EFFECTS OF MARKET POWER AND STRATEGIC MANIPULATION

WITHIN A SIMULATED KYOTO-PROTOCOL

EMISSIONS TRADING PROGRAM

by

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This paper presents a model of a global CO_2 emissions market as envisaged in the Kyoto Protocol. Using an agent-based simulation, six trading regions abstracted from the Annex-I countries are allowed to trade within a market defined by 1) perfect competition, 2) monopoly, 3) monopsony, and 4) unrestrained strategic battling between powerful buyers and sellers. Cost analysis was performed for various scenarios, namely U.S. and "hot-air" inclusion/exclusion. The cost increases caused by strategic manipulation reveal that both buyers and sellers wielded significant market power, and that neither side was able to dominate. Russia's ability to monopolize was impaired considerably by strategic purchasing.

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1 INTRODUCTION

One of the fundamental duties of government is the protection and promotion of public goods. The need to protect one of the most vulnerable and important public goods, the atmosphere, has pushed legislators around the world to control the emission of harmful gases. Society faces a tradeoff between the preservation of this essential public good and the consumption of goods whose manufacturing produces pollution as a by-product. While the socially optimal amount of pollution is intractably difficult to determine, the scientific community is in general agreement that greenhouse gases (GHGs) are being produced globally at a dangerously high rate, leading to global warming. Excessive GHGs are cited by many, including the Executive Director of the United Nations Environment Programme (UNEP), as the “greatest environmental threat this planet faces” (U.N., 2002). GHG emissions have been rapidly increasing since the industrial revolution primarily because of an increase in fossil fuel consumption.

The Kyoto Protocol was the first significant international attempt to address and mitigate global warming, ratified at the United Nations Framework Convention of Climate Change (UNFCCC) Conference of the Parties in 1997. The Protocol was designed to reduce GHG emissions by specifying pollution caps for developed countries, called Annex-I countries, in terms of their respective 1990 emission levels. While many, such as U.N. Secretary-General Kofi Annan, commend the treaty as a “sound and innovative response to a truly global threat” (U.N., 2003), others continue to berate the Protocol as an environmentally ineffective, socially unfair, and economically inefficient agreement based on political "horse-trading"[1] (IPPR, 2003).

One of the key elements of the Kyoto Protocol is the allowance for the transfer of emission rights, implicitly creating a global market for pollution permits[2]. This market was made explicit through further definition in 2002 with the creation of the Marrakesh Accords. If the Protocol enters into force, which is now contingent on Russian ratification, Annex-I countries will be able to redistribute their permits using an emissions trading program, a fairly new and controversial concept. While a market is an ancient and proven mechanism to redistribute goods, the commoditization of environmental resources in the form of pollution rights has not gained widespread social acceptance. However, economic theory views the creation and control of these rights as the key to efficient and cost-effective[3] climate change policy.

If regulators were omniscient, the distribution of a fixed amount of pollution rights, such as the caps specified in the Kyoto Protocol, could be made perfectly cost-effective: the total cost resulting from domestic abatement measures could not be reduced by redistribution of pollution rights. To be completely cost-effective, the cost of abatement at the margin for each country must be equalized. If a differential exists, an allocation where the country incurring higher marginal costs received more permits and the country with lower marginal

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[1] Tony Grayling, associate director of the "progressive" British think tank IPPR, argued two widely-held concerns in a recent article in *New Economy*: the Kyoto Protocol will not reduce GHG emissions by a significant amount, and the burden of emissions reductions was unfairly allocated to countries (IPPR).

[2] Although the Kyoto Protocol does not use the term "permit," this paper will use this term to indicate the transferable pollution rights assigned to each country, or "assigned annual amounts" (AAUs) in the language of the Protocol. Thus, each permit allows a country to emit a certain amount of GHG.

[3] While social efficiency or optimality is based on arbitrary comparison of individuals' preferences, the idea of efficiency can be strictly defined economically. The usual definition is one of Pareto efficiency, defined in the negative as the situation where no one can be made better off without making someone else worse off. Cost-effectiveness, on the other hand, is an outcome that minimizes waste given some exogenous constraint, such as the number and characteristics of pollution permits issued by a governing body. As it pertains to the Kyoto Protocol, efficiency is contingent on setting a socially optimal cap on emissions, as well as a cost-effective distribution of these permits.

costs received fewer permits would provide a more cost-effective solution. A centralized-planning method of distribution requires the regulator to acquire cost information for all the polluters, a pragmatically impossible endeavor. Using a free, competitive market for pollution rights, a cost-effective outcome is possible without significant regulatory interference. The least-cost outcome would be that of perfect competition, where suppliers sell at their true marginal cost. This type of market is based on the assumption that there are a sufficient number of market participants, so that no one player has any ability to manipulate the market through cost misrepresentation. The Kyoto market, with major market players, does not fall into this category. Large traders may be able to reduce cost-effectiveness by manipulating their supply and demand schedules. Because the outcome of an imperfect market is difficult to predict using traditional theory, an innovative method for testing the effectiveness of these markets is required.

One fairly new method of modeling that holds great potential for exploring some of the questions that classically have been intractable is agent-based simulation. By creating representative agents and allowing them to interact within a computer-simulated environment, macroeconomic phenomena can be observed without introducing unrealistic exogenous constraints. Allowing the microstructure to explain the macrostructure is the crux of agent-based simulation. This study[4] uses such a simulation to investigate the feasibility and potential outcome of a global market for GHG pollution permits, as specified in the Kyoto Protocol.

Many studies have estimated the cost of implementation of the Kyoto Protocol for the involved countries and the gains that can be made from trade. As the ultimate determinant of

[4] The project summarized in this paper was a collaborative effort of Mr. Ivan Thomann and Mr. Oliver Levine as an undergraduate thesis for the Robert D. Clark Honors College at the University of Oregon. For a separate but corroborative analysis of this project, see Thomann (in press).

efficiency, many different market structures have been explored, but studies have focused on those that have theoretically well-known outcomes. This study extends the exploration of market outcomes by focusing on the strategic elements involved in emissions trading. A traditional market model will not be assumed; a simulation will be used to model a simple strategic trading game and the market structure will be inductively described by the emergent market outcome. This study hopes to provide insight into the type of market that will emerge from the Kyoto Protocol, and the effects thereof.

Section two will further introduce emissions trading and the Kyoto Protocol, and will describe past research that analyzes the resultant market under various trading scenarios. Following that section, the model used to simulate the market scenarios envisaged in this study will be described, including the algorithms used in the implementation. Section three also will delineate the various trading scenarios simulated. In Section four the results will be discussed for these trading scenarios. The discussion of results will progress from the simplest scenario to the most complex, concluding with a section that will discuss model performance, policy implications, and areas of possible future research.

2 BACKGROUND

2.1 Marketable emission rights

The need to address global environmental issues relating to pollution is recognized as one of the most pressing international social and political concerns. While countries face tradeoffs between consumption and a clean environment, the socially optimal level of pollution is difficult, if not impossible, to determine. Once this level is determined, however, least-cost allocation of pollution rights is not guaranteed. Distribution by bureaucratic oversight, commonly known as Command and Control (CAC), is one method that can be effective when each polluter has somewhat transparent costs, but can be grossly inefficient otherwise (Tietenberg, 1985). In fact, the ineffectiveness of CAC is often cited as a primary motivator for marketable emission rights. Without perfect cost information, a CAC allocation would be unable to equalize marginal abatement costs for all polluters, making cost reduction possible through permit trading.

While the treatment of emission rights as a commodity is often misunderstood and demonized within many environmental and political arenas, the market mechanism is a seemingly viable way to achieve acceptable efficiency within a world of imperfect information. Emissions trading is a theoretically elegant and simple way of achieving efficient distribution of a predefined number of pollution permits, where each permit entitles the holder to pollute a certain volume and/or rate of pollutant within a specified time frame. Abstractly, permits are created by a governing agent that has monitoring and violation enforcement capabilities over the governed polluters, giving the holder the right to pollute a pre-specified amount. The number and characteristics of the permits are chosen based on certain environmental goals, effectively creating a cap on the amount of pollution that can be generated over a given period. Once the agents own these permits, either through auction or some CAC distribution method, trading allows permit holders to buy and sell these permits freely, thus allowing a reallocation of the permits based on market supply and demand. If the market is perfectly competitive[5], the market outcome is known to be efficient: each agent will buy or sell permits until its marginal abatement cost (MAC), the cost incurred by emitting one less unit of pollution, is equal to the market price, thus equating the MAC for each agent (Tietenberg, 1985). In this simple version of emissions trading a cost-effective distribution of permits is achieved, meaning the cost of achieving the pollution cap is minimized. Any disparity of marginal cost would be eliminated through trade within a perfectly competitive market. For example, if two countries have different MACs, the country with the higher MAC has an incentive to buy permits at any price less than its MAC, while the other country has an incentive to sell permits at any price higher than its MAC. This basic and fundamental market theory is what makes emissions trading such an attractive distribution mechanism.

2.2 Global Climate Policy and Greenhouse Gases

While using the “cap-and-trade” system of allowance-based emissions trading to achieve climate policy goals is a relatively new approach, its effectiveness has been demonstrated in the U.S. with the implementation of an SO_2 emissions market (Ellerman,

[5] A perfectly competitive market is one in which no single agent has market power, i.e. no agent is able to affect market price.

2000). The need for global greenhouse gas (GHG) emissions reduction and regulation prompted the drafting of the Kyoto Protocol using a similar allowance-based emissions trading program. The SO_2 emissions program was environmentally effective because of the geographic scope of its regulation; the nature of SO_2 is such that its point of emission corresponds somewhat closely to its point of environmental disturbance. Thus, the negative externality associated with the pollution is, for the most part, contained within the U.S., making a national market appropriate. GHG emissions, on the other hand, are a global externality, requiring an effective market to be global in scope.

Under the Protocol, signatory countries are obligated to reduce GHG emissions to some percentage of their respective 1990 levels between 2008 and 2012, known as the First Commitment Period. Adopted at the Conference of the Parties to the UNFCCC in December 1997, the Protocol will go into force only with ratification by at least fifty-five signatories comprising at least fifty-five percent of carbon dioxide emissions for 1990. The Protocol specifies six gases that are to be controlled, of which carbon dioxide is the most significant and prevalent[6]. Because the environmental effects of GHG emissions are independent of rate of emission and of their geographic origin, a global emissions market that enables free transference of permits between geographic regions does not adversely affect the realization of environmental goals.

