a representative LFE). The forest producers will participate in the timber market and the carbon market while the electrical producers participate in the electrical market and the carbon trading market. Second, there are three market instruments being traded: timber units, carbon credits and electricity (kwh) units. To represent the forest producers' decision making problem, a joint-product model was applied to production decisions that would be required by forest managers. This should impact the participants' trading behaviour. Third, the experiment was designed to run under two scenarios. The first is a status quo situation, where there are two markets running, timber and electrical markets, with no regulation on carbon output from the electricity sector. The behaviour in this before-carbon-trading market would be compared to the one where there is regulation on carbon output in the electricity sector and a carbon offset market in an after-carbon-trading market. Although not modeled dynamically, two different time dimensions, before-carbon-trading scenario and after-carbon-trading scenario, were built into the design. This design is suggested to test the behavioural impacts on the forest/electricity producers and compare their trading surplus, hence the incentives for carbon trading, in these two scenarios. Fourth, the supply curves of electricity producers are designed to be kinked to reflect a limited allocation of pollution permits or credits and high pollution abatement costs above this amount faced by these producers. Finally, robot traders and human subjects are designed to be intertwined in the experiment. The active decision makers, forest producers and electricity producers, will be human subjects. Their trading behaviours would be the focus of the experiment. The counterparties to them in the forest market and electricity markets, i.e., timber and electricity buyers, would be programmed robot traders, myopically maximizing their profits in the current period.

The design of an economic experiment to simulate a domestic carbon emission trading system that incorporates the offset market can potentially assist policy makers by illustrating the incentive behaviours of the various parties involved in the carbon trading market. Furthermore, the design could shed some insight into the institutional design of an integrated Canadian domestic emission trading system that incorporates offsets trading.

1.3 Structure

This thesis is structured as follows. Chapter two contains the literature review. Three areas of the literature are described in detail, (1) the proposed Liberal Government Canadian Offset System, (2) forest management practices that could sequester carbon and generate offsets, and (3) previous economic experiments with an emphasis on emission trading. The experimental design is discussed in chapter three. This includes a description of the market instrument, market parameter and structure, market institution and market subjects. Chapter four, the experimental equilibrium and behavioural hypothesizes are presented and discussed. The preliminary conclusions about the experimental design are in chapter five.

CHAPTER 2: Literature Review

2.1 Canadian Domestic Emission Trading Market

2.1.1 Regulated sectors

The LFEs are made up of nine industrial sectors, which were responsible for approximately 389 Mt GHG out of the total emissions 721 Mt, 53.6% of the national GHG total in 2006. These nine sectors are listed as following: the thermal electricity production (coal, oil and gas); which emitted118Mt, 16% of the total emissions; the oil and gas, which emitted 158Mt and accounted 22% of the total emission; the mining (metallic and non-metallic), which emitted 5.4Mt, 0.7% of the national total; the metallurgy (iron, steel, etc.), with14.2Mt as 2% of the national total; the pulp and paper production, with 10Mt as 1.4% of the national total; the cement and lime (calcium hydroxide) production, with 12.2Mt as 1.7% of the national total; the aluminum smelting, with 12.1Mt as 1.7% of the national total; the chemical production, with 21.7Mt GHG emission as 3% of the national total; Glass and glass container manufacturing—34.7Mt as 4.7% of the national GHG total in 2006 (Environment Canada 2008). Among the ten largest polluters, top five were power generation companies, such as Ontario Power Generation, Transalta Utilities Corporation, Saskatchewan Power Corporation, Alberta Power (2000) Ltd., Nova Scotia Power Incorporated; the rest of five were all oil and gas producers, for example, Petro-Canada, Suncor Energy Inc. Oil Sands (PollutionWatch 2006).

The proposed domestic emission trading system was to regulate the LFEs with emission intensity targets, which restricts the GHGs emission to a specific ratio of GHG emissions per dollar of output. This system can result in increased absolute emissions even if firms make their intensity targets if the demand for this products increase. An alternative approach to regulating emissions is called a "cap-and-trade" system, which puts a specific absolute cap on the emission of a firm or sector. The regulated sectors are not allowed to generate GHG emissions beyond the cap and if they do they will be penalized. The EU emission trading system uses a cap and trade design. Although USA and Australia are not signatories of the KP, they are considering a cap-and-trade emission trading system for their domestic industries.

Under the Liberal Party proposal in 2005, the overall emission reduction target was 45 Mt for LFEs. There are two types of emissions: fixed process emissions and all other types of emissions. The primary difference between these two categories lies in that, the levels of fixed process emissions cannot be controlled by industry, and be lowered only by lowering physical level of production entirely. Therefore fixed process emissions will not be assigned any reduction during the 2008–2012 periods. For the other types of emissions, they should subject to a 15 percent reduction target. However, the targeted reductions from these other emissions cannot exceed 12 percent of total emissions (Government of Canada 2005b). LFEs can achieve their emission reduction task by reducing their own emissions, purchasing emission reduction credits from other LFEs, investing in domestic offset credits, and/or purchase Kyoto compliance units (Government of Canada 2003, 2).

2.1.2 Canadian Offset Sectors

Agriculture, forestry and landfill sectors are unique in that they sequester carbon and potentially can produce low-cost carbon offset credits. Carbon sequestration can be defined as taking carbon out of the atmosphere and deposing it in a sink, e.g. in agricultural soil or forest biomass. These carbon offsets could be sold in a domestic carbon emission trading system to high cost emission abaters who are LFEs. Carbon credits produced by the agriculture, forestry and landfill sectors are called carbon offset credits because these sectors are not regulated, in terms of carbon emission, unlike the LFEs. The participation in offsets credit trading is also voluntary.

Agricultural soil, forests and landfill sites are recognized as potential carbon sinks; hence these sectors could supply carbon credits into the market. Apart from these identified sources of carbon sinks, the proposed offset system tries to be as comprehensive as possible to involve all the possible sources of carbon removal/reduction in the economy. There is a difference between emission reductions and emission removals. Emission reductions are permanent decreases in the emission of GHG. Emission removals are the result of carbon sequestration that remove carbon from the atmosphere and store it in a sink. Forestry projects could include both carbon reductions and removals. In either case, a number of institutional design issues have to be considered:

- Offsets credits are granted based on a project proposal concerning a change in forest management. Each forestry project would generate an absolute number of offset credits that would be verified by a third party.
- Boundary and leakage considerations of forest projects. The boundary of a project includes all anthropogenic emissions under the control of the project proponent that are the result of the project. The spatial boundaries for forest sink and agricultural projects need to be legally recognized by federal and provincial/territorial governments and stakeholders. Leakage is an increase in emissions (negative) or decrease in removals

(positive) outside a project's boundary resulting from the project's activity (Government of Canada 2003, 24-25). Defining project boundaries and identifying leakages is important for forest and agricultural projects.

- Baseline and additionality. The baseline is used to determine the quantity of the emission reductions/removals to be credited to a project. Baseline emissions are the emissions that occur in the business-as-usual (BAU) situation, the amount that the forests inside the boundary would sequester under the existing management in the absence of the project. It is only the "additional" sink enhancement beyond the BAU threshold that can be credited as an "offset". There are five methods suggested to address the baseline estimation: historical/current situation, comparison approach, control group, forward-looking scenario and regional average (Government of Canada 2003, 22-23).
- Non-permanence issue. The non-permanence issue is a problem associated with carbon removal that results from sequestration. Non-permanence of forest carbon sinks significantly influence the willingness of producers to participate in offsets trading. There is one general ex ante way and five ex post means that have been suggested to address the non-permanence of removals projects (Government of Canada 2003 and 2005a) but more research is needed to determine the optimal approach for different sectors. The ex ante alternative is risk management during the project proposal stage, i.e. internalizing the risk, government or the sellers of the offsets assume the responsibility and liability of reversal of the carbon. The five ex post means are as follows: 1) partial or time-delayed crediting, a variation of this is the "tonne-year equivalents" (Thomassin 2003, 174); 2) insured credits from government or private sectors, under which the issuer takes the liability of reversal; 3) offset credit with requiring replacement, in which the seller assume the

responsibility; 4) temporary credits, which provide the greatest flexibility to both buyers and sellers; and 5) rental contracts, which build on the temporary credit approach to providing different market-determined prices for different types of offsets.

- Transaction costs. Forest carbon sinks provide a cost effective alternative for LFEs; however, the transaction cost associated with an offset market could be large enough to eliminate/reduce the market. Transaction costs are "the expenses, which the proponent must incur to complete the project cycle from evaluation to certification of the credits, but do not include costs associated with assessing technical feasibility, project design costs or implementation costs" (Marbek 2004,11). Most of the transaction costs are one time and fixed and include project evaluation, initiation, proposal and validation. However, some of the ongoing costs include the costs in regards to emission reductions/removals of monitoring and quantification, verification, and required replacements if applicable (Marbek 2004, 1).
- Market power. Market power could concentrate in either the buyers or sellers of offset credits. A proper institutional design is required to control either monopolistic or monopsonistic market power to maximize market efficiency.

Among these specific design considerations, the institutional issues such as boundary and leakage, baseline, and additionality, would be addressed in the Qualification Protocols of projects. Two mechanisms to address the non-permanence of GHG removals were formally proposed and elaborated in the Technical Background Document (Government of Canada 2005a). The first one was "the issuance of offset credits with a requirement to maintain the project level of carbon in the reservoir for a set period (the liability period)" (Government of

Canada 2005a, 26), the other was "the issuance of temporary credits" (Government of Canada 2005a, 29). The associated transaction and administration costs in participating in the offset market were listed and discussed in detail in the Marbek' report submitted to Agriculture and Agri-Food Canada (2004).

2.2 Forest Carbon Projects and Offsets

Under the Kyoto Protocol, there is an agreed upon definition of the eligible "forest" and the activities that would generate eligible forest carbon offsets. "Forests have a minimum land area of 0.05-1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10-30 per cent with trees with the potential to reach a minimum height of 2-5 meters at maturity in situ." (von Mirbach 2003, 9). Under Article 3.3 of the KP, the eligible forest activities include afforestation, reforestation, and deforestation (ARD). All three terms have been defined only for the situation where there has been a change in land use since 1990. For example, logging is not considered deforestation, and the regrowth following logging is not considered reforestation, since neither causes a change in land uses (von Mirbach 2003). Under Article 3.4 of the KP, the signatory countries are allowed to choose to account for anthropogenic GHG emissions by sources and removals by sinks resulting from several management practices, including forest management (von Mirbach 2003). For Canada, the carbon sinks from the ARD forest activities are required to be included in the national carbon inventory, while the decision to include the forest management is optional.

2.2.1 Recognition of Forestry as a Joint Product

Carbon sequestration in a managed forest ecosystem is one of the joint products produced by the forest system besides the commercial product, i.e. timber. There are many joint products associated with forests: biodiversity, water quality, air quality, wildlife habitat, and carbon sink (von Mirbach 2003; Sedjo 2001; Murray 2003; McCarney and Armstrong 2006). The recognition in the KP of carbon sequestration as a potential means of addressing the climate change problem puts carbon sinks on a national and global agenda. Sedjo (2001) argued that traditional forest managers, neglect the carbon sequestration because there was no payment for this good. As a result, managers simply determined the optimal rotation to maximize the net present value of the forests, given timber prices. However, if there are payments for both timber and carbon sequestration, they could be regarded as "joint products". This requires the forest managers to consider two output markets in their rotation harvesting decision. Payments for carbon sequestration would be an annual payment while timber payment would be a one-time lump-sum payment. This paper also demonstrates that an optimal rotation can be reached when jointly modelling the prices of timber and carbon, the yield function, and discount rates together. As the price of carbon credits increases, the rotation period will extend. On the other hand, the monetary return will be higher for these joint products than for the timber alone, since both timber and carbon sinks get paid. As for the liability rule for the long-term carbon credits generated in the process, it is argued that the forest managers, or the sellers of these carbon sinks, should bear the liability to maintain the planted forest (Sedjo, 2001). In contrast, the short-term credits, i.e., temporary credits for annual payments, could bypass this institutional issue of a liability rule.

Sedjo's paper provides the "joint-product" concept for timber and carbon credits, while Murray (2003) and McCarney and Armstrong (2006) have quantified this joint-product relationship. Murray (2003) established a carbon supply function based on forest land use, i.e. intensive margin, and the land allocated to forest usage, i.e. extensive margin. His logic was to optimize the bare land value with both timber and carbon revenue. The optimal rotation was determined by the first-order condition of this bare land value function. McCarney and Armstrong (2006) established a constrained optimization model for three joint products: timber, carbon credits, and wildlife habitat. It was assumed that the forest managers tried to optimize the net present value of the timber harvest as the objective function, using regulation on timber flow, carbon dynamics, and wildlife habitat as three constraints to the optimization model. Although focusing on different aspects, both these joint product models provide some insights to deriving the experimental values of the marginal cost to supply forest carbon credits by a forest producer. However, in the experimental design both of these models were too complicated to be used directly by potential subjects in the experiments. A simplified version of the joint-product model (Henderson and Quant 1980, 92-98) could be used in the laboratory to observe market behaviour under different institutional arrangements.

The most relevant experimental paper that looks at emission trading jointly with the product market is Muller et al (2002). In their experiments, the firms optimize in two markets sequentially, the permit market first, and the product market second. The essential difference between their experimental design and this paper's proposed design lies in that, although both the permit and product are interrelated, Muller et al (2002) viewed the carbon permits as one of the inputs in the production process, as a cost-saving item. In this paper, the carbon credit is parameterized as a joint product with the main commercial product, i.e. timber, based on a joint-product model from Henderson and Quant (1980, 92-98). Since the total production decision model for the forest manager is changed from a single-product decision to a joint-product decision, their market behaviours and profits will also change, and could be observed in a controllable laboratory environment. This distinction results in a different experimental design.

2.2.2 Forestry Joint Product Models: Timber-Carbon Models

Murray's Model

Murray (2003) developed a joint-product model of timber land value and terrestrial carbon (C) stocks by calculating the impact of C sequestration incentives on the optimal management of a forest land. Generally, the incentives to sequester C will impact the optimal harvest length as well as the profit generated from forest lands. The supply of C sequestration in terrestrial ecosystems is a function of the allocation of land to each use and the rate of C sequestration from that use. In Murray's model, the aggregate carbon supply function was

$$S_A = \int_i^N c_i^*(v, p, z)\phi_i(v, p, z)Ldi$$ **Equation 2.1**

Where,

"i--indexes one of N different possible land uses;

$c_i^*(v, p, z)$ is the Carbon density of land use i as a function of the C price (v), a vector of non-C output and input prices (p) and land quality (z);

$\phi_i(v, p, z)$ is the share of land allocated to use i;

L is the total area of the land base." (Murray 2003, 223)

There are two variations from the original model. When applying the land use mainly to foresting, rate of C sequestration by forest land (F) use C_F will generate a carbon supply model from the intensive margin. When changing the amount of land allocated to forest ϕ_F, this will generate a carbon supply from the extensive margin. A high C price is expected to induce a higher level of C sequestered on the extensive margin of land use change.

Carbon Supply on the Intensive Margin

Both timber and the amount of carbon sequestered in the forest ecosystem were valued as forest outputs. The original model was a timber-only management model, but this was modified to incorporate carbon sinks so that the joint product nature of decisions could be used to estimate the optimal rotation between timber and C sink. This extension of the model allows forest land to generate C credits when C is stored, or incur debts when carbon is released through harvest or subsequent decay activities. As the Equation 2.2 following demonstrates:

$$BLV_{TC} = \{p^T Q(T)e^{-rT} - R + \int_0^T vC'(t)e^{-rt}dt - [vC(T)\int_0^D d(s)e^{-rs}ds]e^{-rT}\}(1-e^{-rT})^{-1}$$ **Equation 2.2**

Where

" BLV_{TC} is the bare land value of a timber;

C is forest management regime;

T is the rotation age;

$Q(T)$ is the timber volume at the time of harvest;

R is the cost of forest establishment;

p^T is the real price of timber (assumed constant over time);

$C(t)$ is the amount of C sequestered as a function of stand age(t);

v is price per unit of C sequestered or released;

r is the real discount rate;

$d(s)$ is the amount of C released S years after harvest on site or from wood products;

D is the length of time after harvest that C releases occur." (Murray 2003, 225)

Thus the optimal rotation without constraint is determined by the first-order condition of the above bare land value function with respect to T. Hence the optimal harvest-timing rule is calculated as:

$$p^T Q'(T) + vC'(t)[1 - \int_0^D d(s)e^{-rs}ds] + r[vC(T)\int_0^D d(s)e^{-rs}ds] = r[p^T Q(T) + BLV_{TC}] \qquad \textbf{Equation 2.3}$$

This means, at the first-order optimum, the marginal revenue from extending the rotation another year is equal to the marginal delay in the cost of harvesting. Looking at the components on the left side, these three components of the marginal revenue are: (1) the marginal value from the timber growth; (2) the net value of marginal C credits accumulation, and (3) the interest collected on C debits from harvest after the extended rotation. On the right-hand side, the marginal cost of delaying harvesting is represented by the interest on the value of growing timber and the land value. If $v = 0$, meaning there is no payment for carbon sequestration, the optimal harvest-timing rule is just the original version if the model when timber is the only product. The resulting rule is:

$$p^T Q'(T) = r[p^T Q(T) + BLV_{TC}] \qquad \textbf{Equation 2.4}$$

Comparing these above two first-order functions, the rotation age can be delayed when the benefits of the payment for the carbon sequestered outweigh the costs of giving up forest harvesting and holding the land for producing no timber. The forest managers should be willing to accept timber rotations if the loss from delay in the timber harvest is more than compensated by revenues from carbon sequestration.

Summing the carbon quantity terms, the time discount on C supply, is expressed as:

$$S_0 = \{\int_0^T C'(t)e^{-rt}dt - [C(T)\int_0^D d(s)e^{-rs}ds]e^{-rT}\}(1 - e^{-rT})^{-1} \qquad \textbf{Equation 2.5}$$

This indicates that, S_0 is the present value of the net benefits of C stock accumulation from a managed forest land use with a prolonged rotation. The longer the rotation age T, the more C is in the forest reservoir and the longer the delay D in releasing that carbon to the atmosphere.

Carbon Supply on the Extensive Margin

The extensive margin of C stock in each land use can be determined by the amount of land allocated to this type of land use. According to land use theory, to allocate a unit of land to a specific use is determined by its highest economic rent among different alternatives. The economic rent/returns from land use i can be expressed as:

$$\pi_i = \pi_i(v, p, z) = px_i^*(v, p, z) + vc_i^*(v, p, z) \quad \textbf{Equation 2.6}$$

Where

"v is the Carbon (C) price;

p is a vector of non-C commodity and input prices,

z indexes exogenous land quality,

x_i^* is the profit maximizing level of commodity outputs and input demands,

and c_i^* is the profit optimizing level of net C sequestration." (Murray, 2003, p. 230)

The proportion of the land use in use i is represented by $\phi_i = \phi_i(v, p, z)$, then the total differential in land allocated to use i incorporated with the C price is:

$$d\phi_i = (\partial\phi_i / \partial v)dv + \sum_{j=1}^{M}(\partial\phi_i / \partial p_j)dp_j \quad \textbf{Equation 2.7}$$

The marginal value of the land use can be interpreted as the direct effect of C price on the land use and the price feedback from the other commodity markets.

McCarney and Armstrong's Model

McCarney and Amstrong's joint product model incorporates the interaction between forests, carbon and markets by examining the impact of a particular form of a carbon market on timber and non-timber values in a managed forest. Their simulation results are estimated using a three product joint-product model. Their model suggests that the incentive to stored carbon in timber biomass would impact the traditional forest management objectives. The forest producers are faced with tradeoffs of increasing the volume in the carbon sink, the harvesting of the timber product and other non-timber resources depending on the incentives from the carbon market.