The Kyoto Protocol is constructed such that the nations traditionally defined as "advanced," i.e. Organisation for Economic Co-operation and Development (OECD) member countries, plus transitioning Eastern European countries and the former Soviet Union, are defined as Annex-I countries and take on responsibility for all GHG reductions

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[6] Because of the uncertainty and scarcity of information on the other five GHGs, this study concerns itself only with carbon dioxide emissions.

(for a complete list, see Appendix Table 12). While the Protocol specifies various methods for countries to achieve their abatement requirements, the most crucial allowance is a global market in which to acquire and transfer “assigned annual amounts” (AAUs). While the description of emissions trading is explicit but only loosely developed in the Kyoto Protocol, the seventh session of the Conference of the Parties, with the ratification of the Marrakesh Accords, concretely established trading rules to which all but the U.S. agreed (Elzen, Moor, 2002).

One important result of the Marrakesh Accords is the decision to limit emissions trading only qualitatively as a portion of total abatement effort. The European Union (EU) had strongly advocated that emissions trading should exist only as a “supplementarity” to domestic abatement efforts. They feared that allowing a country to simply purchase unlimited permits would undermine the long-term goal of emissions reduction through domestic abatement action, such as investment in green technology. Original EU demands were for a maximum of fifty percent of abatement requirements to be imported, but it settled on the supplementarity issue with the inclusion of the statement that “domestic action shall thus constitute a significant element of the effort.” Without a quantitative restriction on importation, the supplementarity clause likely will have no significant effect on abatement decisions.

Another important decision of the Marrakesh Accords is the decision not to limit the sale of hot air. Because abatement requirements for each country are based on a percentage of 1990 levels, some countries find that their Business as Usual (BAU) projections for emissions during the First Commitment Period are actually below their AAU. This surplus, which can be interpreted as a negative abatement requirement, is hot air that can be sold to other countries at no cost to the supplier. This condition primarily concerns Russia because of its recent economic collapse. The George W. Bush administration rejected the Kyoto Protocol as fatally flawed, making Russia a vital player within the Protocol because its implementation is contingent on Russian ratification (Löschel, Zhang, 2003). With the U.S. leaving the Protocol, the demand for and consequently the value of GHG permits is dramatically reduced, pushing other potential sellers out of the market. As the sole remaining seller, Russia now has greater market power and may be better able to act as a monopolist (Bernard, et al., 2003). Of course, as a major oil exporter, Russia has much to lose from inflating the price of emissions. Without U.S. involvement, Russia is a key player in the Protocol, a position it seemed to exploit in the bargaining of the Marrakesh Accords.

2.3 Marginal Abatement Cost Curves and Related Studies

Each Annex-I country that ratifies the Kyoto Protocol has an abatement requirement during the First Commitment Period. This requirement is defined as the difference between BAU emissions and the emission allotment expressed as a percentage of 1990 levels. The costs of these requirements are very different across countries. The marginal abatement cost (MAC) for each country is a function that describes the cost of abating one more unit of pollution at a given level of abatement (see Figure 1). The MAC curve is upward sloping at an increasing rate to the right for positive quantities and is zero for the hot-air area. For positive quantities, the area under this curve represents the total cost of abatement. Using MAC curves, the abatement costs for a given country can be determined for a locus of abatement requirements.

A country is able to gain from trade by purchasing pollution permits when its marginal cost of abatement is higher than the market price and selling permits when its marginal cost of abatement is lower than the market price. Figure 2 shows the gains from trade by a purchasing region that has abatement requirement q_0. At market price P_0, the region demands $q_0 - q_1$ permits to maximize its gains from trade. Figure 3 shows the same scenario when the market price is above the same region's MAC. At this higher price, P_1, the region wishes to supply at a quantity $q_1 - q_0$, resulting in increased abatement costs but an overall gain due to the sales revenue.

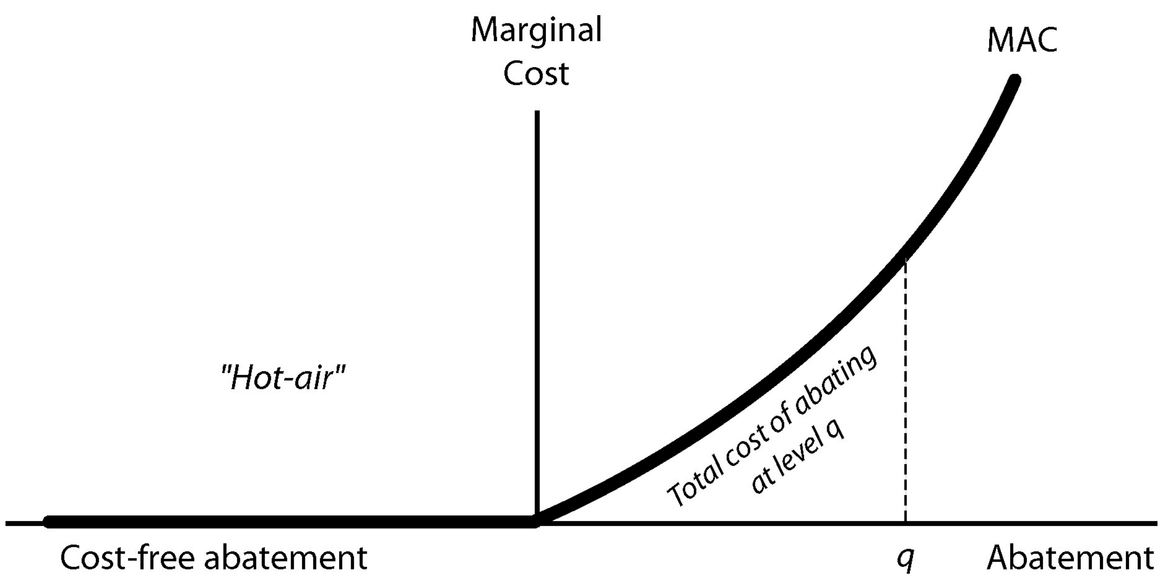

Figure 1. A marginal abatement cost (MAC) curve for a region.

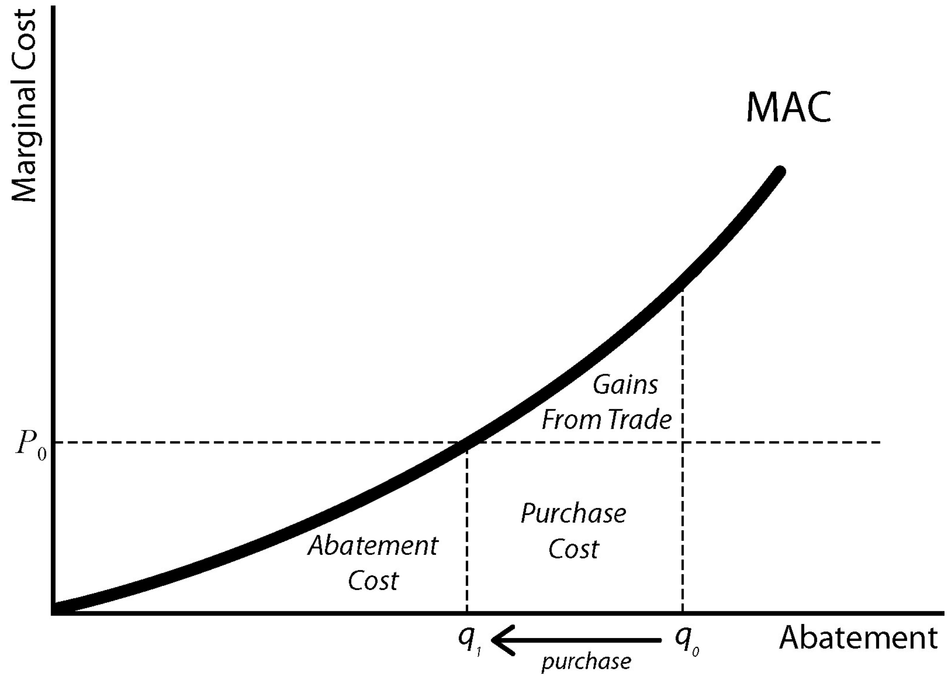

Figure 2. Gains from trade for a country demanding permits.

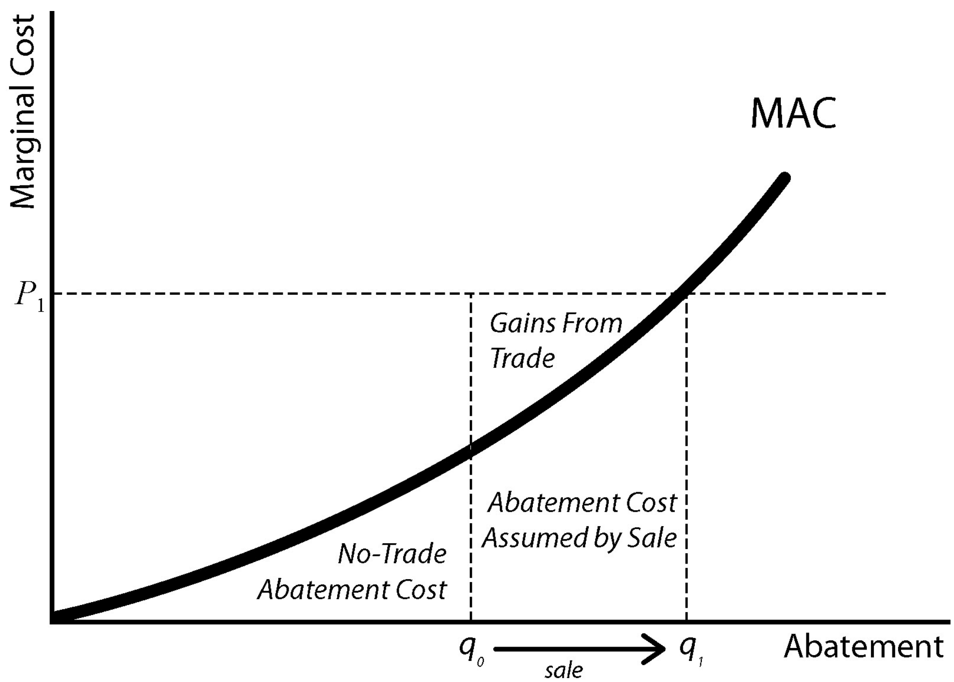

Figure 3. Gains from trade for a country supplying permits.

One convenient method of representing MAC curves for countries is to use the quadratic form $P = \hat{\alpha}A^2 + \hat{\beta}A$, where P is the shadow price of abatement[7] and A is the quantity of abatement (Ellerman, Decaux, 1998)[8]. Using this representation, derived using a simple quadratic regression, each country's MAC curve is described by two coefficients which are constant for a given time period. While $\hat{\alpha}$ and $\hat{\beta}$ are difficult to interpret directly, comparing $\hat{\alpha}$ - $\hat{\beta}$ pairs is useful in determining relative marginal costs between regions. Because an increase in either parameter represents an increase in marginal cost, if a region has both a higher $\hat{\alpha}$ and a higher $\hat{\beta}$ than another, that region has a higher marginal cost of abatement for all levels of abatement. Because a tradeoff exists between $\hat{\alpha}$ and $\hat{\beta}$, it is more difficult to determine relative costs when both parameter estimates are not greater or less than those of another region.

The parameter estimates for each region are not derived empirically but through a complex economic model, meaning they are "better than purely heuristic curves, but not as good as an empirically estimated relationship" (Ellerman, Decaux, 1998). While many studies have estimated these parameters for various regions, this study uses the results of the Emissions Prediction and Policy Analysis (EPPA) model created by the MIT Global Change Joint Program, which divides the Annex-I countries into six regions: the United States (USA), Japan (JPN), other OECD countries (OOE), EU-12 (EEC), Eastern Europe (EET), and the Former Soviet Union (FSU) (for these $\hat{\alpha}$ and $\hat{\beta}$ values, see Appendix Table 13). The results from the EPPA model show that with these six regions trading, JPN, EEC and

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[7] Because a MAC function relates marginal cost to abatement, the function only indirectly describes the price a country would pay for the right to pollute on the margin. Thus, the marginal cost represents what is termed the "shadow price" of abatement.

[8] For this study, the units for prices are 2/3 millions of 1990 U.S. dollars ($) and quantities are in megatons of carbon (MtC).

USA are major demanders and FSU is a major supplier. While later studies suggest that domestic abatement actions by EEC countries have lowered the region's BAU emission levels such that they are no longer a major demander of permits (Grütter, 2001), there is no doubt that JPN and the U.S. would remain major demanders and would be supplied heavily by FSU. With the withdrawal of the U.S., however, the permit price and cost of implementation are much lower. Environmentally, U.S. withdrawal will dramatically reduce the effectiveness of the protocol, leading to emission levels comparable to BAU estimates rather than the five to thirteen percent reduction originally envisioned (Buchner, et al, 2003).

Perfectly competitive market outcomes for a global GHG emissions market have been estimated using MAC curves for various trading scenarios, including full trade, Annex-I trading only, hot air, no hot air, and U.S. inclusion/exclusion (Grütter, 2001; Buchner, et al, 2003; Löschel, Zhang, 2002). This same research has also shown the outcomes and long-term cost implications of non-competitive supply, concentrating on the monopolistic power that FSU may be able to wield.

3 METHODOLOGY

3.1 Agent-based Computational Economics

Traditionally, economic modeling has been done by attempting to aggregate the effects of the numerous agents within the system. Static assumptions about these economic agents define the model, and changes within the system do not affect the agents' behavior. Tesfatsion describes the need for a more dynamic approach that incorporates a realistic two-way feedback between the micro and macrostructure, which until recently has been pragmatically impossible:

> The most salient characteristic of traditional quantitative economic models supported by microfoundations is their top-down construction. Heavy reliance is placed on externally imposed coordination devices such as fixed decision rules, common knowledge assumptions, representative agents, and market equilibrium constraints. Face-to-face interactions among economic agents typically play no role or appear in a form of highly stylized game interactions. In short, economic agents in these models have little room to breathe (Tesfatsion, 2002).

To accommodate the need to model feedback between agents and the environment or system in which they exist, researchers can "build" a system from the ground up by creating many dynamic representative agents. These agents, each with their own set of rules and behaviors, are allowed to communicate and interact just as economic agents do in the real world. The microeconomic interactions of these agents gives rise to an observable macrostructure whose components are generally referred to as emergent phenomena. The close interconnection between microstructure and macrostructure becomes apparent using this type of simulation, which can be viewed as a result of the inherent two-way feedback between the two structures. Because the individual agents can be modeled to follow simple rules and behave in an easily described manner, the implementation of even complex systems can become relatively trivial. The introduction of exogenous components is equally simple, and stochastic modeling[9] does not require complex statistical derivations, although analysis may.

Modeling a global market for GHG emissions lends itself well to this type of simulation because of the nature of the market players: there are too many players to be modeled as a simple oligopoly or monopoly, but players have too much of a market share to expect a competitive outcome. The complexity of both definition and description of this intermediate case makes generalization of this scenario nearly impossible; thus, analytic results are not available. Other studies have partially represented these characteristics by concentrating on modeling the suppliers. Löschel and Zhang investigate the scenarios in which 1) FSU and EEC act as a cartel (restrict supply in a coordinated effort to maximize profit), 2) FSU and EEC behave non-cooperatively to find a Nash equilibrium (find a supply level that is profit maximizing given the behavior of the other supplier), and 3) FSU acts as a monopolist (unilaterally restricts supply to maximize profit). These models, however, treat the other regions as price takers, an unrealistic assumption given that these regions are few in number and thus each possess a significant market share. A similar study examines a market where FSU is the only strategizing agent and investigates the scenarios in which FSU 1) is an unrestricted supplier of its hot air, 2) is a "myopic" monopolist (restricts supply to maximize profit within the current time period), and 3) is an intertemporal monopolist (restricts supply to maximize total profit over the next thirty years) (Bernard, et al, 2003). Again, the other regions behave simply as price takers. Both of these studies use top-down, constraint-based models, where the various scenarios correspond to different constraints.

[9] Stochastic modeling is performed by adding variability, or randomness, to certain model parameters.

This study hopes to make a contribution to global GHG emissions market modeling by simulating a market in which all players are strategizing and profit maximizing within a non-cooperative environment. The model uses elements of both bottom-up and top-down modeling, using an agent-based simulated market based on the former to construct a trading game that is deterministic but computationally complex. The game is deterministic because the outcome is based entirely on exogenous initial parameters. Because the process of finding this outcome is logistically complicated and computationally intensive, the agent-based computer model is indispensable.

With Annex-I countries divided into six independent trading regions, directly solving for a Nash equilibrium[10] is a difficult task. Instead of attempting to fit a well-known market model, such as a monopoly or a Cournot duopoly, in this study no assumptions about outcome are made. The regions are allowed to strategize and trade, and the emergent market outcome is observed. From this market outcome, hypotheses about the structure of the market that contributed to this result can be inductively reasoned. While pure top-down modeling uses theory about market structure to estimate deductively the market outcome, an agent-based approach uses the resultant market outcome to estimate inductively the market structure. It is this agent-based simulation technique that allows the model to include strategizing behavior of not just one or two players, but for all six trading regions.

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[10] A Nash equilibrium is a stable system in which each player has an optimal strategy given the strategies of all other players, i.e. no player want to change its strategy.

3.2 Discrete Event Simulation

The computer model is a multi-agent system built within a discrete event simulation framework[11]. This object-oriented framework, written in C++, allows “models” to interact with each other at discrete time events. The models in this emissions market are *Country* (representing an autonomous trading region), *Market*, and *World*. Each of these object types has associated behavior in the form of methods, and each instance of one of these objects has associated state in the form of variables. Within this basic object-oriented programming paradigm, objects are designed to represent a generic agent, and instantiation of that object creates a specific agent with its own state data as well as the generic behavior. For instance, the *World* object represents the governing board of the emissions market, such as the United Nations, and has the ability (behavior) to open and close a market, and contains (state data) a list of participating *Countries*.

All of these representative objects are also finite-state machines (FSMs): each instance is always currently in one of a finite number of states, which can change when triggered by transition events. Behavior is based on state, and transitions can occur internally or externally. An internal transition occurs when an agent's behavior decides to change its own state, and an external transition occurs when an outside agent interacts with the agent, thus changing its state. Figure 4 describes the FSMs for the *World*, *Market*, and *Country* objects, as well as the interactions between them. Each ellipse represents a state, and the

[11] While a discrete event simulation framework is used, the computer model used is not technically considered a simulation. More precisely, the model is a deterministic system that uses multi-agent or object-oriented techniques for ease of implementation and analysis. While this technique could be considered Computable General Equilibrium modeling, the bottom-up construction used is significant and distinguishing, justifying the emphasis on the object-oriented, discrete event simulation framework used. The term simulation in this paper will be used in the loosest sense to refer to the deterministic, multi-agent modeling technique used.

arrows represent the transitions between these states. External transitions, labeled EXT, are the way in which agents interact with each other. An arrow that points from one type of object to another represents an external transition where an agent is forced to act by the intervention of another agent. Transitions can also occur internally, indicated by arrows contained within the bounds of the object, when an agent has an action to perform at a specified time.