In their model, a constrained optimization model was used to analyze the joint product problem with three products, timber, and carbon and habitat quality. The objective for the forest managers was to maximize the net present value of timber harvest, subject to the constraints of wildlife habitat and carbon dynamics. The x-year planning horizon was divided into 5-year periods. The basic forest planning model was defined as follows:

<u>The Objective Function:</u>

$$\max_{x_{ijk}, w_{ij}} \sum_{i=1}^{I} \sum_{j=-M}^{k-M} \sum_{k=1}^{N} c_{ijk} x_{ijk} + \sum_{i=1}^{I} \sum_{j=-M_i}^{N} E_{ij} w_{ij} \qquad \textbf{Equation 2.8}$$

Subject to the constraints:

$$\sum_{k=1}^{N} x_{ijk} + w_{ij} = A_{ij} \qquad \forall i, j \qquad \textbf{Equation 2.9}$$

$$\sum_{l=k+1}^{N} x_{ikl} + w_{ik} - \sum_{j=-M}^{k-1} x_{ijk} = 0 \qquad \forall i, k \qquad \textbf{Equation 2.10}$$

Where

" A_{ij} ==Area (ha) of forest type i born in period j

x_{ijk} (x_{ikl}) == Area (ha) of forest type i that is regenerated in period j (k) and harvested in period $k(l)$

c_{ijk} == Discounted net revenue ($/ha) generated by harvesting forest of type i born in period j and harvested in period k

$w_{ij}(w_{ik})$ == Area (ha) of forest type i regenerated in period j (k) that is left as ending inventory at the end of the planning horizon

E_{ij} == Discounted value ($/ha) associated with the ending inventory of forest type i that is regenerated in period j

N == the number of periods in the planning horizon

M == the number of periods before period zero in which the oldest age class present in period one was regenerated." (McCarney and Armstrong 2006, 12)

Constraint One: even flow constraints on harvest volumes

In Canada most forest land is highly regulated. In the model, regulation on timber flow is implemented as an even flow constraints on harvest volumes:

$$F_k = \sum_{i=1}^{I} \sum_{j=-M+1}^{k} v_{ijk} x_{ijk} \qquad \forall k$$ **Equation 2.11**

$$G_k = \sum_{i=1}^{I} \sum_{j=-M+1}^{k} z_{ijk} x_{ijk} \qquad \forall k$$ **Equation 2.12**

$$F_k - F_{k+1} = 0 \qquad \forall k$$ **Equation 2.13**

$$G_k - G_{k+1} = 0 \qquad \forall k$$ **Equation 2.14**

Where

" F_k == Softwood volume (m^3) harvested in period k

v_{ijk} == Softwood harvest volume (m^3 /ha) for forest type i that is regenerated in period j and harvested in period k

G_k == Hardwood volume (m^3) harvested in period k

z_{ijk} == Hardwood harvest volume (m^3 /ha) for forest type i that is regenerated in period j and harvested in period k ."(McCarney and Armstrong 2006, 12)

Constraint Two: wildlife habitat area

The quality of wildlife habitat is related to the type and age of the forest. The habitat area constraint requires the habitat area in the forest to be greater than a minimum level of habitat quality for certain species in some planning horizon.

$$\sum_{i=1}^{I}\sum_{j=-M+4}^{k} h_{ijks}x_{ijk} + h_{ijks}w_{ij} \geq \overline{H_{ks}} \qquad \forall k, s$$ **Equation 2.15**

Where
"h_{ijks} == Habitat quality for species s in forest type i, birth period j, and time period k
$\overline{H_{ks}}$ == Minimum level of habitat quality for species s in time period k."

Constraint Three: carbon dynamics

The carbon dynamics constraint requires forest carbon stocks to be maintained at least at a specified level for all periods in the planning horizon, which was similar to a baseline concept in the business as usual measurement

$$\sum_{i=1}^{I}\sum_{j=-M+4}^{k} c_{ijk}x_{ijk} + c_{ijk}w_{ij} \geq \overline{C_{k}} \qquad \forall k$$ **Equation 2.16**

Where
"c_{ijk} == Carbon stock (tones C) for forest type i, birth period j, and time period k
$\overline{C_k}$ == Minimum stock of total forest carbon in period k." (McCarney and Armstrong 2006, 13)

The research concludes that the co-benefits will be determined by forest cover type, the harvest flow regulation faced by the forest managers and the profits from the timber market. Furthermore, forest producers agree to supply carbon sequestration offsets by declining their timber supply, prolonging their harvest rotation or other types of economic activities, which is influenced by the carbon incentives, i.e. price, on the timber supply. The results also show that carbon and non-timber resource benefit move in the same direction. The stronger the incentives to sequester carbon, the more cost-efficient it is to achieve non-timber objectives. Although differing in the specific model and joint products, both Murray (2003) and McCarney et al (2006) concurred that there is a trade-off between timber and carbon from the forest depending on the incentives from the carbon market. Their research not only justifies the concept of a joint-product decision framework between timber and carbon, but provides a quantitative foundation for the joint-product model used to design the experiment in this thesis.

2.3 Experimental Economics: Principles and Practice

Experiments are a relatively new method for economic research. It has been used to test price theory and to investigate the incentives from new market instruments. The primary advantages of this method are "replicability and control". *Replicability* means that the researchers are able to repeat the experiments and validate the findings separately; while *control* enables the manipulation of the laboratory environment so that observed behaviours can be used to predict and evaluate alternative theories and policies (Davis and Holt 1993, 14-15; Davis and Ramagopal 1998, 3). In a relatively cheap and more observable way, controlled laboratory environments can be used to design, modify, and manage the parameters of untested variables, while being able to replicate the experiments and verify the results independently.

Though experiments are being used more often in economics, there are economists who criticize this approach. One of the major criticisms of the laboratory environment is that it is too simple. The results from these simple experiments cannot be applied to a complex reality. Others have argued that the simplicity of the experiments allows for greater control to test behaviour and theory. This is similar to other reductionist approaches used in the economics.

If the theory fails to work in a simple experiment, one would expect it not to work in a more complicated natural world. The use of experiments is justified because of the "control" it provides the research. When the price of collecting data is high or it does not exist, then an experiment is the only way to define and observe the behaviour that results from a set of defined supply and demand curves.

Experimental methods should complement rather than substitute other empirical techniques. Experimental data should be collected in the lab and tested with either parametric tests or with nonparametric tests. Usually parametric tests are based on restrictive statistical assumptions on the underlying data distribution, while nonparametric tests make weaker statistical assumptions about the data set. V.L. Smith (1976) argues that, laboratory experiments can be used to simulate real behaviour if the behaviour is rewarded with factual payment for decisions made. The advantage of an experiment is that you can control the values of payments in the laboratory that cannot be controlled in the real world. This allows the experimenter to provide different payments to subjects based on their performance.

Experimental economics consists of three main dimensions, market experiments for testing competitive price theories, game experiments to test game theories, and individual choice experiments to evaluate basic theory of individual decision under uncertainty, such as expected-utility theory (Davis and Holt 1993). The former two have been applied to game and decision theories, with individuals bargaining with complete information. The latter, in contrast, deals with agents acting in groups, in the market, with incomplete information. In these situations, auctions become an effective and efficient trading arrangement. Since this paper deals with market performance in the forest offset market, this research design will focus on competitive price tests.

Smith (1976) used experimental economics to test induced value theory. This approach introduced demand and supply equations to be used in experimental design. Induced valuation is based on the premise of non-satiation: "utility is a monotone increasing function of the monetary reward, U (M), $U^{'} > 0$" (Smith, 1976, 275). For example, for the subject buyer i, function $R_i(q_i)$ represents the opportunity cost of abating q_i units of emission.

Given the permit price p for these price-takers in a competitive market,

To $\max U_i[R_i(q_i) - pq_i]$

FOC: $U_i^{'}(R_i^{'} - p) = 0$,

Since $U' > 0$,

$\therefore R_i^{'} - p = 0$

$\therefore R_i^{'}(q_i) = p$

Hence the demand curve is derived as $q_i = R_i^{'(-1)}(p)$.

Similarly, j subject seller is given the cost function $C_j(q_j)$ to provide q_j units of emission permits,

To $\max_{q_j} V_j[pq_j - C_j(q_j)]$

FOC: $V_j^{'}(p - C_j^{'}) = 0$,

$\because V' > 0$,

$\therefore p - C_j^{'}(q_j) = 0$

$\therefore C_j^{'}(q_j) = p$

This is the supply curve as $q_j = C_j^{'(-1)}(p)$

Smith (1981) and Smith and Williams (1989) used this method to derive the values used in their experiments. Smith and Williams (1989) argued that the supply and demand curves in their experiments were derived from induced valuation theory for each unit traded. The buyer earns the difference between the opportunity cost of self-abatement (assigned by the experimenter) and the equilibrium permit price reached in the permit market, while the seller earns the difference between the equilibrium permit price and its marginal cost of supplying permits (assigned by the experimenter). The assigned cost values and functions were strictly private that they were only revealed to the relevant individual buyer and seller. The assigned values of opportunity costs of emission abatements for all buyers are ordered from high to low generating the market "induced demand curve". Whereas ordering all the assigned values of marginal costs to generate permits for all sellers from low to high generates the market "induced supply curve". Therefore, the intersection of these "step functions" (discrete functions) results in a competitive equilibrium price and quantity in the permit market. For example, each buyer and seller has a high-value unit and low-value unit. The buyers with multiple units are restricted to buy the high-value unit first thus inducing a downward sloping demand curve. Symmetrically, the sellers are provided with multiple units but are required to sell the low-value unit first, which results in an upward-sloping supply curve (Davis and Holt 1993, 10-11).

When testing competitive price theories, experiments can be classified by both the institution and the subfield of economics (Davis and Holt 1993). Institutions are primarily characterized by the timing of agent's decision, thus there are simple institutions where decisions are made simultaneously/independently, and more complex institutions, where decisions are made sequentially and dependently. Posted-offer auctions are frequently used as an example of a simultaneous institution. Under the posted-offer institutional design, sellers publicly post their offers on a take-it-or-leave-it basis, while simultaneously buyers are selected randomly to purchase at the posted price. In contrast, the double auction is a sequential institution, where buyers and sellers post their prices publicly, however according to a sequential "improving rule", where the buyer's second bid has to be higher than the first one, in contrast, the seller's second ask price has to be lower than the first one, thus when there is a unanimous agreement on the price, the market arrives at equilibrium. Researches using double auctions have concluded that they generate competitive outcomes, i.e. price, quantity, efficiency levels, more quickly and robustly than any other institution design within the same standards (Davis and Holt 1993, 41 and 126). The posted-offer auction can also converge to a competitive equilibrium, but it is slower to reach equilibrium (Davis and Holt 1993, 192; Davis and Ramagopal 1998, 23). Double-auctions are more frequently used when there is more symmetric interaction between the buyers and sellers, such as in financial markets. The posted-offer auction is used more often when there are asymmetric interactions where transaction costs are relatively high (Smith 1991). Davis and Holt (1993, 296) argue that the double auction has three disadvantages. The double auction lacks *feasibility* when there is a large amount of information; the absence of off-hour trading raises a *fairness* issue; all the binding bids and asks do not allow *forgiveness*. Therefore, based on these institutional shortcomings, some alternative market institutions were proposed. One such suggestion was the uniform price auction, which is a sequential, double-sided, continuous bid/offer institution with backtracking allowed (Davis and Holt 1993, 297).

Binding price controls, such as price ceilings (floor), lead to allocative inefficiencies. There is some argument that nonbinding price regulations can also cause inefficiencies, because they may raise mute conspiracies around the controlling price area. However, the experimental results from Smith and Williams (1981) on non-binding price controls showed that the market converged to the competitive equilibrium, although with a different price-convergence path. Smith and Williams (1981, 467) conducted an experiment with 16 double auction markets to examine the effect of nonbinding price controls and found that a nonbinding price regulation will converge from below (above) for a price ceiling (floor). This change in the price-convergence path was caused by the price control truncating the range of acceptable bids and offers. In static price theory, with utility-maximizing traders, nonbinding price ceilings or floors should not affect the competitive equilibrium price in double auction markets; however, they do have substantial effects on price dynamics (Gode and Sunder 2004). This could play an important role if the government places a price ceiling on the price of carbon.

Brown-Kruse, Elliot and Godby (1995), Godby (1998), and Muller et al. (2002) have raised questions concerning the double auction's ability to constrain the market power of both the buyer and seller. In the experiments concerning market power, it was known that subjects exercised market power when there was asymmetric information (Brown-Kruse, Elliott, and Godby 1995). Research has been undertaken from a sellers' perspective in a monopolistic market, and from the buyers' perspective in a monopsonistic market. An effective market institution needs to be designed to constrain the potential market power from both sellers' and buyers' perspectives as well as the potential for collusion between the two parties. They did not, however, suggest a more efficient trading institution for emission trading.

2.4 Previous Experiments on Carbon Emission Trading

Experimental economics is an innovative approach that can test economic theories and behaviours, and investigate the institutional designs of the carbon trading system. Emission trading has grown beyond an academic curiosity into a practical approach for addressing environmental problems. Experimental economics can test bed theoretical regulations and investigate behaviour in a lab environment.

Brown-Kruse *et al*. (1995) investigated the effect of market structure in emission trading market, particularly whether a firm could strategically manipulate a product market from the emission market. In this experiment, firms participate in two markets, first the permit market then the product market. Two cases of manipulation were examined: simple and strategic manipulation. Simple manipulation was a cost minimizing manipulation. The dominant firm maximizes profits by minimizing its cost. In the case of strategic manipulation, the dominant firm not only tries to influence the permit market through its market power but also attempts to influence its rivals' costs in the product market. Results show that strategic manipulation can be used when the dominant firm has asymmetric information about the valuations of the competitive fringe.

Muller and Mestelman (1998) have summarized and compared the laboratory research in the US and Canada in the past decade that have investigated the efficiency of emission trading programs, the role of alternative market instruments and institutions, the effects of permits' bankability, and the extent of market power. They have concluded that, first, emission trading markets work both as a theory and laboratory practice, however, they tend to capture only part of the potential trading surplus when there is market power; second, the market institutions regulating trades in the emission market have an impact on market efficiency; third, the design features of the market instrument, such as whether permits are tradable or bankable, influences the equilibrium and performance; last, market power matters. Muller (1999) has also confirmed that three market design issues affect market performance in emission trading: the market instrument matters; the market institution matters; and market power from either side of the market matters.

The Muller et al. (2002) experimental design has been extended into questioning the ability of the double action to be an "effective" way to restrain market power by combining the permit market and the product market. Conventional theory suggests that the double auction is a very effective institution to constrain market power (Davis and Holt 1993). Using eight sessions, twenty-four hour ten-period markets, in a double ABA cross-over within-subject design that controls for subject effect, it was found that there is successful use of market power in the form of price discrimination. Average prices particularly rose under monopoly and fall under monopsony. Efficiency was not affected; however, the profits were redistributed in favour of the firm with market power.

Muller et al. (2002) experimental design and predictions will be discussed in detail in the following section because they are the most relevant examples of market parameterization and structure in emission trading research. Their design was based on regulated sectors trading emission credits amongst themselves in a sequential approach.

2.4.1 Muller et al. (2002) Design and Predictions

Muller et al. (2002) have done a number of emission trading experiments combining product markets and permit markets, which are based on a regulated cap-and-trade carbon trading system. The firms are regulated to either decrease their own emissions, or purchase permits as cost savings to produce their commercial products. Muller et al. (1999) was the working paper, while Muller et al. (2002) was the published version in a much condensed form. In their experiments, the trading system ran two markets sequentially, an emission permit double auction market and then a production market. The double auction experiment was only conducted in the emission permit market. The emission permits were first purchased by firms with high self-abatement costs, and then were used as cost savings to reduce their total operating costs of supplying products. This was how the two markets and products were interrelated. Every period, the firm obtained the revenue by selling the product and incurred costs from purchasing the inputs.

Market Instrument

In this series of experiments, there were two markets running sequentially, an emission permit double auction market and then a product market, thus the most important feature of the traded instrument was that the emission credit in the first market, i.e. permit market, is an input into the production of the product market, i.e. the second market. The firm produces a product from several inputs, one input, called a “leet”, “was rationed and could only be obtained by surrendering a ration coupon.”(Muller et al. 2002, 73). Therefore the two markets and products were interconnected. Every period, the firm obtained the revenue by selling the product and incurs costs from purchasing the inputs. However, for the *leets* or coupons, there was no additional payment for them; instead they could be used as an input to reduce the firm's costs. They were distributed at the beginning of each period to some firms but not to others, so the firms with the coupons can use the *leets* to reduce costs/increase profits, or sell them to the firms without them, which can choose to buy the *leets* to reduce costs. Thus, "the marginal value of a ration coupon was equal to the increasing total operating profits induced by employing more than one more unit of leets" (Muller et al. 2002, 73). The following two equations estimate net sales revenue and total operating profits of the firm.

- Net sales revenue=revenues—(all costs—leets' costs) **Equation 2.17**
- Total Operating profits=net sales revenue + Σleets' cost savings **Equation 2.18**

The firms are both permitted to buy and sell leets—like traders, but no short sales were allowed. "The use of leets is analogous to the use of the environment to assimilate emissions and ration coupons are analogous to annual emission permits" (Muller et al 2002, 73). Coupons were not bankable. The leet/coupon terminology was adopted to avoid the possible "emotional reactions to the concept of emissions trading and the terms used in the software" (Muller et al. 2002, 73).

Buyers are not allocated any coupons. According to Equation 2.18, they can increase their net revenue by purchasing coupons as oppose to paying the higher costs of self-abatement. Therefore the buyers' profits can be increased by the cost savings between their self-abatement costs and the coupon price they pay. The buyers' net revenues are designed to be positive. For the sellers, since they are initially allocated with coupons, they can increase their net sales revenues by selling coupons, according to Equation 2.17. In the Muller et al. design (2002), the sellers started with negative net revenue. Rather than making a production decision themselves, the parties are given output and net revenue in the product market. The decision making in terms of coupon trades will only occur in the emission permit market under a double auction institution. The parties will trade coupons in the permit market first, and then use the coupons as one of their inputs to produce their commercial products. However, this research did not run experiments on the product market; that is, the parties were simply given determined output levels. The buyers and sellers in the experiment represent the firms in a regulated LFE market under a cap-and-trade system. Some of these firms produce less, with negative incomes and lower abatement costs, and initially were allocated with coupons; those with positive net revenues emitting more GHGs, having a high pollution abatement cost, are intended to purchase low cost coupons from their counterparts in order to save costs and increase their profits.