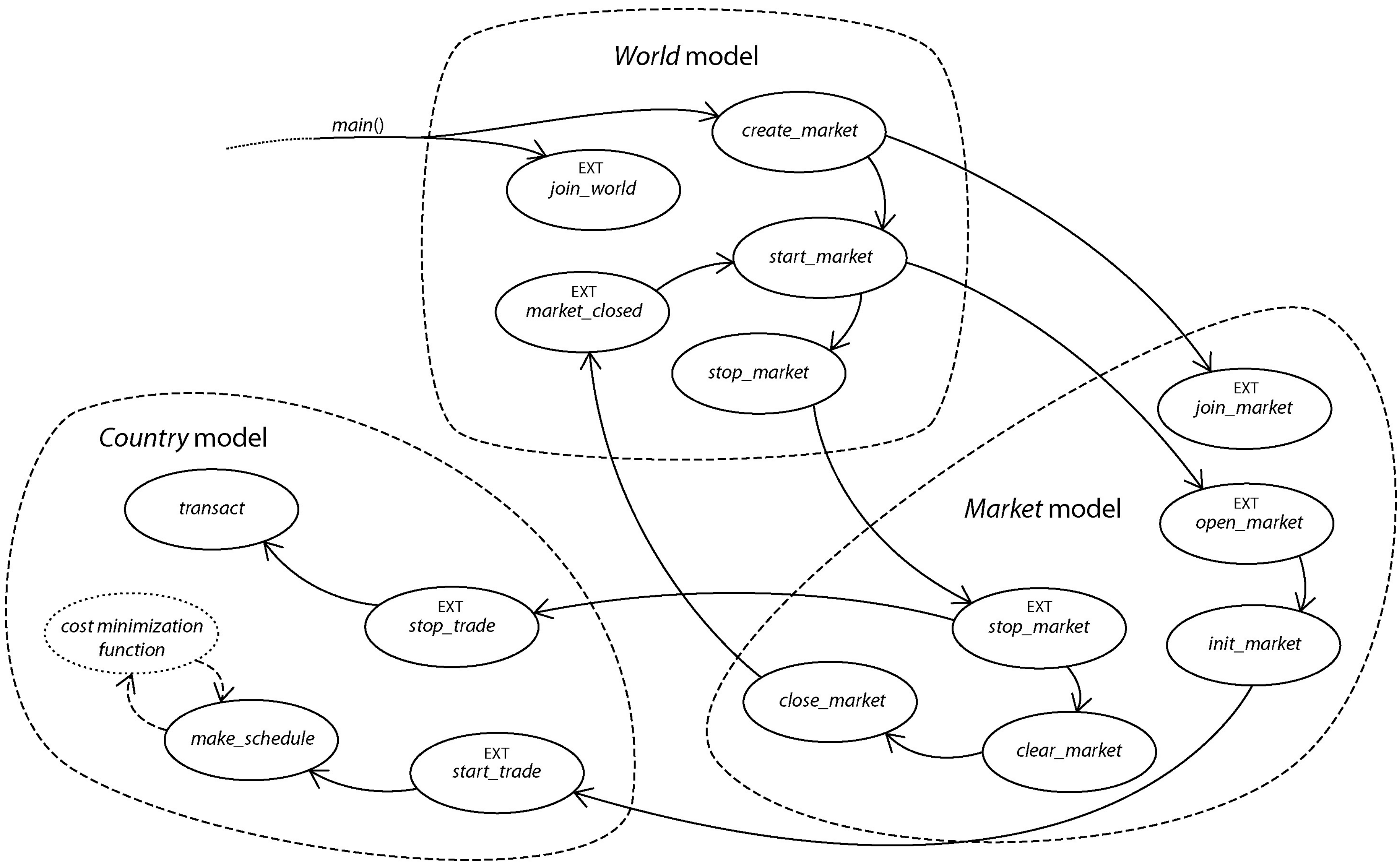

Figure 4. Finite-state machines and interactions for the *World*, *Market*, and *Country* objects.

A discrete event simulation operates by ordering the agents according to the time of their next transition, allowing each agent to perform its event at the appropriate time and then reinserting it in the queue in the appropriate location. Agents may have multiple FSMs, and each agent has a state transition and time associated with each internal FSM. This allows all agents to have the opportunity to operate in the correct order without ever having multiple agents transitioning simultaneously, e.g. each event occurs independently within a discrete time system.

The aforementioned method of simulation is well-suited to model a market in which bidding is not time-critical to the outcome. In other words, the model assumes that all players have sufficient time to strategize before they place their bid. This is the same as a market in which each player has an unlimited amount of time to strategize before bidding, and in which the market will clear and close before the commodity (in this case pollution permits) is needed by the purchasing agent. It is a reasonable assumption that the market resulting from the Kyoto Protocol would be of this nature.

3.3 Market Structure

Within this simulation, the market is implemented as a discrete call market, a structure that has gained popularity within financial markets due to its compatibility with computerization (Economides, Schwartz, 1995). The call market is an auction method that uses aggregation to find market supply and demand curves, which are then used to find a market price that maximizes trading volume. Volume maximization occurs at the intersection of the supply and demand curves, which is equivalent to finding a price that best equates aggregated buys and sells (Economides, Schwartz, 1995). The call market is well-suited for an electronic trading system because finding a market clearing price can be an algorithmically tedious task if many traders are involved. Centralization is a necessity for a market using this framework; a market controller or specialist (whether human or computer) must be aware of all bids and offers and ultimately decree a market clearing price.

While the ultimate Kyoto market will probably use a structure similar to that of a standard financial market, for convenience and generality the type of call market used in this simulation is a modified version of the sealed bid/offer auction, using a continuous schedule of bids rather than discrete price/quantity bids. In the traditional discrete case, used by the U.S. Treasury, bids and offers are accumulated over a fixed time horizon and then ordered by price (Economides, Schwartz, 1995). The highest bids are matched with the lowest offers until the remaining bids are higher than the remaining offers, at which point a market clearing price is determined. This standardized system works well in a highly liquid market for securities, and the nature of a market for GHG emissions suggests that permit trading would occur in a similar fashion for a limited period at the beginning of each emissions period, most likely on an annual basis. Each country will determine its bid or offer based on the MAC facing that country. Because the MAC function is determined by the coefficients $\hat{\alpha}$ and $\hat{\beta}$ of the quadratic form $P = \hat{\alpha}A^2 + \hat{\beta}A$, it is quite natural to use an analogous form to represent a bid/offer schedule relating price to quantity (see Figure 5). In order to make quantity a function of price, the equation is solved for A using the positive root[12]: $A = \frac{-\hat{\beta} + \sqrt{\hat{\beta}^2 + 4P\hat{\alpha}}}{2\hat{\alpha}}$. In order to represent a bid/offer schedule, however, the price must

[12] Even though β may be negative (as is the case for OOE), all MAC curves have a positive derivative over the relevant domain of A, thus assuring that the above solution for A is positive for the relevant range of prices and is the appropriate result from the quadratic formula.

be related to the quantity of permits desired for purchase or sale, not the quantity of abatement A. The quantity of permits desired for sale Q (where a negative value for Q represents the quantity of permits desired for purchase) is the difference between a country's quantity of abatement for a given shadow price and their abatement requirement q: $Q = A - q$. To distinguish the bid/offer schedule from the MAC function, the former will be determined by the coefficients α and β, and the true cost parameters of the latter will remain $\hat{\alpha}$ and $\hat{\beta}$. Using this new notation, a bid/offer schedule, which yields the quantity of permits desired to be sold for a given price, results from solving the two above equations for Q:

$Q = \frac{-\beta + \sqrt{\beta^2 + 4P\alpha}}{2\alpha} - q$. This form of bidding allows each country to submit a single schedule, completely described by α, β and q, and an appropriate transaction will occur at any market clearing price without bid resubmission or multiple trades. Also, each country can be either a supplier or a demander, depending on the market clearing price. The critical price P_0 is determined by q: $P_0 = \alpha q^2 + \beta q$.

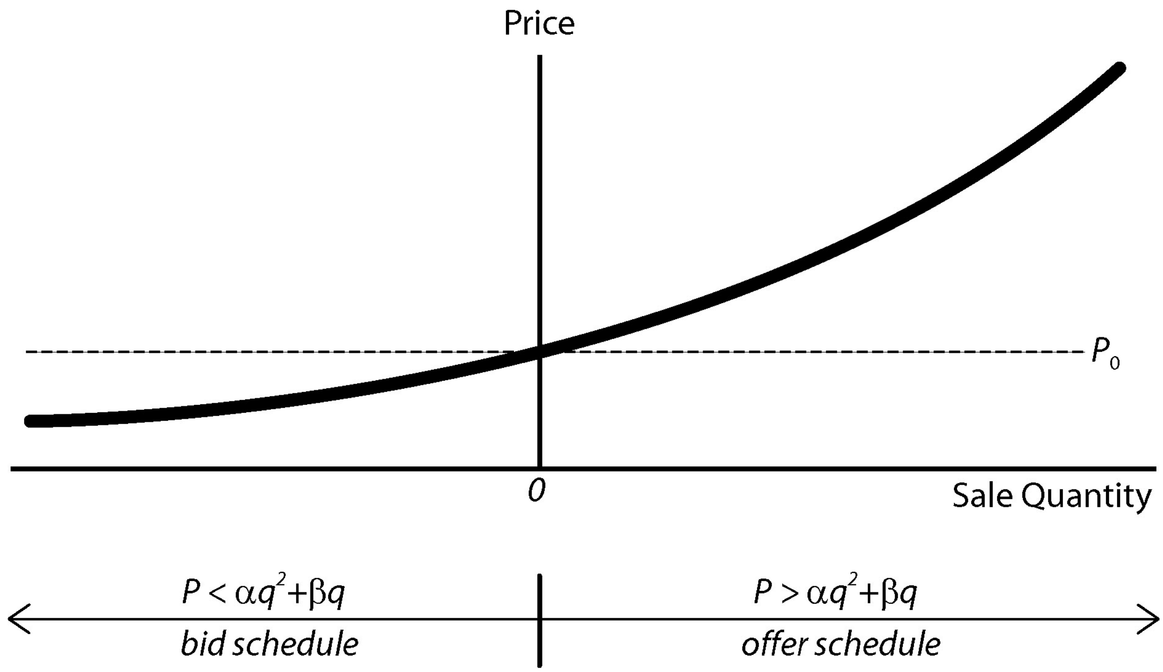

Figure 5. A bid/offer schedule.

3.4 Market Price Determination

Because the bids and offers are represented as continuous functions and not as discrete price/quantity pairs, the simple method of ordering the submissions by price and matching buyers to sellers is not applicable. Solving the system of equations to find a price that maximizes trading volume may be possible but is a complicated task. A numerical method seems more appropriate given that an exact price is not required and computational efficiency is not a foremost concern with only six trading regions being modeled.

After each of the k regions has submitted its bid/offer schedule (i.e. α_i, β_i and q_i for region i, $1 \le i \le k$), the market supply and demand are determined by the k system of equations

$$Q_1 = \frac{-\beta_1 + \sqrt{\beta_1^2 + 4P\alpha_1}}{2\alpha_1} - q_1$$
$$\vdots$$
$$Q_k = \frac{-\beta_k + \sqrt{\beta_k^2 + 4P\alpha_k}}{2\alpha_k} - q_k$$

where P is the market clearing price that minimizes $\left|\sum_{i=1}^{k} Q_i\right|$. For a given price p, Q_i is positive for a seller and negative for a buyer. If the sum is greater than zero, the quantity supplied is greater than the quantity demanded, thus p is too high to maximize trading volume. Conversely, if the sum is less than zero, p is too low. These properties are a consequence of downward sloping market demand and upward sloping market supply curves resulting from continuously increasing MAC curves. The model takes advantage of this outcome and determines the market clearing price by performing a binary search[13] on P using a reasonable limit for the upper bound on the price. The algorithm performs the search until a precision of 10^{-4} on P is reached.

[13] A binary search is a guess-and-check method of searching in which the search space is halved after each iteration. The result is an algorithm that takes on the order of the $\log_2(n)$ iterations, where n is the size of the input.

3.5 Model Progression

3.5.1 Direct Bidding

The simulation is first run without any strategizing on the part of the trading regions, and each region submits bid/offer schedules that reflect their true MAC curves. While this outcome is the most efficient outcome possible with the information given, its real-world efficiency is a function of the accuracy of the MAC curves. These results are similar to those done in other studies and help to confirm the correctness of the bottom-up simulation.

3.5.2 Stochastic Bidding

To observe the effects of imperfect information, the simulation is run with stochastic MAC curves, i.e. a region is able to see its MAC function parameters with only a certain degree of clarity. This loss of clarity is introduced by adding a random distortion to the $\hat{\alpha}$ and $\hat{\beta}$ values estimated in the EPPA model. Each trading period, a new distorted MAC curve is constructed for each region and the market is cleared using these schedules. The distortion to the $\hat{\alpha}$ and $\hat{\beta}$ values occurs at a percentage σ such that the coefficient is scaled by $1+\sigma r$, where r is a uniformly distributed random number between –0.5 and 0.5. The model is run using various values for σ to see the effects on market outcome with MAC curve variability.

3.5.3 Strategic Bidding

Each trading period a region must submit a binding bid/offer schedule that will determine transaction quantities when the market clearing price is determined. During the first trading period, each region submits schedules that represent their true costs, just as in the direct bidding model. Once the market is cleared and the market is reopened for the next period, regions are allowed access to the aggregated market supply and demand curves from the previous period in order to strategize for the current period submission[14]. A player strategizes by adjusting their previous period's schedule such that the market outcome, given the supply and demand of the rest of the market, yields the lowest possible total cost. In other words, after each trading period the player reflects on the market outcome and searches for an α and β which would have yielded an optimal result and uses these values in the subsequent bid/offer schedule submission. Under the assumption of profit-maximizing agents, optimality is minimization of total cost, which is the sum of permit costs and abatement costs. Permit costs are simply the negative of the quantity of permits sold times the market price, $PC = -Q \cdot P$, thus costs are negative if permits are sold. Total abatement costs can be calculated by integrating over the country's MAC curve from zero to the total amount of abatement, $q + Q$:

$$TAC_{q+Q} = \int_0^{q+Q} (\widehat{\alpha}A^2 + \widehat{\beta}A)dA = \left[\frac{\widehat{\alpha}A^3}{3} + \frac{\widehat{\beta}A^2}{2} \right]_0^{q+Q} = \frac{\widehat{\alpha}(q+Q)^3}{3} + \frac{\widehat{\beta}(q+Q)^2}{2}$$

[14] Disclosing market demand and supply information is another way in which the market structure of this model is disparate from a traditional sealed bid/ask auction.

where Q is the quantity of permits sold and q is the abatement requirement. The cost savings CS from trade is the difference between the total cost, $TAC_{q+Q} + PC$, and the cost of abating the full abatement requirement q (see Figures 2 and 3):

$$CS = TAC_q - (TAC_{q+Q} + PC) = \left(\frac{\widehat{\alpha} q^3}{3} + \frac{\widehat{\beta} q^2}{2}\right) - \left(\frac{\widehat{\alpha}(q+Q)^3}{3} + \frac{\widehat{\beta}(q+Q)^2}{2}\right) + P \cdot Q$$

Recall that $\widehat{\alpha}$, $\widehat{\beta}$, and q are constant for the purposes of this model, thus countries strategize by only changing α and β, which affect Q and P.

While directly solving for an optimal α and β is an algebraically complicated task, numerically solving for these values is a computationally intensive task. The numerical method used in this model makes some assumptions about the characteristics of α and β in order to minimize the cost of calculation, but does so in a way that is rationally justifiable within the context of the market. Because a numerical search for α and β must place some reasonable bounds on the search space, α is constrained to a percentage increase or decrease of its previous value, i.e. region i's submission for period two, α_{i_2}, will remain within ε percent of the submission from period one, α_{i_1} : $(1-\varepsilon)\alpha_{i_1} < \alpha_{i_2} < (1+\varepsilon)\alpha_{i_1}$. With these bounds on α, the search is performed iteratively by incrementing through a uniformly spaced, discrete search space for α. The resolution at which α is searched is determined by the size of this spacing: the smaller the spacing, the more precise the results. Thus, if α is searched at a resolution of $\phi >> 1$, this space between test values for α will be of size $\frac{\alpha}{\phi}$[15] (see Figure 6).

[15] Another technique for searching over the range of possible values for α is to increase the search resolution ϕ as the bounds on the search space for α is iteratively constricted. While this multi-pass method of search is computationally more efficient, a single-pass method is used for simplicity of demonstration of correctness and ease of implementation.

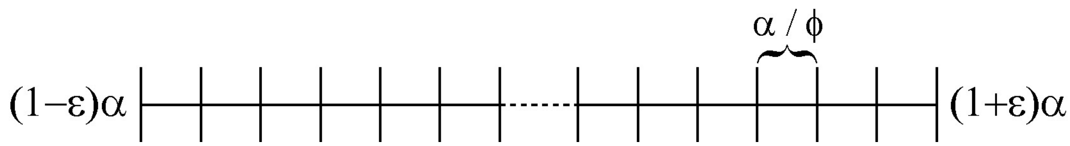

Figure 6. The discrete search space for α, where each tick is a test value.

For each value of α in the search space, an optimal value for β is found. This is done by starting with the previous period's submission value for β, calculating the total cost, and then incrementing β and repeating the process until the total cost for the current α-β pair is higher than the total cost for the previous α-β pair. The same search is then performed by decrementing β. Thus when the search using a specific α is completed, an α-β pair is found that is local optimum for that given α. The search continues for all linearly spaced α over the above defined-range and an α-β pair is found that yields a global optimum. It is important to note that for each α-β pair that is tested during the search, the market clearing process is simulated by a region using the original schedules of the other regions from the previous trading period and a schedule representing the test α-β pair.

Within the context of this study, it seems appropriate to show the correctness of this algorithm using a qualitative argument. The first important observation is that each bid/offer schedule, when expressed as a function of quantity, is continuously increasing at an increasing rate (the function's second derivative with respect to quantity is positive) over the relevant range of quantities, directly reflecting MAC functions with an adjustment made to the quantity axis (see Figure 5). This means that when aggregated, the resulting market schedule is also continuously increasing at an increasing rate. This result essentially describes a downward sloping demand curve and upward sloping supply curve. First a constant α as a region searches for the schedule that would have minimized their costs in the previous trading period. As β is incremented, the price is higher for every quantity value, thus causing an increase in market demand, from *D* to *D′*, and a decrease in market supply, from *S* to *S′*, having an upward effect on market price, from *P* to *P′*, and an ambiguous effect on the quantity of permits sold (see Figure 7). Referring to the total cost function above, this increase in a region's β, *ceterus paribus*[16], has an ambiguous effect on total cost, as both $P \cdot Q$ and TAC_{q+Q} either increase or decrease. The shape of the marginal abatement cost curves (increasing at an increasing rate) has two effects on the total cost function: total abatement costs increase at an increasing rate, and demand and supply shifts have diminishing returns on $P \cdot Q$. The result is that total cost, $TAC_{q+Q} - P \cdot Q$, will eventually be increasing. An analogous result holds for a decrease in β. This reveals that for a given α, the algorithm will find the α-β pair which minimizes cost.

[16] "all else being equal"

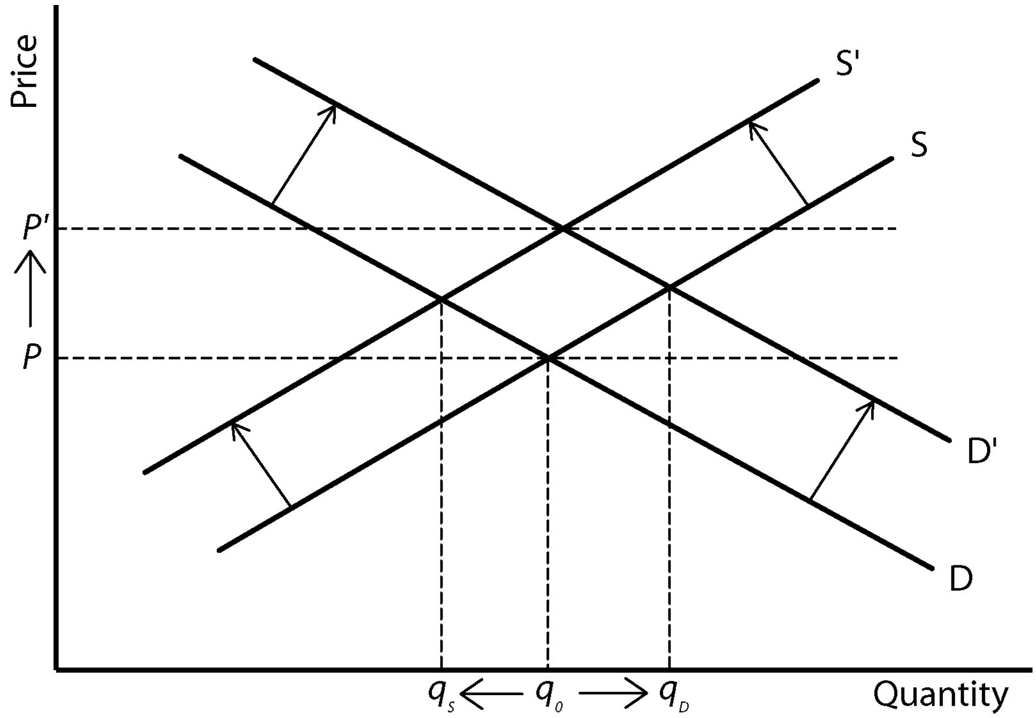

Figure 7. The shifts in supply and demand resulting from an increase in β.