Market Parameters

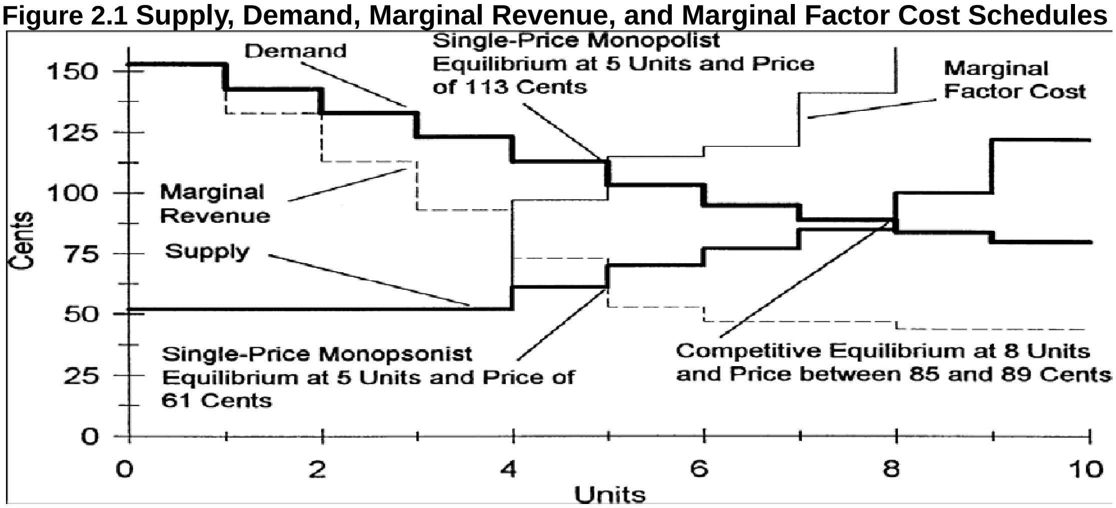
The marginal costs and values of coupons were derived from Smith (1981), Smith and Williams (1989) and Ledyard and Szakaly-Moore (1994). The original parameters were expressed in terms of supply and demand schedules, which induced a single competitive equilibrium price, a competitive trading volume of 8 units, and a market-power quantity of 5. Muller et al. have made several modifications to the parameters. First, they eliminated commissions by increasing the demand curve and lowering the supply curve to create a competitive equilibrium price tunnel of 5 cents, between 85-89 cents, rather than the single equilibrium price. Second, they adjusted the supply curve with a 3-unit difference in the trading quantity between the competitive and market-power scenarios. Third, they called the sellers' marginal opportunity costs a "redemption value"; and finally, they introduced and maintained a profit of 100 cents per period for each subject by introducing fixed revenue and fixed cost in all the market structures. In Table 2.1, the parameters for a competitive market, monopoly market, and monopsony market under baseline scenario were assigned and calculated from the Equation 2.17 and 2.18. These parameters were then drawn as a discrete function in Figure 2.1.

Table 2.1 Basic Parameters for Competitive Market, Monopoly Market and Monopsony Market

	Trader Numbers (Potential Buyers)							Trader Numbers (Potential Sellers)						
	Monopsony		Competition and Monopoly					Competition and Monopsony					Monopoly	
	1	2-5	1	2	3	4	5	6	7	8	9	10	6-9	10
Net Sales Revenue	-156	100	34	44	52	56	58	-109	-87	-74	-74	-74	100	-818
Coupon Allocation	0	0	0	0	0	0	0	2	2	2	2	2	0	10
Redemption Value														
Coupon 1	153	0	153	143	133	123	113	122	100	85	77	70	0	122
Coupon 2	143	0	80	84	89	95	103	52	52	52	52	61	0	100
Coupon 3	133	0	0	0	0	0	0	0	0	0	0	0	0	85
Coupon 4	123	0	0	0	0	0	0	0	0	0	0	0	0	77
Coupon 5	113	0	0	0	0	0	0	0	0	0	0	0	0	70
Coupon 6	103	0	0	0	0	0	0	0	0	0	0	0	0	61
Coupon 7	95	0	0	0	0	0	0	0	0	0	0	0	0	52
Coupon 8	89	0	0	0	0	0	0	0	0	0	0	0	0	52
Coupon 9	84	0	0	0	0	0	0	0	0	0	0	0	0	52
Coupon 10	80	0	0	0	0	0	0	0	0	0	0	0	0	52
Initial Profit	-156	400	34	44	52	56	58	65	65	63	55	57	400	-95
Efficient Profit	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: edited from Muller et al (2002)

Figure 2.1 Supply, Demand, Marginal Revenue, and Marginal Factor Cost Schedules



Source: copied from Muller et al (2002)

Market Structure

Three market structures were compared: competitive, monopoly, and monopsony. The competitive market was the baseline scenario; five subjects were net coupon sellers and received two coupons each per period. The remaining five subjects were net buyers with no coupons. Each subject was allocated two different redemption values. Since all the participants were actually traders, who were allowed to both buy and sell and even to speculate if they wanted, the equilibrium price determined who were the buyers and who were the sellers. High values were buyers and low values were sellers.

In the monopoly market, 10 values of marginal costs were allocated to the five sellers in the competitive markets. In monopoly markets, these 10 values were combined and assigned to a single subject, as the monopolist; the remaining four firms didn't participate in the experiments, however they were required to respond to computer prompts at the start and end of the period. These "locked-out" traders receive fixed revenues to maintain 100 cents of profit; while the fixed costs for the monopolist was also raised to keep a profit of 100 cents as in the competitive market. The monopsony market was similar, except that the combined redemption values, from the net buyers' part in the competitive market, were assigned to a single buyer, the monopsonist.

As noted in Table 2.2, each session consisted of a practice market and three "real "markets. Markets 1 and 3 always had the same market structure CSCB (seen vertically in Table 2.2), which contrasts with the structure in Market 2 SCBC, which makes the monopoly and monopsony market structures independently contrasted with competition in two ABA crossover designs (seen horizontally in Table 2.2). In each market, different marginal cost values were used. There was no relationship between the marginal cost values in the practice market and the ones in the real markets. The basic parameters were used in Market 1 CSCB; in Market 2 SCBC were all the values adjusted downwards by 23 cents from the baseline parameters, while in Market 3 CSCB all the cost values had 26 cents added to them. For each subject, fixed costs were adjusted to maintain 100 cents of profits as under the efficient allocation in the competitive market in order to equalize potential profits for the subjects.

Table 2.2 Summary of Muller's Experimental Design

Treatment		**Market Structure**			
Sessions	**ABA cross-over**	**0**	**1 (CSCB)**	**2 (SCBC)**	**3 (CSCB)**
2	CSC	Practice	Competition	Monopoly	Competition
2	SCS	Practice	Monopoly	Competition	Monopoly
2	CBC	Practice	Competition	Monopsony	Competition
2	BCB	Practice	Monopsony	Competition	Monopsony
	10 subjects in computerized double auction	2 or 3 periods, 10 minutes each, 20-30 minutes	10 periods of 3 minutes each, so each market lasts for 30 minutes		

Source: Muller et al. (2002).

Subjects

Each session required ten subjects in a computerized double auction. Each represented a firm producing the product from several inputs, including leets, and could both buy and sell leets like traders. In the experiments' eight sessions, the 8 subjects with the role of monopolist or monopsonist were post-doc fellows or graduate students in economics and business. The remaining 72 subjects were recruited from the general student population by advertising and class announcement. Sessions were planned for no more than 3 hours, however due to computer failures in some runs, some sessions last longer, up to 3.5 hours. In some of the aborted sessions subjects were given additional knowledge on trading. After each session the subjects had to complete a questionnaire and were paid privately in cash. Generally, the competitive subjects earned between $11.82 and $36.23 (mean $26.22) plus a $5.00 show-up fee. The monopoly and monopsony subjects earned between $39.13 and $66.90, with mean of $48.16 (Muller et al. 2002). The subjects were instructed and guided to trade by a *wizard*, "which informed them how much adding or subtracting one coupon from their holdings would change their operating profits" (Muller et al. 2002, 73).

Benchmarks and Predictions

Table 2.3 provides benchmark prices and quantities, which are also displayed in Figure 2.1. The net sales/trading volumes, prices, profits, gains and profits were calculated under four benchmarks. The no-trade benchmark shows the initial distribution of coupons. In the competitive/efficient benchmark, the total gains from trade were maximized at 451 cents with 8 units traded at a price range between 85-89 cents. In the monopoly/monopsony benchmark, the gains were maximized at a single price for a single seller/buyer. These benchmark predictions were not the experimental outcomes in the lab since the single subjects were not restricted to a single price, which allows the possibility of price discrimination. In addition, since the subjects were buy-sell traders, the total transactions could exceed the net trades in the benchmarks.

Table 2.3 Benchmarks

Benchmark	Net purchases	Price	Profit			Gains from trade	Efficiency (%)
			Buyers	Sellers	Market		
No trade	0		244	305	549		
Competition	8	85–89	500	500	1000	451	100.00
Monopoly	5	113	344	601	945	396	87.80
Monopsony	5	61	604	341	945	396	87.80

Source: copied from Muller et al. (2002)

2.5 Summary

The concept of emissions trading has developed from a theoretical interest to a fundamental initiative in environmental regulation. Several carbon trading experiments have been undertaken. Muller (1999) has investigated issues such as market instruments, institutions, and market power. These studies indicated that market instruments such as banking and trading over time increase efficiency, reduce trading volumes and stabilize market price. It was also argued that, theoretically, the double-auction mechanism as market institution should result in the highest market efficiency and providing control over the use of market power, however, experiments have brought into doubt whether market power can be controlled with the double-auction mechanism (Muller et al. 2002). Muller et al. (2002) argued that the double auction may be ineffective in the use of market power in terms of speculation and price discrimination. In Sedjo (2001) and Murray (2003), they argue that timber and carbon sinks should be treated as a joint product, thus forest managers need to maximize their profit in both markets. In this research, Muller et al. (2002) experiments were modified to include a timber-carbon joint product decision model. In addition, another modification was the integration of the non-regulated timber and offset markets running simultaneously with a regulated LFE market.

CHAPTER 3: Experiment Design

3.1 Conceptual Framework

The objective of this research was to illustrate the dynamic interaction between the regulated and non-regulated industries by designing an experiment that could run three markets simultaneously, the timber market, the carbon market, and the electricity market. The design is intended to affect the down-stream buyer behaviour, electricity producers, and up-stream seller behaviour, forest producers. It is expected that the experimental design will realistically represent the incentives and provide an efficient price discovery mechanism in the carbon market.

In order to illustrate the impacts of the forest offset credits on the market structure and participants' behaviour, there will be two scenarios considered, before carbon trading and after carbon trading. In the before carbon trading scenario, there are two markets running simultaneously, the timber market and the electricity market. They are unrelated; each is running as a single product market. In the after carbon trading scenario, there are three markets running simultaneously, timber, carbon, and electricity markets. These three markets are interrelated with each other by trading carbon credits. Forest producers now make their decisions based on a joint timber-carbon product model, being sellers of both timber and carbon products. Electricity producers sell in the electricity market; however, in the latter scenario they must regulate their carbon emissions by either supplying abatement or purchasing carbon credits. The experimental design is intended to come up with a parameterized carbon trading mechanism that will link the timber producers and electricity producers at the same time. The impact on their behaviour can be observed and compared between the two scenarios. The incentives for the different parties should have policy implications.

3.1.1 Domestic Emission Trading Market: the Carbon Market

The Canadian domestic emission trading market would be developed based on the concept that producers with high marginal emission abatement costs will buy emission credits from those with low marginal cost to abate emission, rather than reducing the emission themselves with high costs. In Canada, there are nine sectors categorized as Large Final Emitters (LFEs), which have high levels of GHG emissions and could be regulated against their quantity of emission in a backstop/covenant system. They are allowed to pollute within a certain quantity freely. If they want to produce more and pollute more, they will have to pay a penalty for the extra emission (Randall 1987, 363). There are four options for LFEs to achieve their emission reduction targets under the backstop or covenant: to "reduce its own emissions, purchase Kyoto compliance units, purchase emission reductions of other LFEs in the form of domestic permits, and/or purchase offset credit" (Government of Canada 2003, 2). The offset market can provide cost-efficient carbon offsets, which are not covered by the backstop/covenant, hence are not regulated. Agriculture, forests, and landfill gas management sectors are indentified as potentially being able to provide low-cost carbon offsets to heavily polluting LFEs.

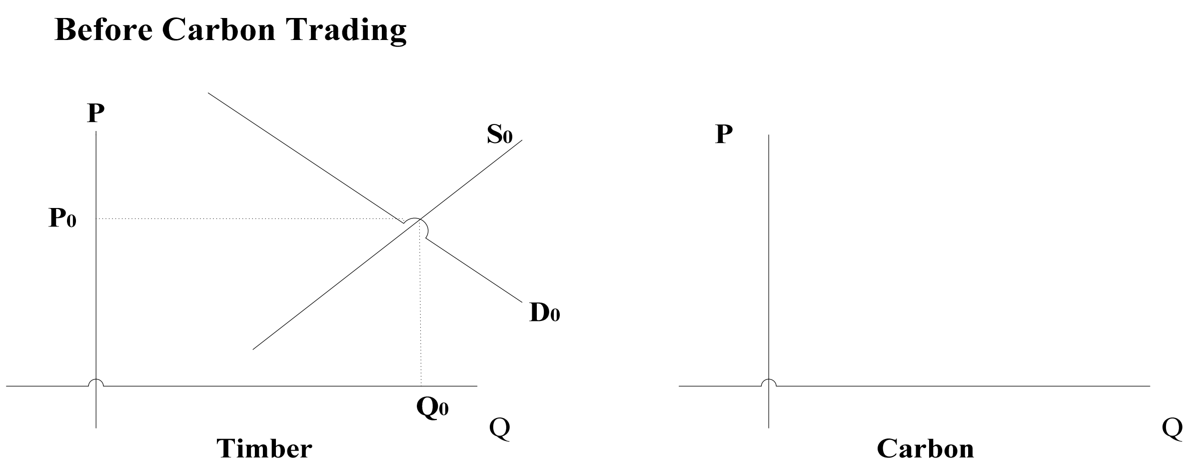
Canada has decided to adopt an intensity-based GHG target, which restricts the GHGs emission to a specific ratio relative to input or output. This system can result in an absolute increase in emissions with a decrease in GHG intensity due to a change in the demand for goods and services or a change in industrial structure. In this research, the trading institution will be designed based on the electricity industry, i.e. a representative of the LFEs, and the forestry sector, i.e. a non-regulated sector, under a cap-and-trade system, which puts an absolute emission cap on the regulated industries.

3.1.2 Forest Producers

Before Carbon Trading

Forest producers were expected to maximize their profits from producing timber. Their production model and trading behaviour in the timber market is the same as other single-product producers, as seen in Figure 3.1. In the timber market, the original timber supply curve is S_0; the timber demand curve is D_0. Competitive equilibrium is reached at the price of P_0 and Q_0.

Figure 3.1 Timber Producers before Carbon Trading

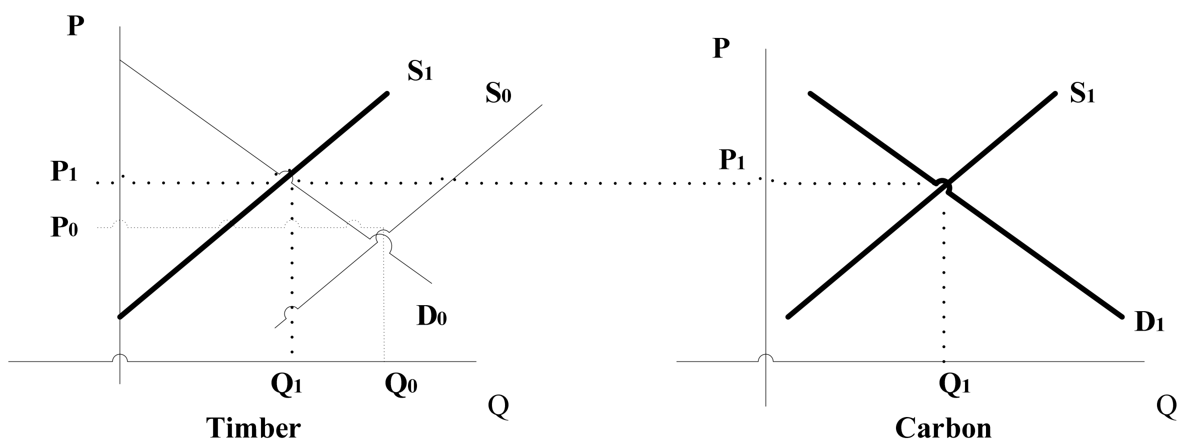


After Carbon Trading

When the government establishes a carbon emission trading system and carbon offset system, the forestry sector is expected to be more cost-efficient in providing GHG emission abatement in terms of carbon sequestration as compared to the LFEs. Therefore, the carbon trading profit for the forest producers is expected to be large enough to change their production decisions.

Forest producers will change their timber production model to a timber-carbon joint product model. They can generate carbon credits from the emission market by prolonging the rotation length or change forestry management practices in order to sequester more carbon. When there is less timber harvested, there are more carbon offsets generated. To maximize their profit in the timber and carbon market, forest producer will need to balance the production between timber and carbon, which becomes a joint-production decision. In the timber market Figure 3.2, forest producers now supply less timber, the supply curve S_0 shifts to S_1 on the left. The demand curve D_0 does not shift. This results in a lower quantity Q_1 and higher price P_1 at the competitive equilibrium.

Figure 3.2 Timber Producers after Carbon Trading



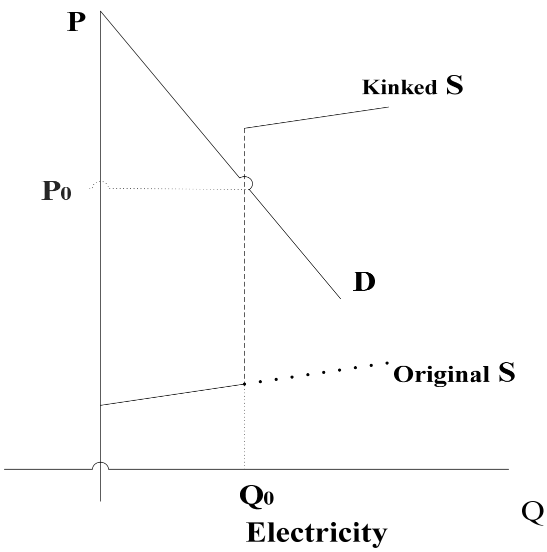
Meanwhile, in the carbon market, forest producers generate carbon offsets following a theoretical joint-product model that will be elaborated in the next section, 3.2 *Parameterization and Structure*. According to the joint-product model which will be elaborated in section 3.2, the carbon supply curve is exactly the same as the timber supply curve, S_1; and there is the same competitive equilibrium at Q_1 and P_1. The buyers of carbon offsets are those LFEs who have high GHG emission abatement costs if they decide to reduce emission themselves. Buying low-cost carbon offsets is less costly than supplying their own abatement. They derive a carbon demand curve of D_1. In this paper, the electricity industry was chosen to represent the group of LFEs. The impact of carbon trading on its production decision and trading behaviour can be studied with this design.

3.1.3 Electricity Producers

Before Carbon Trading

As a representative of the LFEs who generate large amount of GHG emissions, the electricity industry would have their GHGs emissions regulated. There is a relationship between the electricity output and GHG emissions. The firms are provided with an amount of GHG emissions that they can emit freely. When the electrical firms produce electricity within the emission limit, they are allocated with carbon credits either free of charge or auctioned off or some combination of the two. Since they can emit without a penalty, they do not need to consider the cost of GHG emission abatement. However, if they produce over this emission limit, the firms are required to include their pollution abatement costs into their production costs. Their total production costs will be significantly increased. Therefore, for an electricity producer, it is faced with two options if they decide to produce more electricity, one is to produce with a much a higher cost, the other is to purchase low-cost carbon offsets from the forestry producer in the carbon market so as to lower their production cost. Figure 3.3 illustrates the supply curve of electricity as a step function. When the electricity producer supplies below a certain quantity of electricity, Q_0, it is allowed to emit GHGs freely. This part of the supply curve is simply its original single-product supply curve, the solid line. If the producer wants to produce beyond this amount, Q_0, the production costs of electricity will increase substantially because the pollution abatement costs are required to be counted in. This leads to a discrete jump on the original supply curve beyond the quantity of Q_0, the supply curve then shifts upwards to the kinked S, creating a large discrepancy between supply and demand of electricity. Beyond the quantity Q_0, the selling price of electricity is so high that no buyers would purchase it. The equilibrium price P_0 is expected to be at the intersection of demand curve and the vertical kink. Therefore, before carbon trading, the competitive equilibrium in the electricity market is expected to occur at a limited output Q_0 and a high price P_0. There are large losses in welfare for both the producer and buyers.