In the search for the global optimum, the algorithm searches over a finite range of values for α, at each value finding the local cost minimum. The global minimum is selected from this list of local minimums. The result is that the α-β pair that the algorithm yields will be a global optimum with some level of precision only if the true global optimum has an α value within the range of the static search space, determined by the input parameter ε. The motivation for this constraint, besides reducing computational complexity, is that trading regions will be risk-averse: they will not choose to vary their bid/offer schedule greatly from one period to the next for fear of a severely disfavorable outcome. The bid/offer schedule a region will submit after strategizing is optimal only if all other regions do not change their schedules, an unreasonable assumption. Thus regions are not fully confident in their bid/offer schedules, making the submission of an only slightly modified schedule a conservative or risk-averse action. Similarly, if all regions are allowed to strategize, a region will assume that while a market exploitation existed last period, that vulnerability will be discovered by other regions as well, reducing the effectiveness of market manipulation in the next period. Consequently, it may be advantageous to understate this derived optimum so as not to "overshoot" the true optimum. Furthermore, because the market is allowed to evolve and repeat many times as the market equilibrates, regions have multiple chances to adjust their bid/offer schedules[17]. While the approach to equilibrium is affected by the constraint on the range of α, regions can iteratively approach any positive value they choose, i.e. a region is not constrained within an infinite-horizon bargaining game.

Two other motivations for the bounds on the search space for α, determined by ε, exist: α cannot take on a negative value, and multiple optimal α-β pairs may exist. The first condition is an obvious consequence of the form of the bid/offer schedule: negative values for α would result in a nonsensical schedule. As mentioned above, the lower bound on α is $(1-\varepsilon)$ times the previous value for α, thus α is guaranteed to be positive for $\varepsilon < 1$. The second concern, that the optimal bid/offer submission is not unique, is a result of the method of strategizing used by the regions. Without concern for the specifics of derivations, assume there exists an α and β that yield a known optimal market price, P, and transaction volume, Q, for a region. This means that the following equation is satisfied, assuming critical price P_0 and abatement requirement q:

$$P = \alpha Q^2 + \beta Q + P_0 = \alpha Q^2 + \beta Q + (\alpha q^2 + \beta q) = \alpha(Q^2 + q^2) + \beta(Q + q)$$

[17] The general term for an equilibrium resulting from this sort of iterative game is a non-cooperative open-loop Nash equilibrium (Castelnuovo, et al, 2003).

Because a country would not purchase more permits than are needed to meet their abatement requirement entirely through import, $(Q+q)$ will always be positive. Observing the quadratic form of the bid/offer schedule, it is expected that for a given *P*, *Q*, and *q*, there exist many α-β pairs that satisfy this equation, thus the existence of multiple solutions to the optimization problem. This multiplicity can be viewed as the result of a tradeoff between α and β: for a given *P*, *Q*, and *q*, a higher value for α will require a lower value for β in order to satisfy the equation $P = \alpha(Q^2 + q^2) + \beta(Q+q)$. Solving for α, a linear relationship is obtained: $\alpha = \frac{P - \beta(Q+q)}{(Q^2 + q^2)}$. Thus, if the optimal price *P* and quantity *Q* are known for a given region, the locus of optimal α-β pairs is revealed.

With a locus of α-β pairs that minimize costs, the process for selection of an α-β pair must involve more than simply a least-cost search. Avoiding assumptions about a region's preferences concerning the tradeoff between α and β, a simple choice behavior is to select one of these optima at random. Because the search algorithm uses a discrete method of searching, the introduction of unpredictability is an indirect result of the imprecise way in which the search spaces for α and β are traversed. Recall that the optimal value for α, α', is searched for over the range $(1-\varepsilon)\alpha^* < \alpha' < (1+\varepsilon)\alpha^*$ at an interval of size $\frac{\alpha^*}{\phi}$, where α^* is the previous period's submission for α. This means the search space is made discrete at a resolution of ϕ. Similarly, the search space for the optimal β, β', is divided in the same fashion using the same resolution ϕ, although the search space is unbounded. The result of these two discrete search spaces is the aggregate search space pictured in Figure 8, where each intersection on the grid represents an α-β pair that will be tested for optimality[18]. If the line represents the array of points that minimizes costs, the search may never find a precise value for the α-β pair that corresponds to an optimum. Instead, as the search approaches and crosses the line of optimal solutions, an α-β pair is found that closely approximates a true optimum. The closer this find is to the line, the closer this value represents a true optimum, thus the residual is dependent on the position of the grid. This residual, decomposed and labeled in the magnification of Figure 8, is determined by the interaction of the line of optimality and the grid parameters ε and ϕ. It is certainly not random but it can be viewed as a pseudo-random value seeded by ε and ϕ. Although the quality of this random variable is almost certainly considered poor by most standards, the preferences of the regions are unknown, thus this model is not contingent on quality randomness.

[18] More precisely, these vertices represent points of possible search. Recall that the search for β' stops once points of increasing cost are reached, thus eliminating the need to check many of the points.

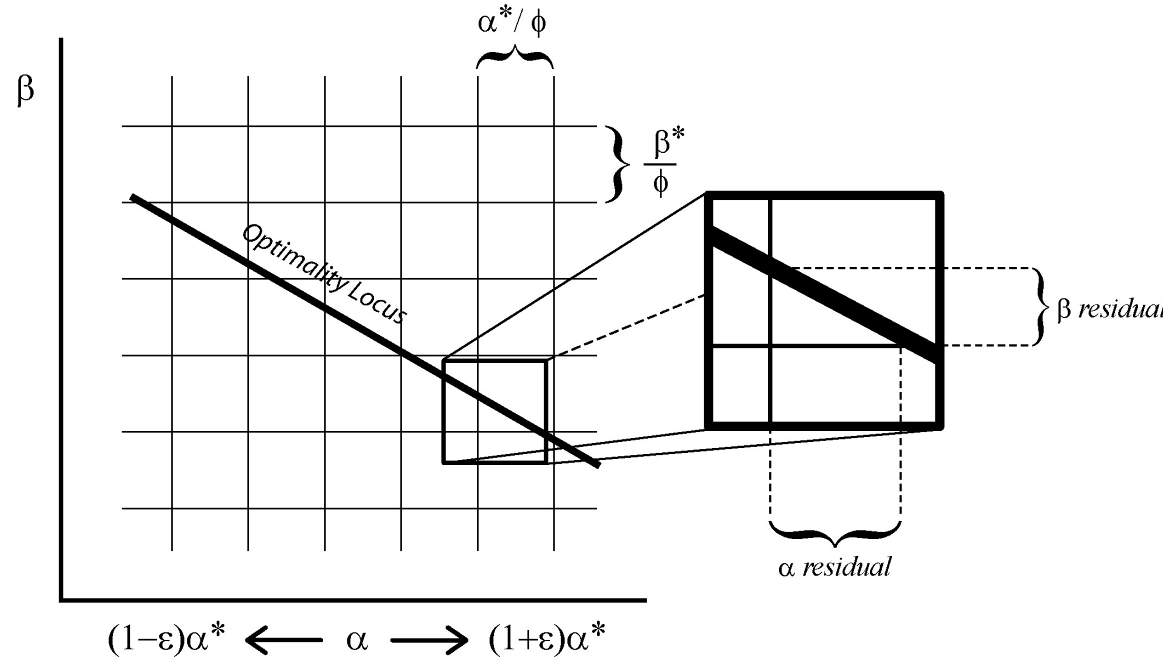

Figure 8. Interaction of the search space and the optimality locus.

3.5.3.1 Monopoly and Monopsony

If not all regions are allowed to strategize, the result is a market in which the strategizing players are able to wield market power and manipulate the market in their favor. Those regions not allowed to strategize continue to submit their true MAC function as their bid/offer schedule, i.e. these regions are simply price takers. Because other studies have concentrated on this genre of trading scenarios, this study will test these types of market structures as a comparison. Much attention has been given to FSU's large market share, which could lead to a monopolistic outcome (Bernard, et al, 2003; Löschel, Zhang, 2002). This structure is tested by allowing FSU to be the only strategizing region, giving it monopoly power as the only major supplier. Turning the tables, the monopsonistic[19] market is tested by allowing only the major buyers (USA, JPN, and EEC) to strategize, while all the other regions, including FSU, are forced to be price takers. This monopsonist simulation is repeated with only the top two buyers (JPN and EEC) as strategizing agents. While not the classical form of monopsony, treating a group of two or three regions as a single buyer is reasonable given the fact that there is essentially only one supplier and thus the regions have the same motivation: even though they are competing for the same permits, they still have incentive to lower market demand and consequently market price. The smaller regions are not allowed to strategize, but even if they were, they are assumed to not have enough market power to significantly influence the result. Hot air is included in both of these scenarios to reflect the increase in market supply awarded in the Marrakesh Accords as a concession to Russia. The monopoly results should be amplified from this inclusion. While the theoretical and experimental outcomes for both the monopoly and monopsony structures are predictable, they cogently reveal the motivation for the full-strategizing case that follows.

3.5.3.2 Full-Trade, Full-Strategizing

After reviewing the outcomes from monopolistic and monopsonistic modeling of an emissions market, it becomes apparent that there is a need for a more inclusive market simulation. In order to address this deficiency, a market with full trading and full strategizing is simulated. As described above, each time the market is cleared, players search for an α-β pair that would have minimized their costs in the previous trading period. This α-β pair is

[19] A monopoly is market with a dominant seller. A monopsony is a market with a dominant buyer. These terms will often be used to refer to the less extreme scenario in which a player or players has partial monopoly or monopsony power, perhaps better termed an oligopoly or oligopsony.

used for their bid/offer schedule submission in the subsequent period, and the simulation repeats in this manner indefinitely. With a potential monopolist and monopsonist, the market may exhibit characteristics of what is known as a bilateral monopoly, which will be explored later. It is important to reiterate that with full strategizing, all regions have some market power, i.e. no regions are price takers.