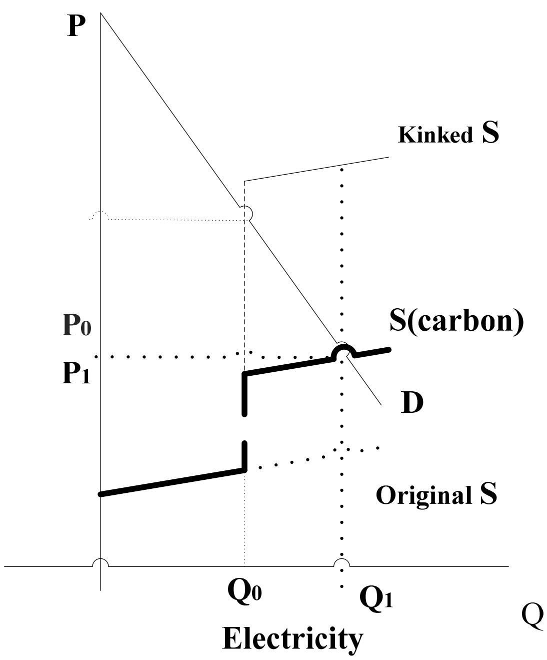
Figure 3.3 Electricity Producers before Carbon Trading



After Carbon Trading

Assume the firms are given free carbon credits to some point, in order to produce more electricity they must: (1) supply abatement themselves, which is costly; (2) use the CDM or JI mechanisms or (3) purchase carbon credits. Let's assume CDM and JI are not an option, then, they must either supply abatement or buy credits. When there is a carbon offset trading market, electricity producers are willing to purchase the low-cost forestry carbon offsets in order to offset their high emission abatement costs as well as their total production costs. In Figure 3.4, the kinked supply curve is lowered downward to the supply curve with carbon trading S (carbon), but not back to the original S. Although the cost-efficient forest offsets can offset a large part of the electrical firm's GHG emission abatement cost, it is not the whole cost. The electricity firms still have to pay some costs for GHG emission abastement, which are the lower of purchasing carbon credits in the carbon market or their self-abatement costs. Therefore, the kink still exists, but at a much smaller level. A new competitive equilibrium is reached at a larger quantity Q_1 and at a lower price P_1. The profit for both the electricity buyers and sellers are increased relative to the initial no carbon market situation.

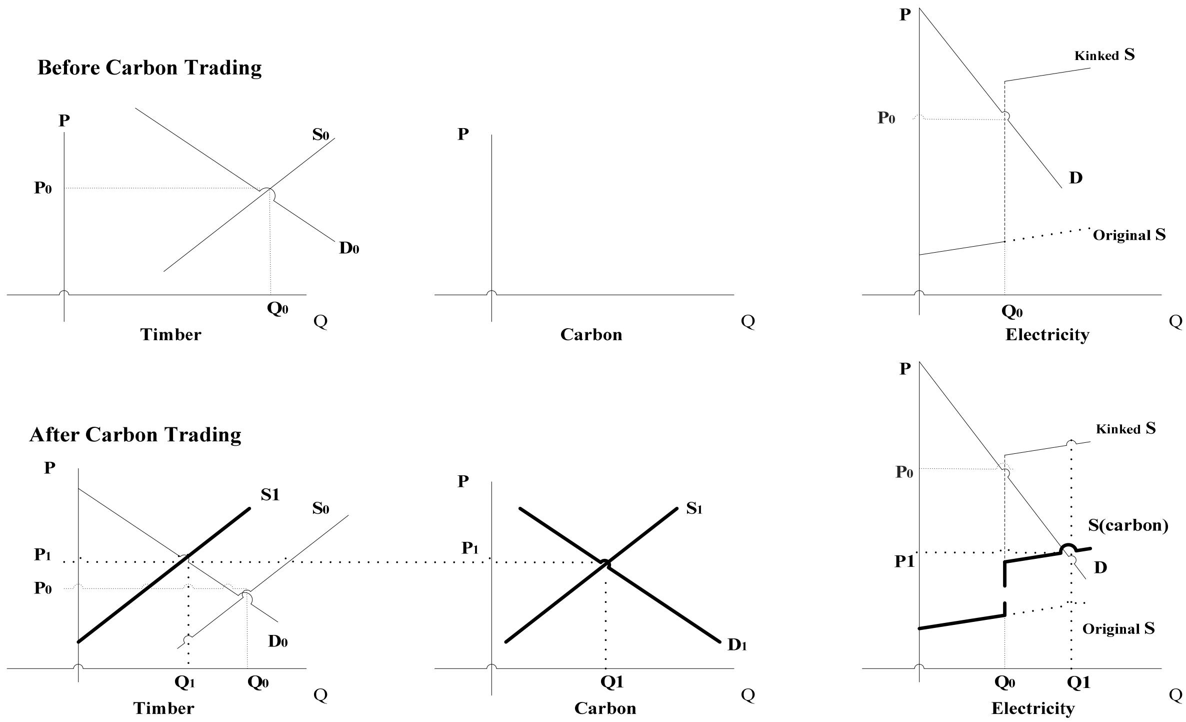
Figure 3.4 Electricity Producers after Carbon Trading



3.1.4 Combination

The whole market structure is illustrated in Figure 3.5. Before carbon trading, the timber market and the electricity market are running separately. In the timber market, timber producers generate and trade timber as a normal single-product supplier. In the electrical market, it is a single-product case as well; however, the electricity supply is impacted by a regulation that limits their output of GHGs. This regulation is designed into the supply curve as a kink. Assuming there is a relationship between the electricity output and GHGs emissions, when electricity producers generate and trade electricity below a certain amount of Q_0, they are allowed to pollute freely. When they produce beyond that amount, they are required to provide abatement or purchase carbon credits that increases their total production cost. Therefore, the supply curve is kinked with a large discrete jump when the industry supply goes beyond Q_0.

Figure 3.5 Three Markets Running Simultaneously



After carbon trading, there are three markets running simultaneously. For forest producers, they change their timber management model to a timber-carbon joint production model. To maximize their joint product profits, they will choose among the options of logging less timber, extending the rotation length, or changing their forestry management practices to sequester more carbon, generating more carbon offsets. The profit from the joint product is higher than the profit from only selling timber. This is due to the higher timber price, since the supply of timber has decreased, and the revenue from the carbon market. The timber and carbon market also reach competitive market equilibrium according to the joint-product model applied. The timber-carbon joint competitive equilibrium price P_1 is higher than the timber price P_0 in the timber market alone, which provides the incentive for the forest managers to switch timber logging to carbon sequestration. In the electricity market, the kinked supply curve is still kinked, however less kinked. The electricity firms with the highest GHG emission abatement costs have an incentive to purchase less costly carbon offsets from the forest producers. As a result, the kinked supply curve shifts down, but not back to the original supply curve, since the electricity firms have the added costs of purchasing carbon credits, instead of their own abatement costs. In the following section 3.2, the parameterization of the experimental design will be illustrated.

3.2 Parameterization and Structure

This section describes in detail the theoretical model and parameterization process to quantify the joint-product decision and market structure. The parameters, although virtual figures derived from the models with no relation to real industrial data, have their economic meaning. For forest producers, the parameters assigned to them are marginal costs of supplying timber and/or carbon offsets. For electricity producers, the figures represent their marginal production costs of producing electricity. For timber buyers, these figures are the marginal costs of supplying timber themselves. For forest offsets buyers, the parameters are their demand for carbon offset credits. For electricity buyers, the figures represent their marginal opportunity costs of producing electricity. The sellers' marginal production costs should be lower than the marginal opportunity costs of the buyers, when there is profit and incentive for the counterparties to trade. Each trader only knows their own cost structure. These parameters could then be traded in the lab by subjects, who would make their trading decisions to maximize profits. At the end of the experiment, they would be paid with real money corresponding to the virtual trading profits. The subjects would be observed to identify the incentives in the market and their impact on market behaviour.

3.2.1 Forest Producers

Before Carbon Trading

The timber market before carbon trading is derived from the after carbon trading scenario. There are five forest producers. Each is faced with a normal single-product decision. The production model applied to the timber producer is[1]:

$$\pi = (P_T + m)Q_T - rQ_T^2 \quad \textbf{Equation 3.1}$$

Where,

π is the profit for the seller;

P_T is the selling price of the timber;

Q_T is the quantity of the timber;

r is the parameter for the *cost function* rQ_T^2, different firms are assigned with different cost functions.

m is a positive controlled parameter assigned to all the firms in order to function as a shift of the timber supply curve. This means, the after carbon trading timber supply curve is expected to shit to the left compared with the one before carbon trading. Since the after-carbon-trading scenario is designed first, this *m* parameter is created to shift the post-carbon supply curve left of the pre-carbon trading curve. Because for each forest producer three units are designed to be produced before carbon trading, two units are designed to be produced after carbon trading, the specific figure for *m* parameter is assumed as roughly one third of the timber equilibrium

[1] This single product decision model is derived from the joint-product model from the scenario of after carbon trading, which is to be elaborated immediately in the following text. In fact, the author started designing the joint-product trading first, afterwards plugged in a shift factor *m* to shift the after carbon timber supply curve to the right side as the before carbon timber supply curve.

price under the after carbon trading scenario.[2] The before-carbon timber supply curve is reached via shifting the post-carbon timber supply curve by roughly one third of the post-carbon equilibrium price to the left.

Thus the first order condition of Equation 3.1is:

$$\frac{\partial \pi}{\partial Q_T} = (P_T + m) - 2rQ_T = 0$$ **Equation 3.2**

i.e. $$\frac{P_T}{Q_T} = 2r - m$$ **Equation 3.3**

Table 3.1 Marginal Production Costs of Timber for Forest Producers before Carbon Trading

Timber Sellers	MC_{T_1}	MC_{T_2}	MC_{T_3}	r	M
S1	**24**	**158**	**292**	67	110
S2	**44**	**198**	352	77	
S3	**62**	**234**	406	86	
S4	**78**	**266**	454	94	
S5	**106**	**322**	538	108	

Table 3.2 Timber Marginal Factor Costs for Forest Producers before Carbon Trading

Quantity	1	2	3	4	5	6
Marginal Costs	**24**	**44**	**62**	**78**	**106**	**158**
Total Costs	24	88	186	312	530	948
Marginal Factor Costs	24	64	98	126	218	418

In Table 3.1, each forest producer is allowed to supply three units of timber. The numerical values are virtual numbers only and not based on industrial data. The values bolded and shaded are designed and predicted to be sold in the timber market. However they are not totally random, they have to satisfy the quantitative relationship in Equation 3.1, including following the principle of increasing marginal factor costs, as in Table 3.2. The marginal

[2] The parameterization of joint timber-carbon production model and trading behaviour will be elaborated in the after carbon trading scenario in the following text. The author designed the after carbon trading scenario first, then derived the before-carbon trading scenario from the joint product model, since the main purpose of this design is to study the market behaviours of forest producers after carbon trading.

factor cost for the N^{th} product is the total costs of N units minus the total costs of (N-1) units. For example, the marginal factor cost for 3^{rd} unit is 98 cents, which is equal to the total cost of 3 units, 186 cents, minus the total cost of 2 units, 88 cents. The marginal factor cost for the 3^{rd} unit 98 cents should be higher than that of 2^{nd} unit, 64 cents. In the following design, all the marginal factor costs for producers under both scenarios are parameterized in this manner.

Table 3.3 Demand from Timber Buyers before Carbon Trading

Timber Buyers	MV_{T_1}	MV_{T_2}	MV_{T_3}
B1	**512**	**468**	**324**
B2	**548**	**436**	303
B3	**580**	**406**	284
B4	**620**	**378**	267
B5	**650**	**348**	252

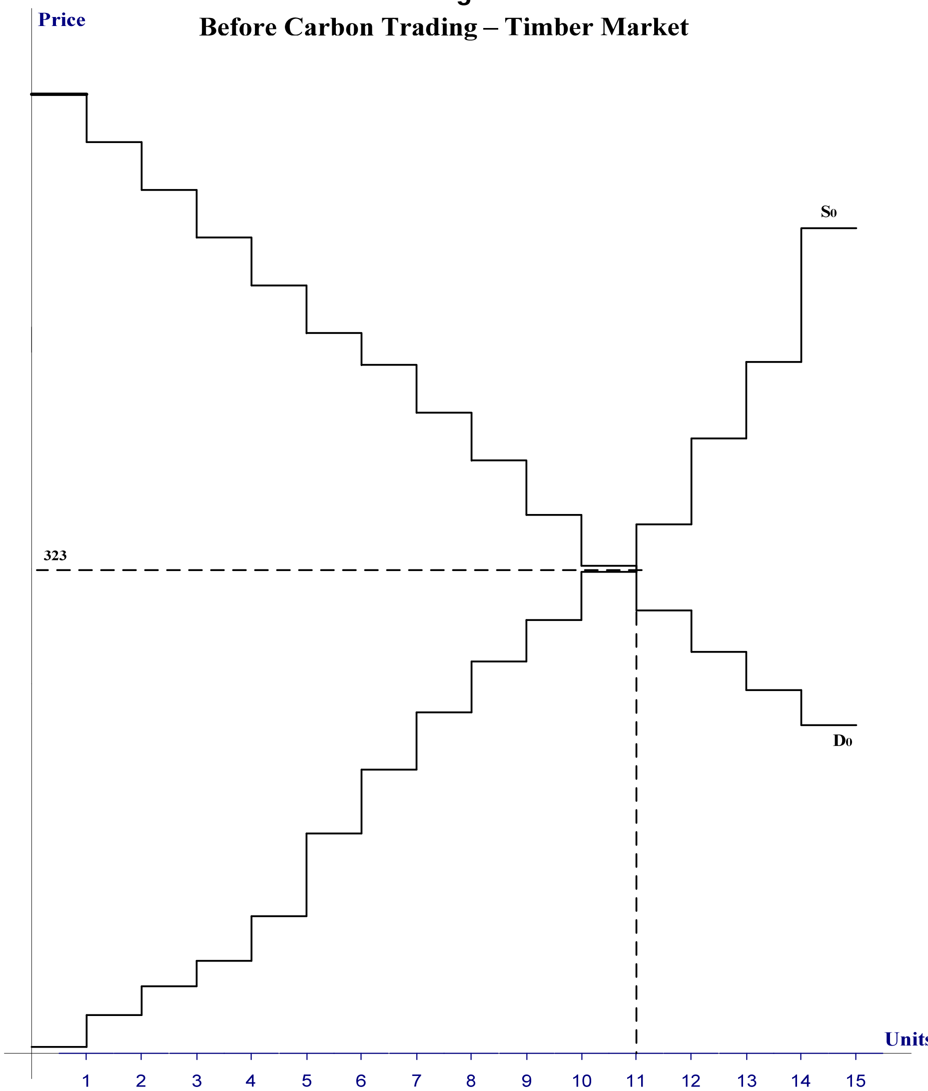
Table 3.4 Marginal Revenue Products for Timber Buyers before Carbon Trading

Quantity	1	2	3	4	5	6
Marginal Value	**650**	**620**	**580**	**548**	**512**	**468**
Total Value	650	1240	1740	2192	2560	2808
Marginal Revenue Product	650	590	500	452	368	248

For the timber buyers, each is designed to demand three units of timber. Parameterizing their demand for timber does not follow any particular theoretical model. The figures represent the demand schedule for timber in the current market (Table 3.3). The numbers in bold are designed to be traded for lower costs from timber sellers. These parameters have to satisfy the economic condition of diminishing marginal revenue products. The marginal revenue product for the N^{th} unit is equal to the total value of N units minus the total value of (N-1) units. For example, in Table 3.4, the marginal revenue product for the 4^{th} unit of timber purchased, 452 cents, is equal to the 4 units' total value (2192 cents) minus 3 units' total value (1740 cents). The marginal product revenue for each additional product purchased is decreasing. In the following design, the demands from the other buyers are parameterized in the same manner. When the parameterization for timber sellers and buyers' cost structures was completed, the conceptual linear graph of Figure 3.1 (p.44) becomes a discrete graph in Figure 3.6. The total timber market supply is 15 units. The competitive equilibrium is at 11 units being traded with an equilibrium price of 323 cents. The price of 323 cents is the mid-point of the narrowest bid-ask spread between $\mathbf{MC}_{T_3}$ of S1's 292 cents and that of $\mathbf{MV}_{T_3}$ of B1's 324 cents.

Figure 3.6 illustrates the discrete graph in the timber market before carbon trading.

Figure 3.6 Timber Market before Carbon Trading



After Carbon Trading

Under carbon trading the scenario, forest producers optimize their profit simultaneously in the timber and carbon market. With the same input, two products, timber and carbon offsets, are jointly produced. They are also competitive in each production. The less timber harvested, the more carbon sequestered. During the process of balancing the supply of timber and carbon, this becomes a joint-product decision. In this experimental design, the joint product model for forest producers follows the model of Henderson and Quant (1980, 92-98).

$$\pi = P_T Q_T + P_C Q_C - r(Q_T^2 + Q_C^2) \qquad \textbf{Equation 3.4}$$

Where,

π is the profit for the seller;

P_T is the selling price of the timber;

Q_T is the quantity of timber;

P_C is the selling price of the carbon credit;

Q_C is the quantity of carbon credits, i.e. is the number of the carbon credits allocated;

r is the parameter for the *joint cost function* $r(Q_T^2 + Q_C^2)$, different firms are assigned with different cost functions, thus they are a series of concentric circles in the space (Q_C, Q_T), the negative of the slope of these concentric circles is defined as the *rate of product transformation (*RPT):

$$RPT = -\frac{dQ_c}{dQ_T} = \frac{Q_T}{Q_C} = \frac{P_T}{P_C} > 0 \qquad \textbf{Equation 3.5}$$

Thus the First Order of Equation 3.4:

$$\frac{\partial \pi}{\partial Q_T} = P_T - 2rQ_T = 0 \qquad \textbf{Equation 3.6}$$

$$\frac{\partial \pi}{\partial Q_C} = P_C - 2rQ_C = 0 \qquad \textbf{Equation 3.7}$$

i.e. $\frac{P_T}{Q_T} = \frac{P_C}{Q_C} = 2r$ **Equation 3.8**

Timber Supply: $S_T = 2rQ_T$ **Equation 3.9**

Carbon Supply: $S_c = 2rQ_c$ **Equation 3.10**

The timber and carbon supply curves can be derived from the joint-production model above. They are exactly the same, in the shape of the supply curve and competitive equilibrium. Table 3.5 shows the marginal production costs of generating timber and carbon, parameterized from the joint-production model Equation 3.4. The parameters must satisfy the condition of increasing marginal factor cost. Each forest firm can produce two units of timber, as well two units of carbon. The total supply in the timber market is 10 units, which is the same in the carbon market. The figures in bold and shade are designed to incur more profits than before carbon trading scenario. Therefore in both the timber and carbon markets, it is expected that 9 units will be traded in the competitive equilibrium situation.

Table 3.5 **Marginal Production Costs of Timber/Carbon for Forest Producers after Carbon Trading**

Timber/Carbon Sellers	Q_T	Q_C	r	MC_{C1}	MC_{C2}	MC_{T1}	MC_{T2}
S1	2	2	67	**134**	**268**	**134**	**268**
S2	2	2	77	**154**	**308**	**154**	**308**
S3	2	2	86	**172**	**344**	**172**	**344**
S4	2	2	94	**188**	**376**	**188**	**376**
S5	2	2	108	**216**	432	**216**	432

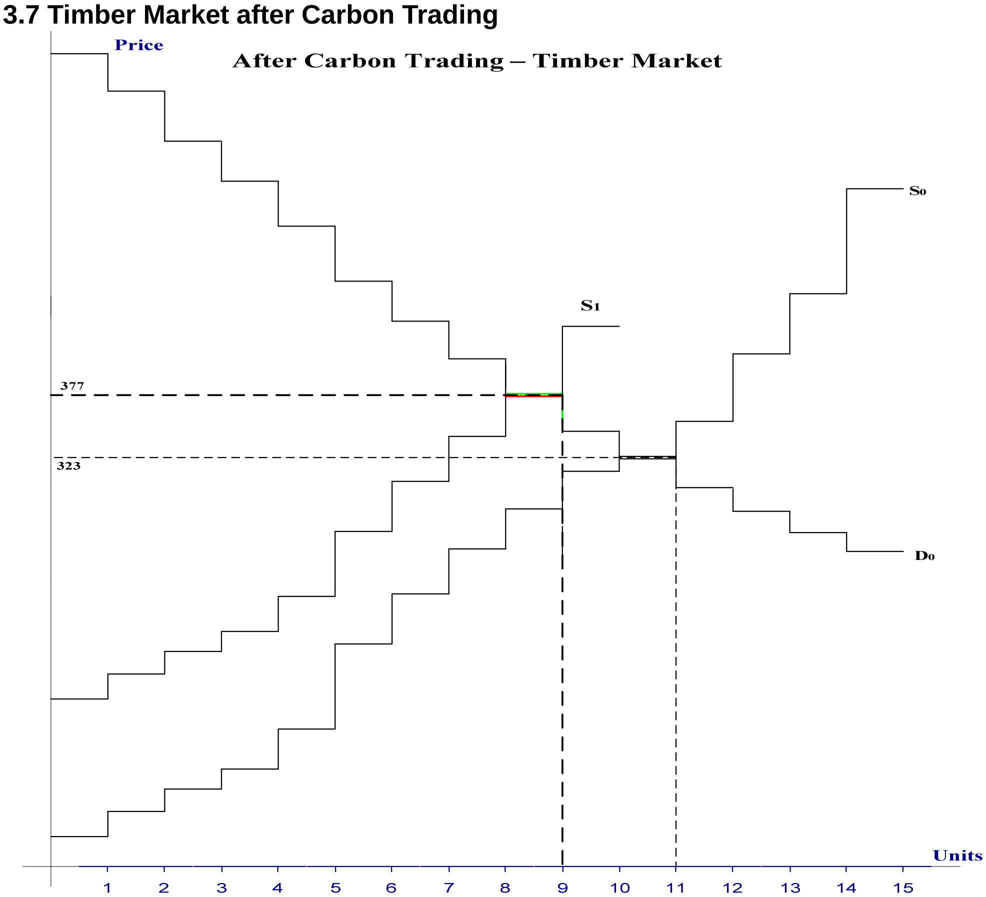
Table 3.6 is the demand schedule from timber buyers after carbon trading. The values do not follow any specific theory, but satisfy the rule of diminishing marginal revenue product. Each buyer wants two units of timber. The figures highlighted are those expected to be traded with a total demand of 10 units of timber, 9 units should be purchased. The equilibrium price of 377 cents is the mid-point of the narrowest bid-ask spread between the 378 cents of the first unit from Buyer 4 and 376 cents of the first unit from Seller 4.

Table 3.6 Demand from Timber Buyers after Carbon Trading

Timber Buyers	MV_{T_1}	MV_{T_2}
B1	512	468
B2	548	436
B3	580	406
B4	620	378
B5	650	348

Figure 3.7 illustrates the discrete graphs of the supply and demand curves for timber before and after carbon trading. The demand curve D_0 remains the same. The timber supply curve $S_{0,}$ as a single product, shifts to timber supply S_1, as a joint product to the left. The total supply decreases from 15 units to 10 units, because to generate carbon offsets less timber is harvested. The equilibrium quantity to be traded also decreases from 11 units to 9 units. The timber price at the equilibrium is increased from 323 cents to 377cents.

Figure 3.7 Timber Market after Carbon Trading

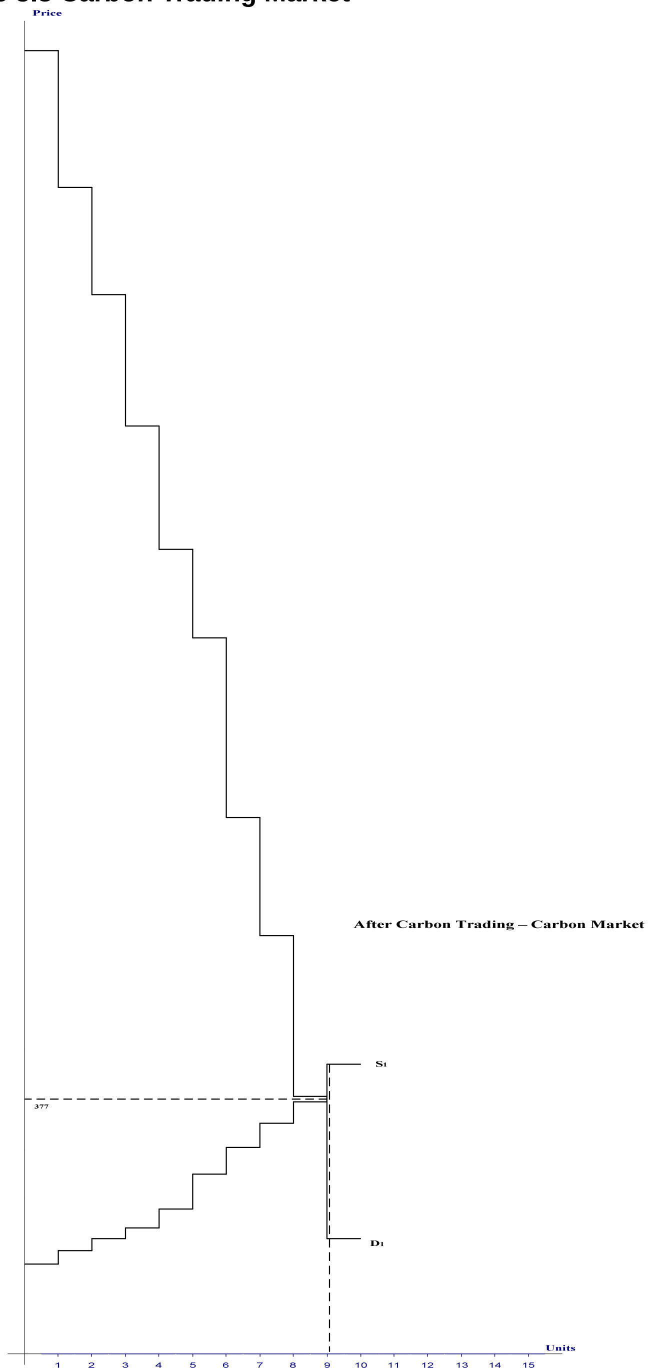


Carbon offset buyers are those firms that have high GHG emission abatement costs. Table 3.7 illustrates the marginal opportunity cost of abating for electricity producers, i.e. the demand from offset buyers to purchase carbon offsets. The values do not follow any specific theory or observed values, but they satisfy the economic conditions of diminishing marginal revenue product. Each buyer wants two units of forest offsets. It is not hard to notice that these marginal opportunity costs of offset buyers are much higher than the marginal offset production costs of forest producers in Table 3.5 (p.56). The values bolded and shaded are designed to be traded in the carbon market. Therefore, from the total demand of 10 units of offsets, 9 units are anticipated to be purchased. The equilibrium price of 377 cents is the mid-point of the narrowest bid-ask spread between the 378 cents of the first unit from Buyer 4 and 376 cents of the first unit from Seller 4. This is very similar to the timber market. The parameters in a discrete graph of the carbon market running are illustrated in Figure 3.8.

Table 3.7 Marginal Opportunity Abatement Costs (Demand) for Offset Buyers

Carbon Offset Buyers/ Electricity Producers	MVc_1	MVc_2
1	**1240**	**1080**
2	**1420**	**840**
3	**1620**	**624**
4	**1780**	**378**
5	**1980**	172

Figure 3.8 Carbon Trading Market



3.2.2 Electricity Producers

Before Carbon Trading

The model used for the electricity sector is one where firms maximize profits as a single product firm, similar to the timer production model Equation 3.1 (p.51)

$$\pi = P_E Q_E - rQ_E^2$$ **Equation 3.11**

The original supply curve derived from Equation 3.11 is $S_E = 2rQ_E$. **Equation 3.12**

It is assumed each unit of electricity produced generates pollution at a certain ratio. When the electricity firms produce beyond a certain quantity the emissions, which is regulated by the government, the firms are required to include the GHG emission abatement costs for the extra output into their total costs. Assume here when the firms produce the first unit of electricity, they are allowed to pollute without penalty; when they decide to produce beyond the first unit, their GHG emissions surpass the regulated amount of emissions they are allowed to produce.. In this case, the original supply curve becomes a kinked function. The kink is the added cost of abating GHGs emissions for each unit of electricity beyond the regulation. Therefore, the kinked supply curve is derived as:

- Kinked Electricity Supply Curve:

$$P_E = 2rQ_E \quad (Q_E < 1);$$ **Equation 3.13**

$$P_E = 2rQ_E + \text{abatement cost} \quad (Q_E > 1),$$ **Equation 3.14**

The abatement costs of the firm are the marginal opportunity cost of not buying carbon credits. The parameters for this model are given in Table 3.7 (p.58). Therefore, the offset demand curve in the carbon market is interrelated with the kinked supply curve in the electricity market by the electricity industry’s GHG emission abatement costs.

Table3.8 represents the marginal production costs for electricity producers. When each firm produces its first unit, there is no cost for its GHG emissions. It is assumed that the emissions of the first unit of electricity incur no penalty. So the values for MC_{E1} units are calculated from the original supply curve, equation 3.12. If the firm wants to produce the second unit of power or more, its pollution level would surpass its emission regulation and would require the abatement costs for the extra output to be incorporated into the total production costs. It has to be noted that, in this paper, the GHG emission abatement costs for each unit of additional electricity generated beyond the correspondent regulation are designed to be offset by each two units of forestry carbon credits in order to equate the trading volume in carbon and timber markets. Take Electricity Seller 1 for example, the marginal production cost for the first unit is 600 cents. When it produces the second unit, its total cost is not the value of $\mathbf{MC_{E2original}}$, but rather the $\mathbf{MC_{E2original}}$ plus its self-abatement costs for the second unit in Table 3.7 (p.58). Therefore, the total production costs now for the second unit are 3520 cents, equal to 1200 cents plus 1240 cents for MV_{C1} and 1080 cents for MV_{C2} of Seller 1. The same mechanism was used to parameterize the rest of the marginal costs. Only the 5 values in bold and shade are designed to be traded in the electricity market, the other 5 units were designed to be so costly that they would not be purchased by electricity consumers.

Table 3.8 Marginal Production Costs of Electricity for Electricity Producers before Carbon Trading

Electricity Sellers	$\mathbf{Q_E}$	**r**	$\mathbf{MC_{E1}}$	$\mathbf{MC_{E2original}}$	$\mathbf{MC_{E2kinked}}$
S1	2	300	**600**	1200	3520
S2	2	270	**540**	1080	3340
S3	2	240	**480**	960	3204
S4	2	210	**420**	840	2998
S5	2	180	**360**	720	2872

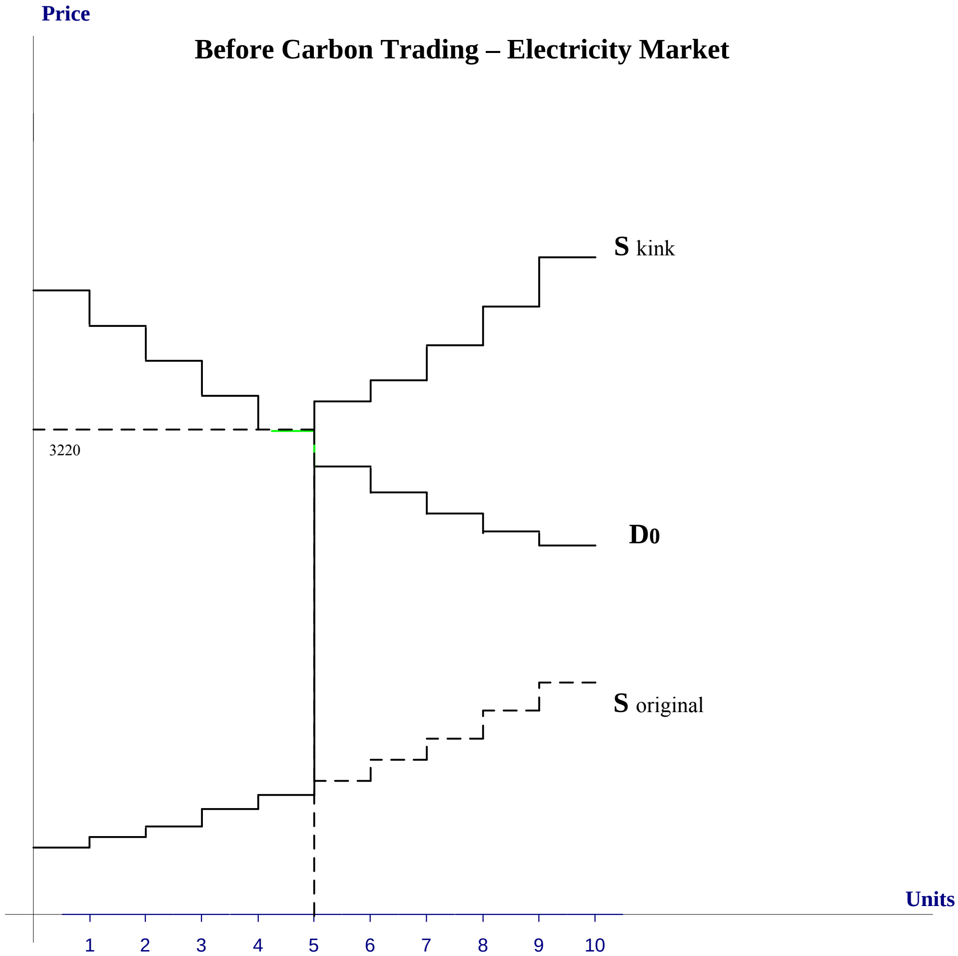
Table 3.9 shows the demand schedule from electricity consumers. These parameters do not follow any specific theory, but satisfy the economic condition of diminishing marginal revenue product. Each buyer wants two units of electrical power; however they will only trade 5 units given the parameters used in the demand and supply determination. The units highlighted and shaded are profitable to be traded. The parameterization can be seen in the discrete graph in Figure 3.9. The equilibrium price of 3,220 cents is at the intersection of the buyers' demand schedule and the vertical kink of the supply schedule, in the case of the discrete graph, the equilibrium price is the 5th highest bidding price. For the rest of the bidding prices from buyers, they are not high enough to strike trades with sellers who need to be compensated for their GHG emission abatement costs. The trading in the electricity market before carbon trading is expected to cease at the equilibrium of a limited quantity, 5 units, and a price of 3220 cents.

Table 3.9 Demand from Electricity Buyers before Carbon Trading

Electricity Buyers	MV_{E1}	MV_{E2}
B1	**3220**	3120
B2	**3320**	2968
B3	**3420**	2670
B4	**3520**	2322
B5	**3620**	1966

Although competitive market equilibrium can be reached, the electricity market is suffering a great welfare loss. The large discrepancy in bid-ask price increases the transaction and liquidity cost in the electricity market, and severely damages of the consumers' well-being.

Figure 3.9 Electricity Market before Carbon Trading



After Carbon Trading

After the electricity producers purchase forest carbon offset credits in the carbon market, their high self-abatement costs will be replaced by the offset price they pay. The real supply curve of electricity shifts down towards the original supply curve. Since they only partly replace their high self-abatement cost with low-cost carbon offsets, there is still a kink in the supply curve but it is smaller than the original kink.

- The Electricity Supply Curve is:

$$P_E = 2rQ_E + \min(\text{carbon equilbrium price,self-abatement costs}) \quad (Q_E > 1)$$ **Equation 3.15**

When parameterizing the supply curve for the experiment, the smaller kink is calculated as the lesser of the carbon credits' payments (the offset equilibrium price 377 cents) and the self-abatement costs. The self-abatement costs for each extra unit of output were designed to be offset by two units of forestry carbon credits to match the trading behaviours in the carbon and timber markets. In Table 3.10, each of Seller **1, 2**, **3** and **4** has two units of self-abatement costs (Table 3.7, p. 58) that are higher than the offset price. As a result, electrical producers would purchase two offsets credits from the forestry sector as oppose to pay the higher self-abatement costs. Take Seller 1 for example, the value for $\mathbf{MC_{E2trade}}$ is 1954 cents, which is equal to its $\mathbf{MC_{E2original}}$ value 1200 cents plus two offsets credits at 377 cents per offset. In contrast, for Sellers **5** (Table 3.7, p. 58) , only one unit of their pollution abatement costs is higher than the carbon offset trading price, so they only need to pay for one offset credit in carbon market and reduce another unit of their pollution with their own low cost abatement, which is lower than the carbon offset credit price. For Seller 5, $\mathbf{MC_{E2trade}}$ is1269 cents, which is equal to the sum of $\mathbf{MC_{E2original}}$ value of 720 cents and one carbon offset credit at 377 cents and its own unit of self-abatement cost of 172 cents (Table 3.7, p. 58).

Table 3.10 Marginal Production Costs of Electricity for Electricity Producers after Carbon Trading

Electricity Sellers	Q_E	r	MC_{E1}	$MC_{E2original}$	$MC_{E2kinked}$	$MC_{E2carbon}$
S1	2	300	**600**	1200	3520	**1954**
S2	2	270	**540**	1080	3340	**1834**
S3	2	240	**480**	960	3204	**1714**
S4	2	210	**420**	840	2998	**1594**
S5	2	180	**360**	720	2872	**1269**

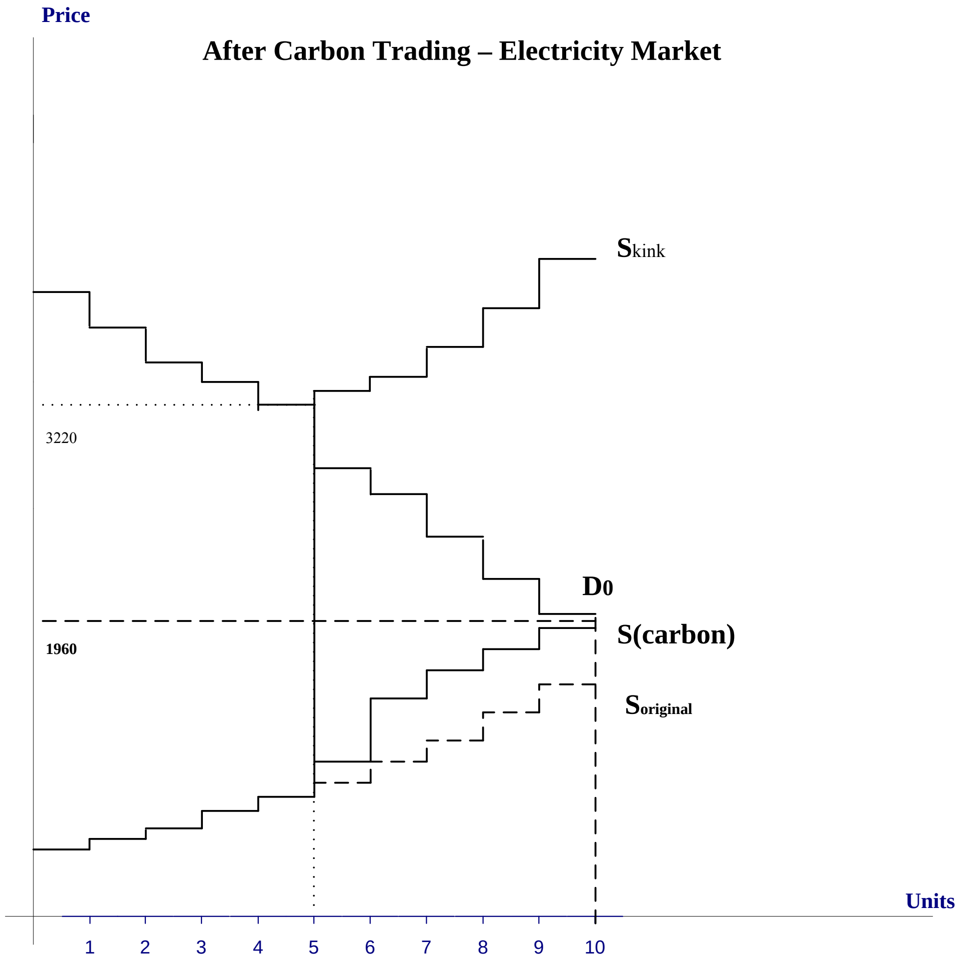
Table 3.11 shows the demand for electricity s after carbon trading. They do not follow any specific theory, but satisfy the economic condition of diminishing marginal revenue product. Figure 3.10 illustrates the parameterized graph of the electricity market after electricity producers purchase carbon offsets credits to reduce their production costs. It is designed so

that all 10 units of electricity are profitable for trading. The equilibrium price is 1960 cents and is the mid-point of the narrowest bid-ask spread between 1966 cents and 1954 cents.