3.5.4 Various Strategic Scenarios

Using the strategic bidding described above, many market scenarios can be examined. The simulation will be rerun with the exclusion of the U.S., as well as with the inclusion and exclusion of a hot air allowance for FSU. These results reveal how FSU's market power varies depending on U.S. involvement, as well as the effects of an allowance to sell cost-free abatement.

4 RESULTS

4.1 Direct Bidding

The market outcome with no-strategy full-trading between Annex-I countries was consistent with the results from the EPPA model from which the MAC parameters were borrowed for this study (Ellerman, Decaux, 1998). The results for the four combinations of hot air and USA inclusion/exclusion are reported in Table 1[20]. As predicted, FSU was a major seller, accounting for 94% of sales in the full-trading case, and JPN, EEC, and USA were major buyers. In the case with USA, a major demander, excluded and FSU's supply was increased by inclusion of hot air, the market price was 36.5% lower and FSU became the sole supplier of permits. The result from this no-strategy trading round represents the most efficient outcome possible for the given MAC curves because each region submitted bid/offer schedules that reflected their true costs. Each region submitted a bid/offer schedule (their true MAC curve) such that permits would be purchased or sold up to the point where the market price was equal to the shadow price of abatement, thus equating the MACs for all trading regions. The gains from trade were high for both FSU and JPN because of the significant discrepancy between the MAC for each country and the market clearing price. With each permit purchased representing a reduction in a region's domestic abatement requirement, trading was shown to reduce significantly implementation costs for the Kyoto Protocol, providing higher gains from trade for countries that had a high differential between market price and MAC.

[20] The results of the no-strategizing, or efficient, market scenario will be used in the analysis of the various strategizing scenarios. The tables with these strategizing outcomes will express values in terms of the nominal increase or percentage increase of specified variables from the no-strategizing outcome.

Table 1. Efficient market (no-strategizing) outcomes for various scenarios.

Full trade

	Hot air excluded		Hot air included	
Price	149.60		126.84	
Volume	270.68		350.59	

	Quantity Sold	Total Cost	Quantity Sold	Total Cost
USA	-62.4	36409.3	-105.6	34504.9
JPN	-88.2	16919.2	-94.8	14837.3
EEC	-87.7	25320.1	-107.3	23104.0
OOE	-32.4	11443.6	-42.9	10588.1
EET	16.6	4378.5	5.7	4633.3
FSU	254.1	-25298.5	344.9	-33820.1
Total	**0.0**	**69172.2**	**0.0**	**53847.5**

USA excluded

	Hot air excluded		Hot air included	
Price	128.59		95.02	
Volume	242.08		313.35	

	Quantity Sold	Total Cost	Quantity Sold	Total Cost
USA	N/A	N/A	N/A	N/A
JPN	-94.3	15003.2	-104.8	11664.9
EEC	-105.7	23290.9	-137.9	19215.4
OOE	-42.1	10662.7	-59.3	8968.5
EET	6.5	4622.6	-11.4	4549.3
FSU	235.5	-20153.3	313.3	-23337.3
Total	**0.0**	**33426.1**	**0.0**	**21060.8**

4.2 Stochastic Bidding

When regions did not know their MAC with perfect clarity but bidding was still done without strategy, the result was, of course, a market with price and volume variability. The standard deviations for various levels of parameter distortion, expressed as the percentage σ

for samples of one thousand runs are listed in Table 2. The results represent the expected variability in the market price and volume given a certain level of error in parameter estimation. Unsurprisingly, the standard deviation of the market price and volume were linearly related to the percentage of parameter distortion, σ, of the individual regions' MAC curves. Because the result with the inclusion of MAC uncertainty caused variability but did not affect market outcomes on average, ignorance of the stochastic aspect of MAC estimation does not detract from the general results within the iterative strategizing simulation that follows.

Table 2. Standard deviation of market outcome with stochastic MAC parameters.

	Standard Deviation	
σ	**Price**	**Volume**
0.00	0.000000	0.000000
0.01	0.189509	0.353013
0.05	0.985151	1.881569
0.10	1.908639	3.756285
0.15	2.846678	5.530583
0.20	3.802235	7.342337
0.25	4.616204	9.184679
0.50	9.485029	18.638122
0.75	14.124112	28.337680
1.00	19.320104	36.805925

4.3 Strategizing

Using the direct bidding simulation, regions had no flexibility in their method of trading; thus an equilibrium was reached immediately that represented the efficient, total cost minimizing outcome. When countries were allowed to strategize between trading periods and submit a bid/offer schedule that reflects this strategizing, market equilibration was not guaranteed. The results from the simulation, however, reveal that the market price and volume did stabilize sometime after the sixth to eighth trading period for most runs. This was an important result from a system that could in theory oscillate indefinitely as market players adjust and readjust their bids in response to other players, as could be the case when more than one region was allowed to strategize.

As described above, the bounds and resolution parameters for the α-β optimization search were an important consideration for the outcome of the simulation. The resolution parameter, ϕ, was calibrated by testing various values and observing the market evolution. Values of 1000, 2000, 4000, and 6000 for ϕ were tested, and the results showed that the outcomes for the latter two were nearly identical to each other but disparate from the former two. For this reason, all runs were performed using a ϕ value of 4000, as a higher value imposed undue computational complexity without any real increase in precision. The parameter specifying the upper and lower bounds for the search on α, described as the percentage ε, had notable effects on the outcome and will be discussed as the they present themselves.

4.3.1 Monopolistic Strategizing

With FSU as the only region allowed to strategize, the outcome was consistent with the basic theory of monopoly: the dominant seller restricted supply such that the market price was increased and the quantity sold was reduced. In general, the ability of a monopolist to increase profits through supply restriction is based on the responsiveness of the market in terms of quantity demanded resulting from changes in price. This responsiveness is commonly measured using a units-free value called price elasticity of demand, which, for a given demand, is the absolute value of the ratio of the percentage change in quantity to the percentage change in price: $\left|\frac{\%\Delta Q}{\%\Delta P}\right|$ (Parkin, 1999). The higher this ratio, the more elastic the demand, and thus the quantity demanded is more sensitive to changes in price. With only one seller in a monopoly market, a change in quantity supplied changes market price, marginal revenue, and marginal cost. A monopolist's profit is maximized by setting the price such that marginal revenue, the change in revenue from selling one more unit, is equal to marginal cost, the change in cost from selling one more unit. This profit is affected by the price elasticity of market demand: a market with higher responsiveness to price changes is more difficult to exploit. In fact, a monopolist within a market with a price elasticity of demand less than one, called inelastic demand, receives unambiguous gains from increasing the market price. Price elasticity of demand is thus a valuable indicator of potential ability of a monopolist to cause inefficiency within a market through exertion of market power. For example, it is easy to imagine how effective a monopolist would be that had complete control over the supply of water, as water has demand that is almost perfectly inelastic.

The price elasticities of demand, and their associated quantities, are listed for individual regions and the aggregate market demand in Table 3 for both the perfectly competitive market and the monopoly outcome resulting from strategizing by FSU[21]. As expected, JPN had an inelastic demand because of its high MAC, and USA had a relatively elastic demand because of its low MAC. The market elasticity, falling somewhere in between

[21] The market elasticities were calculated using the price and quantity changes between periods one and two for the perfectly competitive scenario and between periods nine and ten for the monopoly scenario. Thus, these values only approximate the price elasticities of the demand represented as a continuous function. The elasticities for the individual demanding regions, however, were calculated using the continuous version of price elasticity of demand, $\frac{dQ}{dP}\frac{P}{Q} = \frac{P}{Q\sqrt{\beta^2 + 4P\alpha}}$, where quantity Q is a function of price P describing a region's bid/offer schedule (Wolfstetter, 1999).

these two extremes, was only slightly elastic. This suggests that the monopolist, FSU, should have a significant degree of market power. In the study, FSU was able to increase the market price by 11.8%, reducing its sales by 17.6% (see Table 4). The overall market volume decreased significantly, as expected, by 15.3% (see Figure 9). By raising the market price, and thus reducing the quantity demanded, FSU increased the price elasticity of demand: at a higher price, demanders more readily substituted away from permits by performing more abatement domestically.

Table 3. Price elasticities of demand before and after FSU strategized.

	Perfect competition		**FSU as monopolist**	
	Elasticity	**Quantity**	**Elasticity**	**Quantity**
USA	2.3780	-105.6	3.4648	-76.7
JPN	0.4004	-94.8	0.4513	-90.4
EEC	1.0614	-107.3	1.2802	-94.2
OOE	1.4219	-42.9	1.7985	-35.9
Market	**1.3442**	-350.6	**1.6812**	-297.1

Table 4. Effects of strategizing within a market where FSU was sole strategizing agent.

Market Price	141.86	Market Volume	297.11

			Increase from perfectly competitive case			
	α(%)	**β(%)**	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
USA	N/A	N/A	28.9	27.4	1367.2	4.0
JPN	N/A	N/A	4.4	46.5	1391.5	9.4
EEC	N/A	N/A	13.1	12.2	1513.1	6.5
OOE	N/A	N/A	7.0	16.4	591.6	5.6
EET	N/A	N/A	7.3	128.6	-140.5	-3.0
FSU	104.68	-0.05	-60.8	-17.6	-2447.7	-7.2
Total					**2275.2**	**0.4**

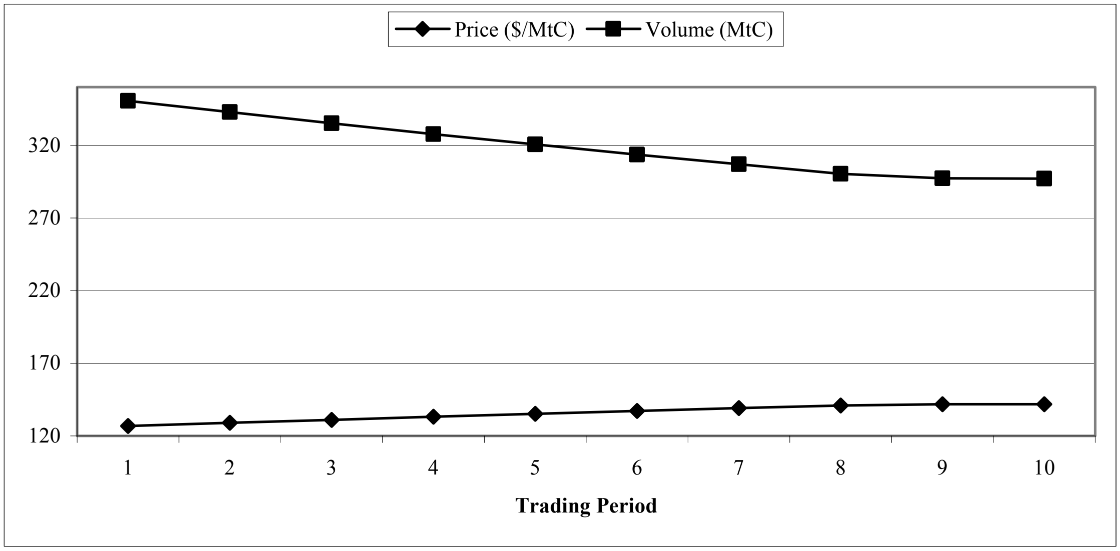

Figure 9. Market price and volume evolution when FSU acted as monopolist.