Table 3.11 Demand from Electricity Buyers after Carbon Trading

Electricity Buyers	MV_{E1}	MV_{E2}
B1	3220	3120
B2	3320	2968
B3	3420	2670
B4	3520	2322
B5	3620	1966

Figure 3.10 Electricity Market after Carbon Trading



3.2.3 Combination

Table 3.12 is a combination of all the basic parameters for timber and electricity producers in three competitive markets under two scenarios from Table 3.1-3.11. In each competitive market, there are five subjects as buyers, and five subjects as sellers. Before carbon trading, in the timber market each seller is allocated three units of timber to sell; each buyer is designed to purchase three units. After carbon trading, each forest producer supplies timber and carbon jointly. Each producer is allocated two units of timber and carbon to sell. The changing timber quantity reflects the shifts in the supply and demand curves. When forest producers decide to become joint producers, they want to maximize their profits from the timber and carbon markets. As a result, they harvest less wood to generate more carbon sequestration offsets credits. In the electricity market under both scenarios, each seller is allocated two units of its product to sell. Since all the participants are potential traders who are allowed to both buy and sell and even to speculate if they want, the equilibrium prices will determine who are the buyers and who are the sellers. High values are buyers and low values are sellers.

Table 3.12 Basic Parameters for Three Markets Before and After Carbon Trading

Producers	Carbon Trading	Markets	Units	Buyers					Sellers				
				B1	**B2**	**B3**	**B4**	**B5**	**S1**	**S2**	**S3**	**S4**	**S5**
Forest Producers	BEFORE	**Timber**	**1**	**512**	**548**	**580**	**620**	**650**	**24**	**44**	**62**	**78**	**106**
			2	**468**	**436**	**406**	**378**	**348**	**158**	**198**	**234**	**266**	**322**
			3	**324**	303	284	267	252	**292**	352	406	454	538
	AFTER	**Carbon**	**1**	**1240**	**1420**	**1620**	**1780**	**1980**	**134**	**154**	**172**	**188**	**216**
			2	**1080**	**840**	**624**	**378**	172	**268**	**308**	**344**	**376**	432
		Timber	**1**	**512**	**548**	**580**	**620**	**650**	**134**	**154**	**172**	**188**	**216**
			2	**468**	**436**	**406**	**378**	348	**268**	**308**	**344**	**376**	432
Electricity Producers	BEFORE	**Electricity**	**1**	**3220**	**3320**	**3420**	**3520**	**3620**	**600**	**540**	**480**	**420**	**360**
			2	3120	2968	2670	2322	1966	3520	3340	3204	2998	2872
	AFTER	**Electricity**	**1**	**3220**	**3320**	**3420**	**3520**	**3620**	**600**	**540**	**480**	**420**	**360**
			2	**3120**	**2968**	**2670**	**2322**	**1966**	**1954**	**1834**	**1714**	**1594**	**1269**

The experiment would be run in two sessions; each session consists of one non-paid practice market and three “real” markets. For the practice market, there are 2 or 3 periods, 10 minutes each, hence one practice market will last approximately 20-30 minutes. For each of the real markets, there are 10 periods with each period lasting 3 minutes, hence each real market should last approximately 30 minutes. One session should last approximately two hours. The first session would involve the timber market and the electricity market running without the carbon trading market. The second session would incorporate the three markets; timber, carbon and electricity, simultaneously. The parameters in the practice market bear no relationship with the ones in the real markets.

3.3 Market Institution

The most prevailing manner of trading in exchanges is the double auction because of its efficiencies and effectiveness and its ability to constrain market power (Smith 1981; Williams and Smith 1989; Davis and Holt 1993). Although some recent work has cast doubts on its capability to constrain market power, this experimental design will use the double auction as the trading institution.

Double Auction

Double auction has performed well as the laboratory trading institution with sequential decisions. The critical rule in this mechanism is the "improvement rule"— a new bid from a buyer must be higher than all the present bids, and a new asks price must be lower than all the standing offers. Hence, this is a "double" auction in the sense that the buyers' bids rise, meanwhile the sellers' offers drop, until the two sides agree on a price and quantity at equilibrium. The market participants usually have no information about the other party's costs and values.

The double auction is well known for its robust market performance. Under the competitive and market power environments, the market price, quantity and market efficiency are able to approach the competitive benchmark outcomes more quickly and reliably than the alternative trading rules. In the monopoly case, the competitive quantity, price and efficiency levels can be achieved fairly quickly, which means that the double auction is very effective at constraining market power. The only known exception is when there is “an extreme market power design with excess supply of only one unit at supracompetitve prices” (Davis and Holt 1993, 155). Although there are no generally accepted theoretical models, some observations have been made on the bases of the behavioural assumptions behind the double auction design:

(1) There is no need for complete information from the supply and demand schedule; instead, more information may slow down the convergence process to a competitive equilibrium.

(2) Even with every participant holding their own cost/value schedule privately, the bargaining process is sufficient enough for both sides of the market to split the trading surplus.

(3) The closing price at the end of every trading period is a good signal for the potential competitive price.

(4) The “sequential” nature of the double auction matters, that is, “early contracts appear to have an important influence on the terms of trade for later contracts.” (Davis and Holt 1993, 168)

3.4 Human Subjects and Robot Traders

It is planned that each session requires ten subjects in a computerized double auction. The timber buyers and electricity buyers are always robot traders that are programmed to trade for short-term profits. In each session, five students will act as forest producers making their decision according to the joint-production model, i.e. sell timber and carbon credits. Another five students represent electricity producers, making their decisions using a single-product model and kinked supply function to sell electricity and buy carbon offset credits. Sessions are planned to run no longer than 3 hours. After each session the subjects have to complete a questionnaire and are paid privately in cash. The amount of money each subject earns will depend upon their market performance in the trading sessions and a conversion ratio between lab dollars and real dollars, plus a fixed show-up fee.

CHAPTER 4: Benchmarks and Predictions

4.1 Equilibrium Benchmarks

Corresponding to Table 3.12 and Figure 3.6-3.10, Table 4.1 provides a summary of the competitive equilibriums in each market under the two scenarios as well as the trading surplus for each industry and market.

Table 4.1 Benchmarks and Predictions

Producers	Carbon Trading	Competitive Benchmark	Volume	Price	Trading Surplus			
					Buyers	Sellers	Market	Producer
Forest Producers	Before	Timber	11	323	1717	1769	3486	1769
	After	Carbon	9	377	7569	1233	8802	**2466**
		Timber	9	377	1205	1233	2438	
Electricity Producers	Before	Electricity	5	3220	1000	13700	14700	13700
	After		10	1960	10546	8835	19381	**16404**

The *before carbon trading* benchmarks in the timber and electricity markets represent the profit situation with the initial timber and electricity unit distribution. In the timber market, it is predicted that 11 units will be traded at an equilibrium price 323 cents. Forest producers can earn a profit of 1,769 cents, while the timber robot buyers can earn 1,717 cents. The whole market can reach 100% efficiency since this is a competitive market. In the electricity market, there are 5 units to be traded, at the 5th highest bidding price of 3,220 cents. The robot electricity buyers can earn profit of 1,000 cents, while electricity producers can earn 13,700 cents. Although a competitive equilibrium is predicted, a limited trading volume and large bid-ask spread cast doubt on the market performance.

The *after carbon trading* benchmarks include the timber market, the carbon market, and the electricity market. Both the timber and carbon markets reach equilibrium with 9 units traded at a price of 377 cents, as the supply curves for timber and carbon are identical according to the joint-product model. Both the timber sellers and carbon sellers can earn 1,233 cents; so the forest producers can earn a total of 2,466 cents, which is higher than their profit in the before carbon trading situation. It is noted that timber buyers have reduced their profit to 1,205 cents from 1,717 cents due to the carbon trading. The offset buyers can earn a trading surplus of 7,569 cents. In the electricity market with a less kinked supply curve, it is predicted that 10 units will be traded at a price of 1,960 cents, which was designed to be a lower price than the electricity equilibrium price before carbon trading, i.e. 3,220 cents. The electricity sellers' surplus increased from 1,000 cents to 10,546 cents. The electricity producers can earn a profit of 8,835 cents on electricity trading, due to their much higher self-abatement costs in carbon emissions, which is much lower than their profit before carbon trading. However, as forest offsets buyers in the carbon market, the total surplus for electricity producers in fact includes both the trading surplus from selling electricity and purchasing offsets. Thus the total surplus for the electricity industry is 16,404 cents which is equal to the electricity selling profits of 8,835 cents plus their offsets' cost savings 7,569 cents. Therefore, their total trading surplus is increased compared to the before carbon trading scenario.

4.2 Behavioral Predictions

Competitive outcomes are almost always achieved in non-monopolized double auction markets with private incomplete information and stationary supply and demand conditions. Plenty of experiments with various designs have verified the superior competitive tendency of the double auction, which indicates that neither complete information nor a large number of traders is necessary for convergence to competitive equilibrium levels. The striking performance of the double auction probably is a result of its sequential nature and improvement rule, which induces more interaction between the subjects and entices price concessions at the end of each period in order to trade the marginal units. Another stylized fact about double auction dynamics is that the prices tend to converge to the competitive level from below if producer surplus exceeds consumer surplus at the competitive price, and from above in the reverse situation. Furthermore, in early trading periods the initial prices appear to deviate from the competitive situation towards the average of the costs and values of the first several units on the left sides of the supply and demand functions. By contrast, in posted-offer markets, the direction of price convergence is not influenced by the division of the surplus at the competitive price, where prices tend to exceed competitive equilibrium in most designs.

All the markets in different scenarios are running under the mechanism of the double auction. After carbon trading, all three markets; timber market, carbon market and electricity market, will be running simultaneously, achieving higher total trading surplus for forest and electricity producers. Robot traders act as timber buyers and electricity buyers and are programmed to maximize profits myopically. Because of the different markets, the producers' and consumers' surplus are designed with different values and the price will converge from different directions.

Forest Producers

Before carbon trading, forest producers produce a single commercial product, timber, and participate only in the timber market, which would be run under a double auction mechanism and reach full allocative efficiency. As in Table 3.12 (p.66), the timber buyers' surplus and sellers' surplus are designed with about the same value, therefore it is expected that the prices should converge from both above and below the competitive level with similar speed. However, in the early periods, the initial prices will have a larger deviation from the competitive level than the later trading periods. Under the after carbon trading scenario, forests producers will participate simultaneously in both the timber and carbon markets in terms of producing and trading. Both the timber and carbon markets will achieve competitive equilibriums under the double auction mechanism. In the timber market, less timber will be produced and traded compared to the before carbon trading scenario. A new equilibrium is expected to be reached at a higher timber price and a lower trading volume. The producer and consumer surplus are designed to be at about the same value, hence the new higher equilibrium price should converge from both above and below this new competitive level. In the carbon market, the incentive is designed to be high enough for forest producers to jointly produce forest carbon offset credits and supply them to the LFEs with high pollution abating cost. As in Table 3.12 (p.66), the carbon buyers' (electricity producers) surplus is designed much higher than the carbon sellers' surplus. Therefore, the price should converge from above the competitive level and then reach full efficiency. For forest producers, the surplus from the timber and carbon markets is larger than the surplus when forest producers provide timber only. The forest producers have incentive to switch from timber-only production to a joint product of timber and carbon.

Electricity Producers

Before carbon trading, the electricity producers only participate in the electricity market with a double auction as the trading mechanism. There is a larger bid-ask (the kink) designed in the electricity price in order to reflect the regulation and high self-abatement costs. Due to this large kink, it is expected to see a truncating in the trading quantities compared to the original electricity supply without pollution regulation. The competitive equilibrium will be reached at a limited trading volume with a higher price. The producers are assigned with surplus much higher than the consumers; hence the price is expected to converge from below the competitive level. After carbon trading, the electricity producers will participate simultaneously in both the electricity and carbon markets in terms of producing and trading. In the carbon market, the electricity producers will purchase low-cost forest carbon offsets from the forest producers to substitute for their high self-abatement costs. As stated above, the prices will converge from above the competitive levels because electricity producers as carbon credits buyers' surplus is much larger than the forest producers as carbon credits sellers' surplus. In the electricity market, the electricity producers will produce and trade more quantity, at a lower equilibrium price. This is because, after the electricity producers purchase carbon offset credits to reduce their abatement costs, there is a decrease in their total production costs resulting in a smaller kink in their supply curve. Their total production cost will be lower after carbon trading, achieving a new equilibrium at a lower electricity price and higher volume. At this new equilibrium, the buyers' surplus is larger than the sellers'; hence the price should see convergence from above the new lower competitive level. In the electricity market alone, the trading surplus for the electricity producers will be lower, their total surplus including the surplus from the carbon market, is larger than under the before carbon trading scenario. Therefore, their producing and trading behaviours will be impacted and they will be enticed to participate in both the carbon and electricity markets.

CHAPTER 5: Conclusions

The Kyoto Protocol included market-based emission trading as one of three flexible mechanisms to address the issue of global greenhouse gas emission and global warming. Although Canada has indicated its willingness to withdraw from the Kyoto Protocol due to a changed political environment, it still has a commitment in the first period 2008-2012, to reduce it greenhouse gas emission by 6% below the 1990 level by 2010, i.e. a reduction of 270 Mt carbon dioxide equivalents. The large final emitters (LFEs) could contribute a significant amount of emission reductions. It has been suggested that the LFEs should reduce their GHG emissions by 45 Mt. As a non-regulated, voluntary-based complement to the proposed regulated Canadian domestic emission trading market, an offset system is proposed to provide low-cost carbon offset credits that may be generated from the forestry, agriculture, and landfill gas sectors to offset the emission caps of the large final emitters. This research focused on the institutional and behavioural aspects of the forest sector, as a non-regulated sector, trading with a regulated sector, the electrical sector, in the domestic emission trading market. It is argued that forest management practices can be changed to generate carbon offset credits as a joint product with timber. These management changes can also benefit the conservation of biodiversity and improvement of the environment. Previous economic experiments on carbon trading have generated positive experimental results and applicable policy implications for the country's decision makers. The most relevant emission trading design is the experiment of Muller et al. (2002). While they were mainly testing whether the double auction could constrain market power, they used a rather simplified "joint-product" model to parameterize the opportunity cost of emission abatement for the permit buyer, and the marginal cost of abatement for the permit seller.

Two issues should be noted about their experiment. *First*, Muller et al. (2002) used carbon permits as a cost reduction input to offset the total costs, i.e. they viewed the emission permits here more as an input to produce a commercial product. *Second*, they did not differentiate the nature of the sellers and buyers. Rather, in their experiments, the two parties could be regarded as being part of the regulated industries, i.e. the LFEs.

This thesis designed an economic experiment that could simulate the behaviours of buyers and sellers in the carbon offsets market. This experimental design provides a testbed for the carbon offset trading institution in a controlled laboratory environment. Since no practical experiment was conducted in the lab, the main contribution of this paper was the design of the experiment of how a carbon offset market might operate with a non-regulated sector; i.e. forest producers, and a regulated sector; i.e. the LFEs. The experimental design is focused on illustrating how these markets might interact, and particularly predicting the impacts on production and trading behaviours from the market participants when they are faced with altered incentives in different scenarios. The experimental design could contribute to the design of the forest offset trading system in five ways. (1) The market structure is designed as three markets running simultaneously with two types of producers; forest producers and electricity producers (a representative of LFE), who will participate in the forest market, carbon market, and electricity market at the same time, in terms of production and trading. Therefore, a firm in an emission-regulated industry has a direct interaction with another firm in a non-regulated industry in the emission-trading market. The regulated electricity firm purchases low-cost carbon offsets from the non-regulated forest producer in order to reduce their input costs. This differs from the market behaviour in the Muller et al. (2002) experiment.

(2) The forest industry production decision model is a joint product model as compared to a single output model. The three products being traded are: forest units, carbon offset credits, and electricity units. A joint-product decision-making model was used to illustrate the forestry decision making framework. This model was used to set the quantity of timber units and carbon offset credits produced jointly by each forest producer. This is predicted to have a strong impact on the participants' trading behaviour. The joint-product model and a single-product model were used to parameterize all cost values in the experimental design. (3) The experiment was designed to run the joint-product model and the single-product models under two scenarios. The first is a status quo situation, where there are two markets running, timber and electrical markets, with neither being regulated for carbon output on the electricity sector or the carbon market. The behaviour in the before-carbon-trading market will be compared to when there is regulation of carbon output in the electricity sector and a carbon offset market is established, i.e. the after-carbon-trading market. (4) The supply curves of electricity producers are designed to be kinked to reflect a limited allocation of carbon emission permits or credits and high abatement costs above the limited permit allocation. This corresponds to the industry regulations on the LFEs. (5) Robot traders and human subjects are designed to interact in the experiment. The active decision makers, forest producers and electricity producers, will always be human subjects. Their trading behaviours would be emphasized in the experiment. The counterparties to them in the forest market and electricity markets, i.e. timber and electricity buyers, are behaviourally programmed as robot traders, myopically maximizing their profits in the current period.

This preliminary research on forest carbon offset trading is designed to capture the interaction between non- regulated offset producers, i.e. forest producers, and regulated carbon emission sectors, LFEs represented by electricity producers. Two scenarios are designed in order to compare the market performance before and after carbon trading. Forest producers will change their single production decision model in a pre-carbon trading scenario to a joint-product decision model in a post-carbon trading situation. Electricity producers use a single product decision model in both scenarios; however, they must account for excess carbon emissions in the latter scenario. Electricity producers should purchase comparatively cheaper forest-generated carbon offset credits to compensate their high self-abatement costs and increase their profits (reduce the kink on the supply curve). Thus in a pre-carbon trading scenario, there is no interaction between forest and electricity producers. By contrast, under the post-carbon trading scenario, three markets would be running simultaneously—timber, carbon, and electricity markets. In the carbon market, forest and electricity producers will trade forest carbon offset credits. Forest producers sell in both the timber market and the carbon market according to the joint-product model. Electricity producers have an incentive to buy low-cost forest carbon offset credits to reduce their high self-abatement costs and narrow the kink in their supply curve. The qualitative behaviours of the two types of producers are hypothesized to follow the research design, making the three markets efficient simultaneously. The quantitative predictions are derived from the economic theories and parameterization of the experiment. The predicted equilibrium prices, volumes, trading surplus for the market are compared before and after carbon trading, which justifies the behavioural changes and impacts for the market players. Robot traders and human subjects are also intertwined in the experiment. The active decision makers, forest producers and electricity producers, will always be human subjects. Their trading behaviours would be the focus of the experiment. The demand for forest products and electricity, i.e. timber and electricity buyers, are behaviourally programmed as robot traders, myopically maximizing their profits in the current period.

The experiment designed in this thesis is intended to be test-bedded in the controlled laboratory environment to investigate the carbon offset institution. Since no actual experiments were conducted, simulated experimental results are not available to be contrasted and compared with the benchmark predictions. The whole framework is expected to examine the potential interaction between a regulated sector and non-regulated sector in a new market. The regulated sector is regulated in terms of an emission cap. The experimental design is limited to one representative of the regulated sector, power generation, and an absolute cap on their GHG emissions. Policy makers may think of expanding and enforcing some similar regulations to other GHG emission-intensive sectors. In terms of the non-regulated sectors, the forest sector is the focus of the thesis. Policy makers do not regulate the GHG emissions from this sector, but they can encourage a new market, the carbon market, and support issues such as verifying, monitoring, protocol development, etc., to minimize the transaction costs. Incentives from carbon offset credit trading are critical enough to impact forest managers' harvesting decisions as well as electricity producers' production decisions.

Future research would include running the laboratory experiment following the design features prescribed above, so as to test the quantitative equilibrium prediction and qualitative behavioural hypotheses. This could be followed by field testing with actual offset credit supplies and LFEs. This framework could be expanded to include other sectors, such as the landfill gas sector and agriculture. Other components of the carbon trading institution could be incorporated into the experimental design. This would include such things as: the ability to bank credits, insurance on carbon credits in the case of reversals; i.e. forest fires, and a price ceiling on carbon credit value. Finally, the parameterization of the experimental design was based on certain economic concepts. These include marginal factor costs were increasing for production and decreasing marginal product revenue of products when consumed. The model could be re-calculated to mirror actual costs and demand patterns of the timber and electricity producers. Experiments on the market power of joint-product firms can be designed and conducted. This could be done by modifying the current experimental design to take into account firm concentration and potential market power. In this experiment several auction mechanisms could be tested to control market power. These could include the double auction, uniform-price double auction, and sealed bid. Insurance of bankable carbon credits, and price controls on the carbon credits, can also be studied using experimental economics.

BIBLIOGRAPHY

Allan, Travis, and Kathy Baylis. 2005. Sinks, Emissions Intensity Caps and Barriers to Emissions Trading. *Canadian Journal of Agricultural Economics* 53: 291-305.

Anderson, Christopher M. 2004. How Institutions Affect Outcomes in Laboratory Tradable Fishing Allowance Systems. *Agricultural and Resource Economics Review* 33(2): 93-208.

Amano, Masahiro, and Roger A. Sedjo. 2003. Forest Carbon Sinks: European Union, Japanese, and Canadian Approaches. Discussion paper 03-41. Washington, DC: Resources for the Future. http://www.rff.org/documents/RFF-DP-03-41.pdf (accessed February 2, 2009)

Brown, Katrina, and Neil Adger. 1993. Forests for International Offsets: Economic and Political Issues of Carbon Sequestration. CSERGE Working Paper GEC 93-15. Centre for Social and Economic Research on the Global Environment, University of East Anglia and University College London. http://www.uea.ac.uk/env/cserge/pub/wp/gec/gec_1993_15.pdf (accessed February 2, 2009)

Brown-Kruse, Jamie, Steven R. Elliott, and Rob Godby. 1995. Strategic Manipulation of Pollution Markets: An Experimental Approach. Working Paper Series 95-10, Department of Economics, McMaster University. http://socserv.socsci.mcmaster.ca/econ/rsrch/papers/archive/95-10.pdf (accessed January 26, 2009)

Buckley, J. Neil, Stuart Mestelman, and R. Andrew Muller. 2006. Implications of Alternative Emission Trading Plans: Experimental Evidence. *Pacific Economic Review* 11 (2):149-166.

Buckley, J. Neil, Stuart Mestelman, and R. Andrew Muller. 2005. Baseline-and-Credit Style Emission Trading Mechanisms: An Experimental Investigation of Economic Inefficiency. Working Paper Series, Department of Economics, McMaster University. http://socserv2.socsci.mcmaster.ca/~econ/mceel/papers/buckleyetal-cea2005-lrerc.pdf (accessed February 2, 2009)

Buckley, J. Neil, Stuart Mestelman, and R. Andrew Muller. 2005. Baseline-and-Credit Emission Permit Trading: Experimental Evidence under Variable Output Capacity. In *Experimental Methods in Environmental Economics*, ed. Todd Cherry, Stephan Kroll and Jason Shogren, 9-28. London: Routledge Press.

Buckley, J. Neil, Stuart Mestelman, and R. Andrew Muller. 2003. Long-Run Implications of Alternative Emission Trading Plans: An Experiment with Robot Traders. Paper presented at the Canadian Economics Association, May 30–June1, in Ottawa, Canada. http://socserv2.socsci.mcmaster.ca/~econ/mceel/papers/Buckley_et_al_Cea2003-May24.pdf (accessed February 2, 2009)

Buckley, J. Neil. 2004. Short-Run Implications of Cap-and Trade versus Baseline-and-Credit Emission Trading Plans: Experimental Evidence. Job Market Paper, Department of Economics, McMaster University. http://socserv.socsci.mcmaster.ca/econ/mceel/papers/srerc.pdf (accessed February 2, 2009)

Canadian Electricity Association. 2006. Power Generation in Canada: a Guide. http://www.canelect.ca/en/Pdfs/HandBook.pdf (accessed May 5, 2009)

Carpentier, Chantal Line. 2002. Carbon Sequestration in Agriculture and Forestry to Offset Carbon Emissions and Achieve Sustainable Production Systems. *American Journal of Alternative Agriculture* 17 (3):106-108.

Cason, Timothy N.. 2003. Buyer Liability and Voluntary Inspections in International Greenhouse Gas Emissions Trading: a Laboratory Study. *Environmental and Resource Economics* 25: 101-127.

Cason, Timothy N.. 1995. An Experimental Investigation of the Seller incentives in the EPA's Emission Trading Auction. *the American Economic Review* 85 (4):905-922.

Cason, Timothy N., and Daniel Friedman. 1996. Price Formation and Exchange in Thin Markets: a Laboratory Comparison of Institutions. Presented at "Money, Markets and Methods: a Conference in Honor of Robert Clower", May 9-10, in University of Trento, Italy. http://www.mgmt.purdue.edu/faculty/cason/papers/fourinst.pdf (accessed February 2, 2009)

Cason, T.N., and C.R. Plott. 1996. EPA's New Emission Trading Mechanism: a Laboratory Evaluation. *Journal of Environmental Economics and Management* 30: 133-160.

Chapman, D., C.A. Vossler, T.D. Mount, V. Barboni, R.J. Thomas, and R.D. Zimmerman. 2004. Market Efficiency, Competition, and Communication in Electric Power Markets: Experimental Results, *Ecological Economics* 48: 317-327.

Chan, Kenneth S., Stuart Mestelman, and R. Andrew Muller. 1997. Three Essays in Experimental Economics: Market Performance, Voluntary Contributions and Emissions Permit Trading. Working Paper 97-07, Department of Economics, McMaster University. http://socserv.socsci.mcmaster.ca/econ/faculty/mullera/papers/3essays.pdf (accessed February 2, 2009)

Chomitz, Kenneth. 2000. Evaluating Carbon Offsets for Forestry and Energy Projects: How do they Compare? Policy Research Working Paper 2357. Washington, DC: the World Bank. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=630729 (accessed February 2, 2009)

Chomitz, Kenneth. 2000. Arguments For and Against Forest Carbon Offsets: an Analytic Note. Washington, DC: the World Bank. http://www.climatebiz.com/files/document/CustomO16C45F41718.pdf (accessed February 2, 2009)

Davis, Douglas D., and Charles A. Holt. 1993. *Experimental Economics*. Princeton: Princeton University Press.

Davis, Douglas D., and K. Ramagopal. 1998. Demand Shocks, Advance Production, and Market Power: Some Lessons about Markets from the Laboratory. *Managerial and Decision Economics* 19, 205-233.

Ellerman, A. Denny, and Ian Sue Wing. 2003. Absolute vs. Intensity-Based Emission Caps. Report No. 100, Joint Program on the Science & Policy of Global Change, Massachusetts Institute of Technology. http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt100.pdf (accessed February 2, 2009)

Engle-Warnick, Jim and Bradley J. Ruffle. 2005. Buyer Concentration as a Source of Countervailing Power: Evidence from Experimental Posted-Offer Markets. Departmental working paper # 2006-12. Montréal: Department of Economics, McGill University. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=310339 (accessed February 2, 2009)

Environment Canada. 2008. Canada's Greenhouse Gas Emissions: Understanding the Trends: 1990-2006.http://www.ec.gc.ca/pdb/GHG/inventory_report/2008_trends/trends_eng.cfm (accessed May 5, 2009)

Feldman, Todd, and Daniel Friedman. 2008. Humans, Robots, Market Crashes: a Laboratory Study. Preliminary Draft, University of California, Santa Cruz. http://expecon.gsu.edu/docs/Hubnet10-08.pdf (accessed February 2, 2009)

Fisher, Ann, William J. Wheeler, and Rami Zwick. 1993. Experimental Methods in Agricultural and Resource Economics: How Useful Are They? *Agricultural and Resource Economics Review* 10: 103-116.

Friedman, Daniel and John Rust. 1991. *The Double Auction Market Institutions, Theories, and Evidence.* Perseus Publishing, Cambridge, Massachusetts

Friedman, Daniel, and Shyam Sunder. 1994. *Experimental Economics: A Primer for Economics*. Cambridge: Cambridge University Press.

Gjerstad, Steven and John Dickhaut. 1998. Price Formation in Double Auctions. *Games and Economic Behavior* 22, 1-29. Article NO. GA970576.

Griss, Paul. 2003. Forest Carbon Management: Overview. Presented at Winnipeg Kyoto Mechanisms Seminar, on March 14, Winnipeg, Canada. www.iisd.org/pdf/2003/climate_paul_griss.ppt (accessed February 2, 2009)

Godby, Robert. 2000. Market Power and Emission Trading: Theory and Laboratory Results. *Pacific Economic Review* 5 (3): 349-363.

Godby, Robert, Stuart Mestelman, and R. Andrew Muller. 1999. Experimental Tests of Market Power in Emission Trading Markets. In *Environmental Regulation and Market Power: Competition, Time Consistency and International Trade*, ed. E. Petrakis, E. Sartzetakis, and A. Xepapadeas, 67-94. Cheltenham: Edward Elgar Publishing Limited.

Godby, Rob. 2002. Market Power in Laboratory Emission Permit Markets. *Environmental and Resource Economics* 23: 279-318.

Gode, Dan K., and Shyam Sunder. 2004. Double Auction Dynamics: Structural Effects of Nonbinding Price Controls. *Journal of Economic Dynamics and Control* 28:1707-1731.

Government of Canada. 2005a. Offset System for Greenhouse Gases, Papers for Consultation; Overview Paper and Technical Background Document. http://www.climateregistry.org/resources/docs/protocols/project/livestock/Canada%20offsets%20program%20Sept%2005.pdf (accessed February 3, 2009)

Government of Canada. 2005b. Moving Forward on Climate Change: a Plan for Honouring our Kyoto Commitment. http://www.eboardoftrade.com/files/Productivity_Reports/Advocacy/CdnChamber2.pdf (accessed April 28, 2009)

Government of Canada. 2003. Offset System Discussion Paper. http://dsp-psd.pwgsc.gc.ca/Collection/En40-885-2003E.pdf (accessed February 3, 2009)

Graham, Peter. 2005. Canada's Offset Trading System: Developing Offset Quantification Protocol for Forestry Projects, Presented on August 25, in Savolinna, Finland. http://carbon.cfs.nrcan.gc.ca/ (accessed February 3, 2009)

Gulati, Summeet, and James Verammen. 2005. The Optimal Length of an Agricultural Carbon Contract. *Canadian Journal of Agricultural Economics* 53: 359-373.

Henderson, James M., and Richard E. Quandt. 1980. 3rd ed. Chapter4: The Theory of the Firm. In *Microeconomic Theory: a Mathematical Approach*, 92-98. New York: McGraw-Hill Companies, Inc.

Hizen, Yoichi, Takao Kusakawa, Hidenori Niizawa and Tatsuyoshi Saijo. 2001. Two Patterns of Price Dynamics were Observed in Greenhouse Gases Emissions Trading Experiments: An Application of Point Equilibrium. Institute of Social and Economic Research Discussion Paper No. 557, Osaka University.

Ishikida, Takashi, John O. Ledyard, Mark Olson, and David Porter. 2000. Experimental Test bedding of Pollution Trading System: Southern California's RECLAIM Emissions Market. Social Science Working Paper 1094, Divisions of Humanities and Social Science, California Institute of Technology. http://www.hss.caltech.edu/SSPapers/wp1094.pdf (accessed February 3, 2009)

Kagel, John H., and Alvin E. Roth. 1995. *The Handbook of Experimental Economics*. Princeton: Princeton University Press.

Klemperer, Paul. 2004. *Auction: Theory and Practice.* Princeton and Oxford: Princeton University Express.

Kristofferson, Peter. 2003. Implementing a $15 Price Cap on Domestic Trading CO_2 Emissions. Discussion paper, Department of Finance, McGill University.

Ledyard, John O., and Kristin. Szakaly-Moore. 1994. Designing Organizations for Trading Pollution Rights. *Journal of Economic Behavioural Organization* (25): 167-196.

Lippke, Bruce, John Perez Carcia, and Carolina Maniquez. 2003. Executive Summary: the Impact of Forests and Forest Management on Carbon Storage - a condensation of Manriquez 2002, and Bowyer et al 2002. http://www.ruraltech.org/pubs/theses/manriquez/exec_sum/manriquez_exec_sum.pdf (accessed February 3, 2009)

Lowey, Mark. 2005. Kyoto Plan called Too Late and Too Expensive: Strategy Faces Fire From All Sides of Debate. *Business Edge* 5 (16). http://www.businessedge.ca/article.cfm/newsID/9217.cfm (accessed February 3, 2009)

Marbek Resource Consultants Ltd. In association with PricewaterhouseCoopers and the International Institute for Sustainable Development. 2004. Administration and Transaction Cost Estimates for a Greenhouse Gas Offset System: Final Report. Submitted to Strategic Policy Branch, Agricultural and Agri-Food Canada.

Marshall, Dale. 2007. Briefing Note: Intensity-based Targets, Not a Solution to Climate Change. Vancouver: David Suzuki Foundation. http://www.davidsuzuki.org/files/climate/Intensity_Targets_Not_The_Solution.pdf (accessed February 3, 2009)

Mascher, Sharon. 2004. Designing a Canadian Offset System: Comparing Approaches in Other Jurisdiction. College of Law, University of Saskatchewan. http://www.csale.usask.ca/PDFDocuments/designCdnOffsetSystem.pdf (accessed February 3, 2009)

McCabe, Kevin A., Stephen J. Rassenti, and Vernon L Smith. 1991. Designing a Uniform-Price Double Price Auction: an Experimental Evaluation. In *the Double Auction Market Institutions, Theories, and Evidence*, ed. Daniel Friedman and John Rust, 307-332. New York: Perseus Publishing.

McCabe, Kevin A., Stephen J. Rassenti, and Vernon L Smith. 1991. Designing "Smart" Computer-Assisted Markets: an Experimental Auction for Gas Networks. In *the Papers in Experimental Economics*, ed. Vernon L Smith, 678-702. Cambridge: Cambridge University Press.

McCarney, Geoffrey, and Glen W. Armstrong. 2006. Implications of a Market for Carbon on Timber and Non-Timber Values in an Uncertain World. Presented at the Canadian Agricultural Economics Society Annual Meeting, May 25-28, in Montréal, Québec. http://ageconsearch.umn.edu/bitstream/34175/1/sp06mc01.pdf (accessed February 3, 2009)

McCarney, Shawn. 2009. Ottawa Takes Aim at Coal-Fired Power Plants. *Toronto Globe and Mail,* April 2009, International section. http://www.scrippsnews.com/node/42829 (accessed May 5, 2009)

Mooney, Sian, John Antle, Susan Capalbo, and Keith, Paustian. 2004. Design and Costs of a Measurement Protocol for Trades in Soil Carbon Credits. *Canadian Journal of Agricultural Economics* 52: 257-287.

Muller, R. Andrew. .2006. Personal Communication.

Muller, R. Andrew. 1999. Experimental Methods for the Research into Trading of Greenhouse Gas Emissions. Working Paper Series 99-14, Department of Economics, McMaster University. http://socserv.socsci.mcmaster.ca/econ/rsrch/papers/archive/99-14.pdf (accessed February 3, 2009)

Muller, R.Andrew, and Stuart Mestelman. 1998. What Have We Learned from Emissions Trading Experiments? *Managerial and Decision Economics* 19(4-5): 225-238.

Muller, R. Andrew, Stuart Mestelman, John Spraggon, and Rob Godby. 1999. Can Auctions Control Market Power in Emissions Trading Markets. Working Paper Series 99-12, Department of Economics, McMaster University. http://socserv2.socsci.mcmaster.ca/~econ/mceel/papers/acea99.pdf (accessed February 3, 2009)

Muller, R. Andrew, Stuart Mestelman , John Spraggon, and Rob Godby. 2002. Can Double Auctions Control Monopoly and Monopsony Power in Emissions Trading System. *Journal of Environmental Economics and Management* 44 (1): 70-92.

Murray, Brian C. 2003. Economics of Forest Carbon Sequestration. In *Forests in a Market Economy*, ed. Erin O. Sills and Karen Lee Abt, 221-241. Boston: Kluwer Academic Publishers.

Murphy, James J., Ariel Dinar ,Richard E. Howitt, Steven J. Rassenti, and Vernon L Smith. 2000. The Design of "Smart" Water Market Institutions Using Laboratory Experiments. In *Environmental and Resource Economics*17, 375-394. Boston: Kluwer Academic Publishers.

National Energy Board. 2008. Coal-Fired Power Generation: a Perspective. http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/lctrcty/clfrdpwrgnrtn2008/clfrdpwrgnrtn-eng.html (accessed May 5, 2009)

Natural Resource Canada. Canadian Forest Service. 2007. Is Canada's Forest a Sink or a Source? http://cfs.nrcan.gc.ca/news/544 (accessed April 26, 2009)

Ortman, Andreas. 2003. Charles P. Plott's Collected Papers on the Experimental Foundations of Economic and Political Science. *Journal of Economics Psychology* 24: 555-575.

Pohjola, Johanna, Leena Ketkela, and Raisa Makipaa. 2003. Credited Forest Carbon Sinks: How the Cost Reduction is Allocated among Countries and Sectors. *Climate Policy* 3: 445-461.

PollutionWatch. 2006. Greenhouse Gas Emitters Exposed. http://www.pollutionwatch.org/pressroom/releases/20061011.jsp (accessed May 5, 2009)

Thomassin, Paul J. 2003. Canadian Agriculture and Development of a Carbon Trading and Offset System. *American Journal of Agricultural Economics* 85 (5):1171-1117.

United Nations Framework Convention on Climate Change (UNCCC). 1992. http://unfccc.int/resource/docs/convkp/conveng.pdf (accessed February 3, 2009)

United Nations Framework Convention on Climate Change (UNCCC). 2007. http://unfccc.int/kyoto-protocol/background/items/3145.php (accessed February 3, 2009)

Randall, Alan. 1987. 2nd ed. Chapter 20: the Control of Polluting Emissions. In *Resource Economics: an Economic Approach to Natural Resource and Environmental Policy*, 358-368. New York: Wiley Publishing Inc.

Rosenberg, Nicole, and Mariétte Geyser. 2005. Applicability of a Carbon Derivative in South African Agriculture. University of Pretoria.

Sedjo, Roger A. 2001. Forest Carbon Sequestration: Some Issues for Forest Investments. Discussion paper 01-34. Washington, DC: Resources for the Future. http://www.rff.org/Documents/RFF-DP-01-34.pdf (accessed February 3, 2009)

Sedjo, Roger A., Gregg Marland, and Kristy Fruit. 2002. Carbon Emissions Trading: A Tradable Permit System for Temporary Carbon sequestered. Paper presented at Concerted Action for Tradable Emissions Permits Workshop on the Design and Integration of National Tradable Permit Schemes for Environmental Protection, March 25-26, in University College London, UK.

Seres, Stephen. 2001. The Power Generation Sector's Demand for Fossil Fuels: a Quantitative Assessment on the Viability of Carbon Fees for the Reduction of Greenhouse Gas Emissions. Master Thesis, Department of Agricultural Economics, McGill University.

Sills, Erin O., and Karen Lee Abt. 2003. *Forests in a Market Economy*. Boston: Kluwer Academic Publishers.

Smith, Vernon L. 1976. Experimental Economics: Induced Value Theory. *The American Economic Review* 66 (2): 274-279. Papers and Proceedings of the 88th Annual Meeting of American Economic Association.

Smith, Vernon L. 1981. An Empirical Study of Decentralized Institutions of Monopoly Restraint. In *Papers in Experimental Economics*, ed. Vernon L. Smith, 707-730. Cambridge: Cambridge University Press.

Smith, V.L., and Arlington W. Williams. 1981. on Nonbinding Price Controls in a Competitive Market. *The American Economic Review* 71: 467–474.

Smith, Vernon L., and Arlington W Williams. 1989. The Boundaries of Competitive Price Theory: Convergence Expectations and Transaction Costs. In *Bargaining and Market Behaviour: Essays in Experimental Economic*, ed. Vernon L. Smith, 286-319. Cambridge: Cambridge University Press.

Smith, Vernon L. 1991. *Papers in Experimental Economics.* Cambridge: Cambridge University Press.

Straub, Ben. 2004. Emission Permit Double Auctions and Market Power. Master thesis, Department of Economics, the Florida State University.

Subak, Susan. 2003. Replacing Carbon Lost from Forests: an Assessment of Insurance, Reserves, and Expiring Credits. *Climate Policy* 3: 107-122.

Van Kooten, G. G., A. J.Eagle, James Manley, and Tara Smolak. 2004. How Costly are Carbon Offsets: a Meta-analysis of Carbon Forest Sinks? *Environmental Science and Policy* 7: 239-251.

von Mirbach, Martin. 2003. Forests, Climate Change & Carbon Reservoirs: Opportunities for Forest Conservation. Discussion Paper, Sierra Club of Canada. http://www.sierraclub.ca/national/programs/biodiversity/forests/forests-cc-cr.pdf (accessed February 2, 2009)

Wilman, Elizabeth A., and Mahen S. Mahendrarajah. 2002. Carbon Offsets. *Land Economics* 78(3): 405-416.

Yefimov, Vladimir. 2003. On Pragmatic Institutional Economic. Presented at the EAEPE Conference, November 7-10, in Maastricht, the Netherlands. http://esnie.u-paris10.fr/en/archives/2004.php?id=104 (accessed February 2, 2009)

Preliminary Experimental Instructions

Introduction

Thank you for attending this experiment on the economics of decision-making. In the experiment, you will participate in a series of four markets, one practice market and three real markets. The practice market is intended for preparing you for the trading in real markets following. The practice market is planned to last 2 or 3 periods, 10 minutes each period. The real market will continue for 10 periods each, 3 minutes for each period. You will have a show-up payment, as well as extra payment depending on your trading performance in the real markets. If you make good decisions compared to other players in the market, you could earn **more money**. At the end of the session you will be paid in cash/check privately. You won't be paid in the practice market.

Please read the following instructions carefully. Raise your hands if you have any questions. The experimenter or a helper will explain to you privately.

Market Structure and Decision Model

Market Structure

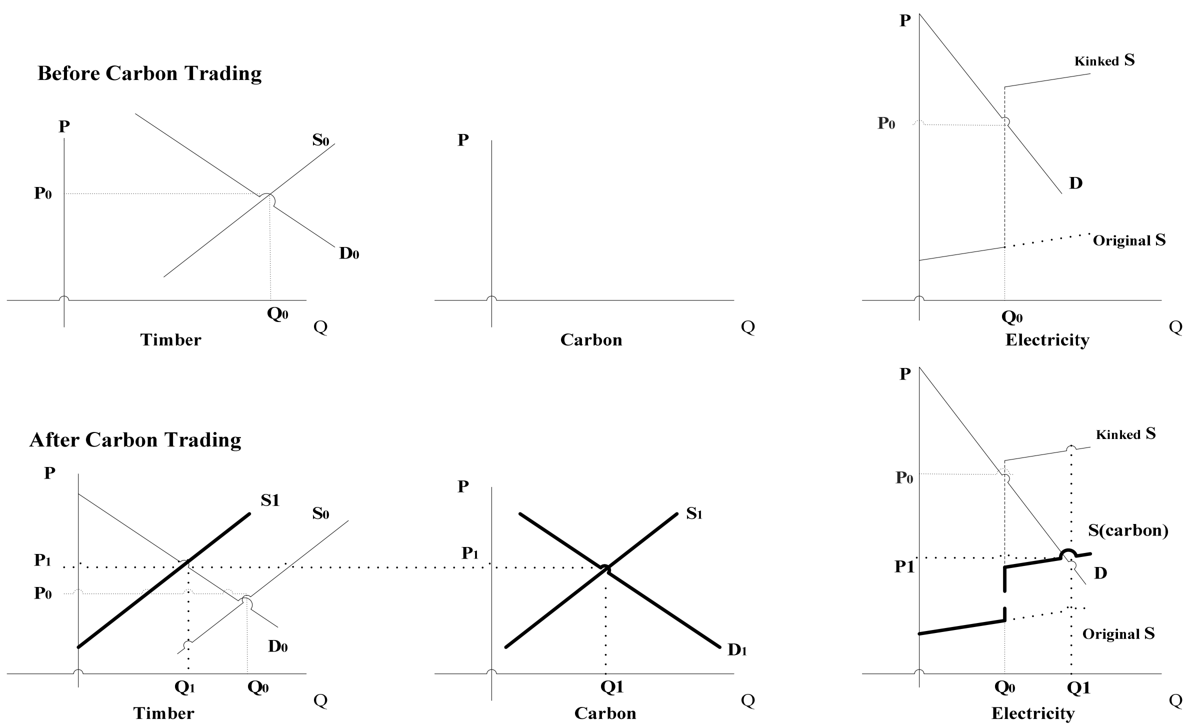
In the whole experiment, there will be three markets running simultaneously. These three markets running at the same time are: timber market, carbon market and electricity market. The whole experiment will be conducted as before carbon-trading session and after carbon-trading session. Pay attention, this "market" is different from the "market" mentioned above. Each practice and real market will be operated with these two sessions.

There will be 10 human subjects, categorized into two groups: forest producers and electricity producers. 5 of you will represent 5 forest producers. You are the special in a way that if you log less timber, more carbon will be sequestered in these unlogged woods. The sequestered carbon can supply low-cost carbon credits to high-polluting firms with high abatement costs .During the before carbon-trading session, you will trade only in the timber market, selling timber units. During the after carbon-trading session, you will produce two products jointly—timber and carbon credits—at the same time, and trade in two markets—timer and carbon markets— simultaneously. The buyers in the timber market will always be robot traders, who are programmed to trade as long as there is profit. The buyers of carbon credits will be electricity producers. Your decision models and payoff calculation will be elaborated in detail in the following session.

The other 5 of you will represent 5 electricity producers. You are the type of firms polluting a lot but hard to cut your abatement costs. The cheaper way for you to continuing supply electricity with a low affordable price is to purchase the carbon credits in the carbon markets produced by forest producers. During the before carbon-trading session, you will be trading only in the electricity market, selling units of electricity. However after a few periods, you may notice that your prices are too high to be afforded by the buyers. This is because your unit costs also include high abatement costs. During the after carbon-trading session, you will trade in two markets—electricity market and carbon market—simultaneously. You will purchase carbon credits in the carbon market to lower your own abatement costs; hence your unit costs are also reduced meanwhile in the electricity market. Similar to the forest producers, the buyers in the electricity market will always be robot traders, who are programmed to trade as long as there is profit. Your decision models and payoff calculation will be elaborated in detail in the following session.

Refer to figure 1 as a general concept of the whole experiment, although the real trading is in discrete value and not exactly the same as this conceptual figure.

Figure 1 Three Markets Running Simultaneously



Source: self-calculated

Decision Model

Forest Producers

Before Carbon Trading

Forest producers are producing only timber and participate only in the timber market. To optimize this production decision, it is designed that they all follow a decision model as below:

$$\pi = (P_T + m)Q_T - rQ_T^2 \qquad (1)$$

$$P_T = 2rQ_T - m \qquad (2)$$

π is the profit to be optimized, P_T can be understood as the unit cost to produce a certain amount of timber, Q_T. r is a cost parameter assigned to each firm. Hence $P_T Q_T$ is the product revenue, rQ_T^2 is the production cost, π is the profit. It is designed that each forest firm can produce up to 2 units of timber. Obviously, each firm has a different profit curve, different timber revenue and cost. *m* is added as an adjustment parameter to actually shift the after-carbon-trading curve to the before-carbon-trading curve (this *m* is assigned as 1/3 of the after carbon trading equilibrium price). Since the after-carbon-trading scenario is designed first, this *m* parameter is aftermath created to shift post-carbon supply curve left to the pre-carbon trading curve.

Nevertheless, the decision model is provided to assist you to understand better the decision process and make a better trading. In the real experiment, you are already provided with the unit costs derived from the model (1). All you need to do is to trade them.

After Carbon Trading

The forest producers will try to optimize simultaneously in the timber and carbon market. Hence their decision model becomes a joint-product case, the same one input producing two outputs. During the process of balancing the supply of timber and carbon, the joint-production model (Henderson and Quant, 1980, p.92-98), as model (3) has been utilized to derive the unit costs for producing both timber and carbon in a joint manner.

$$\pi = P_T Q_T + P_C Q_C - r(Q_T^2 + Q_C^2) \qquad (3)$$

Ceribus paribus, P_C represents the unit marginal cost to produce carbon corresponding to the quantity of carbon supplied, Q_C. r remains the same as the assigned cost parameter for each firm, constant before and after carbon trading. Likewise, each producer can produce up to 2 units of carbon credits as one of the joint products. π is the joint product revenue $P_T Q_T + P_C Q_C$ is the joint production revenue, $r(Q_T^2 + Q_C^2)$ is the joint producing cost , thus they are a series of concentric circles in the space (Q_C, Q_T), the negative of the slope of these concentric circles is defined as the *rate of the product transformation (*RPT):

$$RPT = -\frac{dQ_c}{dQ_T} = \frac{Q_T}{Q_C} = \frac{P_T}{P_C} > 0$$

Thus the First Order Condition of (2):

$$\frac{\partial \pi}{\partial Q_T} = P_T - 2rQ_T = 0$$

$$\frac{\partial \pi}{\partial Q_C} = P_C - 2rQ_C = 0$$

i.e. $\frac{P_T}{Q_T} = \frac{P_C}{Q_C} = 2r$

According to the model, to maximize the joint profit, the timber and carbon credits are always produced in a one-to-one relationship. The supply of timber and carbon for each firm are exactly the same. The price of timber/carbon is always $2r$ times of the quantity of timer/carbon. For example, for forest producer 1, when it produces 1 unit of timber, it can correspondingly produce 1 unit of carbon credits. These two products have the same unit costs. In the real experiment, you will be provided with all the unit costs derived from model (3), rather than calculating yourself. The timber buyers are always robot traders, trading as is designed to.

Electricity Producers

Before Carbon Trading

Each electricity producer makes its production decision based on model (4) as below. Meanwhile, there is a policy restriction applied on its extra electricity supplied beyond the quota allowed. That is, for its quantity supplied within the quota, each electricity firm is allowed to pollute free, needless to include its pollution abatement cost into its production cost. In this *first* stage, each producer maximizes its production profit according to the original single-product model, model (4):

$$\pi = P_E Q_E - rQ_E^2$$
(4)

In the *second* stage, when each firm produces beyond the quota allowed, it has to include its high pollution abatement cost into its unit cost of producing electricity. This high abatement cost is actually the resale value for the carbon credit, i.e., the demand curve, in the carbon market. That is why you can see a huge kink in the electricity supply curve before carbon trading, which makes the extra quantity highly unaffordable by the electricity buyers. In this stage, the unit cost for electricity is derived from model (4) and each firm's abatement cost, i.e., the original unit cost based on model (4) plus its abatement cost. In the real markets, you are provided with all the unit costs and resale values derived as illustrated above. You need to understand the logic behind those numbers assigned to you, rather than calculate them yourselves. The electricity buyers will always be robot traders, trading as is designed.

After Carbon Trading

Each electricity producer has bought a certain amount of carbon credits in the carbon market, depending on its own abatement cost. The purchased carbon credits hence replace the original abatement cost. When being included as part of the electricity production cost, they lead to a lower cost, leading to a supply curve still, but less, kinked. Purchasing carbon credits does reduce each firm's supply cost; however, each firm still has to pay a price to pollute. The benefit of carbon market is replacing old high abatement cost thus reducing the total supply cost, rather than keeping the firm from paying a price.

The decision model is the same single product profit maximization model (4), as timber/electricity producers before carbon trading. The electricity supply curves are exactly the same below the supply quota. The difference rests at the second stage when producing beyond the quota. Rather than adding its own original abatement cost to the total supply cost, each firm only needs to include the carbon credits they have purchased in the carbon market. If one firm has purchased X carbon credits, it should use these X credits to replace X units of its abatement cost. Purchasing low cost carbon credits in the carbon markets to replace the electricity producer's higher abatement costs, lowers the electricity supply curve to a less kink. However, in the real markets, you are provided with all the unit costs and resale values derived as illustrated above. You only need to understand the logic behind those numbers assigned to you, rather than calculate them yourselves. The electricity buyers will always be robot traders, trading as is designed.

Payoff Calculation

Forest Producers

Before Carbon Trading

Units of timber Q_T	Product Revenue $P_T Q_T$	Total Cost rQ_T^2	Profit π	Unit cost of this timber $P_T = 2rQ_T - m$	Marginal factor cost of this timber
0	0	0	0	0	
1	120	60	60	90	120
2	480	240	240	210	360
3	1080	540	540	330	600

Please note that this table is only an example. The numbers in the experiment are quite different.

Here is an example for one forest producer; the cost factor r is always the same for one firm. Here $m = 30, r = 60$, when $Q_t = 1, P_t = 120$; when $Q_t = 2, P_t = 240$; when $Q_t = 3, P_t = 360$. A marginal cost is just a FOC of the cost function, eg. Here the cost function is rQ_t^2, and then the marginal cost is 2rQ_t. With more units producing, the marginal cost is also increasing. This is similar to understand that marginal revenue is decreasing with the increasing units bought. Hence this is the reason in this value design, there is an increasing marginal cost for producers and decreasing marginal revenue for buyers, which actually works as constraints when the author assigned the values according to the models, and is also the case in Muller et al's experiments.

After Carbon Trading

Units of timber Q_T	Units of Carbon Q_C	Product Revenue $P_T Q_T$	Car bon Revenue $P_C Q_C$	Total Cost $r(Q_T^2 + Q_C^2)$	Profit π	Unit cost of this timber P_T	Marginal factor cost of this timber	Unit cost of this carbon credit P_C	Marginal factor cost of this carbon credit
0	0	0	0	0	0	0			
1	1	120	120	120	120	120	120	120	120
2	2	480	480	480	480	240	360	240	360
3	3	1080	1080	1080	1080	360	600	360	600

Please note that this table is only an example. The numbers in the experiment are quite different. $r = 60$ always (that is in experimental design, the before carbon trading and after carbon trading r is the same)

Please answer the questions below. When you finish please raise up your hand and I will check your result.

1. Suppose that you are producing two units of carbon as in the table above. What is the *least* amount of money that you will be willing to accept for selling one more unit?

Answer: ________600_____________

2. Suppose that you are producing two coupons as in the table above. What is the *most* amount of money that you will be willing to pay for buying one carbon credit?

Answer: ________360_________

Electricity Producers

Before Carbon Trading

Units of electricity Q_E	**Abatement cost for *n* units of electricity**	**Product Revenue** $P_E Q_E$	**Total Cost** rQ_E^2	**Profit** π	**Unit cost of this electricity** P_E	**Marginal factor cost of this electricity**
0	0	0	0	0	0	
1	0	200	100	100	100	200
2	100	1000	500(=400+100)	500	500(=100+400)	800
3	1000	4800	3900(=900+1000*3)	900	1600=(600+1000)	3800

Please note that this table is only an example. The numbers in the experiment are quite different. $r = 100$ always for a same producer

During Carbon Trading (Muller's Experiment)

Units of Carbon Q_C	**Sales Revenue= Product Revenue--Total Cost**	**Profit** π	**Total Resale values of the carbon credits**	**Marginal revenue of this carbon credit** P_C
0	6000	6000	0	
1	6000	7200	1200	1200
2	6000	9200	3200	1000
3	6000	10000	4000	800

Please note that this table is only an example. The numbers in the experiment are quite different.

Please answer the questions below. When you finish please raise up your hand and I will check your result.

1. In the carbon market, suppose that you are assigned two carbon credits as in the table above. What is the *most* amount of money that you will be willing to pay for buying one more carbon credit?
   Answer: _________800_ __________
2. In the carbon market, suppose that you are assigned two carbon credits as in the table above. What is the *least* amount of money that you will be willing to accept for selling one carbon credit?
   Answer: _________1000___ ________

After Carbon Trading

Units of electricity Q_E	Abatement cost for *n* units of electricity	Carbon credits bought for replacing abatement cost	Product Revenue $P_E Q_E$	Total Cost rQ_E^2	Profit π	Unit cost of this electricity P_E	Marginal factor cost
0	0	0	0	0	0	0	
1	0	0	200	100	100	100	100
2	100	0*	1000	500	500	500	800
3	1000	**200**	2400	1500(=900+3*200)	900	800(=600+200)	1200

Please note that this table is only an example. The numbers in the experiment are quite different. R=100 always

* means since 200>100, the firm does not need to buy a carbon credit to reduce its already-low abatement cost

Trading

Double Auction Market

All of the trading will take place in a computerized double auction market. In this market you can offer to buy a unit of timber, electricity or carbon with certain amount of price. This is called a **bid.** You can also sell a unit of timber, electricity or carbon, with some price. This is called an **ask**. Finally when a trade has agreed on, you can **buy** a unit of timber, electricity and carbon, by paying the price someone has **asked**, or you can **sell** a unit of timber, electricity or carbon at a price someone has **bid**.

Improvement Rule
When you post a new bid, it has to be higher than all the present bidding prices. When you post a new ask, it has to be lower than all the current asking prices.

Final Instructions

Do not speak with any other participant during the experiment. If you have any questions, please raise your hand. The experimenter or a helper will speak with you privately.

End of Instructions