This monopoly result is comparable to the myopic monopolist outcome based on the same EPPA model, where price was estimated to increase by about 21% (Bernard, et al, 2003). It is critical to note that the results were based on slightly different MACs, devaluing a quantitative comparison. Both results demonstrate one of the basic results of a monopoly: while the monopolist increases profits by reducing supply, the result is a divergence from the competitive and efficient outcome. FSU increased the market price by increasing its bid/offer schedule, thereby closing the gap between marginal revenue and marginal cost (see Figure 10); trading volume was reduced below its efficient level and a deadweight loss occurred. Deadweight loss is the difference between the cost of implementation with competitive trading and the cost of implementation with FSU restricting supply, i.e. the cost of monopoly. While FSU was able to increase profits by 7.2% through strategic manipulation, global implementation costs increased by 4.2% from the least-cost outcome.

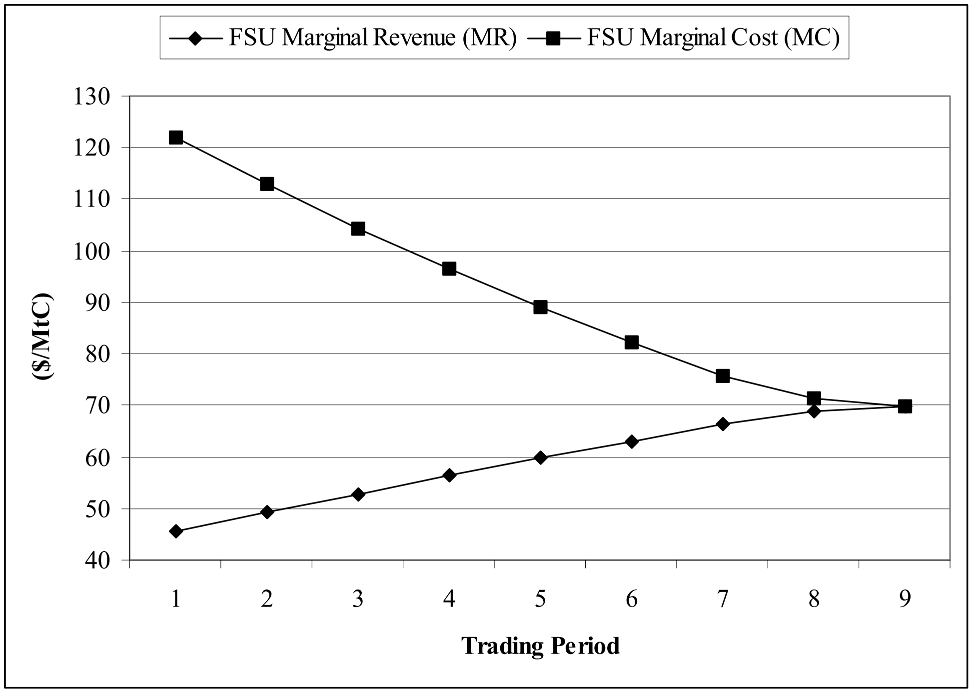

Figure 10. Convergence of FSU's marginal revenue and marginal cost as a result of increasing supply restriction in each trading period.

The monopolistic outcome stabilized after about nine trading rounds. Using an ε value of 10%, FSU simply chose to increase α by the maximum allowable amount after each period, while β was left mostly unchanged. Because other regions could not respond to the market manipulation by FSU, the value of ε affected only the speed at which an equilibrium was reached; raising ε should not significantly affect the outcome, just decrease the number of iterations before convergence.

4.3.2 Monopsonistic Strategizing

Converse to the monopolistic outcome, the result of allowing USA, JPN and EEC to act non-cooperatively as a dominant buyer was consistent with the expected monopsonistic outcome: demand was decreased in order to lower prices, resulting in a lower trading volume. FSU was the only supplier because EET became a demander after the decrease in price. With a calculated price elasticity of supply of 0.34 at the perfectly competitive quantity, FSU seemed to be susceptible to market manipulation by the monopsonistic buyers. An inelastic supply meant FSU would not respond greatly to changes in price caused by demand changes. These results confirm some degree of monopsony. The three countries, accounting for 88% of all purchases in a competitive market, were able to reduce the market price by 11.4%, thus reducing trading volume by 5.5% (see Table 5 and Figure 11). When only JPN and EEC were considered, accounting for 65% of all purchases in a competitive market, the effectiveness of the monopsony was decreased, as expected: market price was reduced by only 3.8%, resulting in a meager 2.0% decrease in trading volume (see Table 6). The results were similar to the monopolistic case, where inefficiency caused by strategizing agents decreased their costs but increased total implementation costs.

Table 5. Effects of strategizing within a market where USA, JPN, and EEC acted as a non-cooperative monopsonist.

Market Price	112.39	Market Volume	331.14

	Increase from perfectly competitive case					
	α(%)	**β(%)**	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
USA	-9.4	-7.3	20.7	19.6	-1116.9	-3.2
JPN	-15.9	-12.8	1.0	1.1	-1353.2	-9.1
EEC	-9.5	-38.9	6.7	6.2	-1429.0	-6.2
OOE	N/A	N/A	-7.2	-16.7	-671.1	-6.3
EET	N/A	N/A	-7.4	-1.3	28.8	0.6
FSU	N/A	N/A	-13.8	-4.0	4884.6	14.4
Total					**343.2**	**1.1**

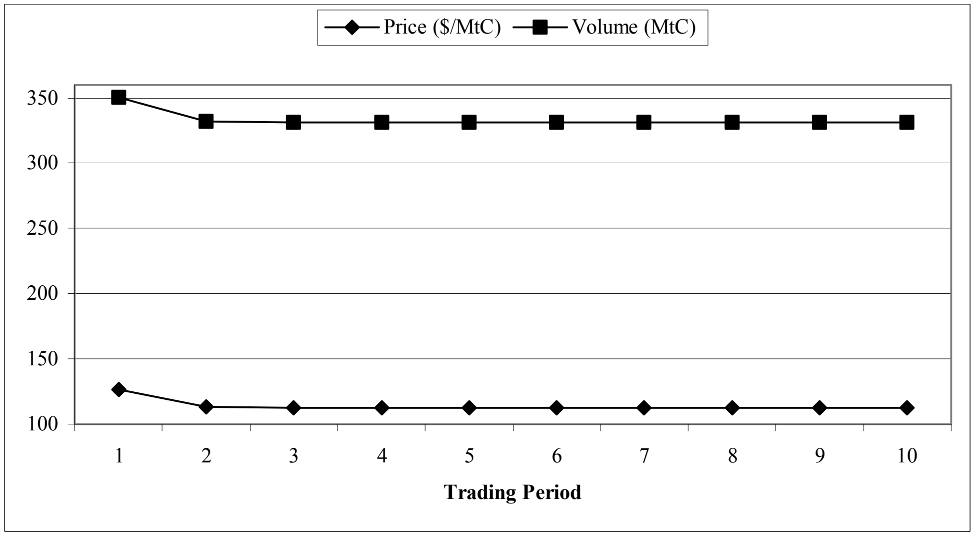

Figure 11. Market price and volume evolution with USA, JPN, and EEC acting as a non-cooperative monopsonist.

Table 6. Effects of strategizing within a market where JPN and EEC acted as a non-cooperative monopsonist.

Market Price	122.07	Market Volume	343.74

			Increase from perfectly competitive case			
	α(%)	β(%)	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
USA	N/A	N/A	-9.5	-3.8	-525.7	1.5
JPN	-0.04	-32.4	4.0	4.2	-405.5	-2.7
EEC	-0.02	-5.9	14.7	13.7	-318.8	-1.4
OOE	N/A	N/A	-2.4	-5.4	209.9	2.0
EET	N/A	N/A	-2.4	-42.4	21.3	0.5
FSU	N/A	N/A	-4.5	-1.3	1632.9	4.8
Total					**614.1**	**1.1**

Despite the use of the same ε value, market equilibration was much quicker than in the monopolistic case, occurring after three or four rounds in both cases. This was a result of the fact that, unlike FSU in the monopolistic case, the buyers varied β to manipulate the market and changed α only slightly. Since the search does not impose a constraint on variations of β, the globally optimal bid/offer schedule for these regions was approached rapidly. It is interesting to note that even though three countries were strategizing in a non-cooperative manner, equilibrium was reached almost immediately. The significance of the disparity in α-β manipulation between the dominant buyer and dominant seller cases will be discussed subsequently.

4.3.3 Full-Trade, Full-Strategizing with USA Involvement

When all regions were allowed to strategize and use their market power to manipulate the market to the best of their abilities, the result was a market price and volume that stabilized after about eight trading periods. The behavior of the players was as expected: demanders attempted to reduce the market price by understating their MACs, and suppliers attempted to increase the market price by overstating their MACs. A player's ability to manipulate the market traditionally is based on its market share; thus regions with a small market share should have little ability to affect price and should be essentially price takers. Regions with a large market share, however, are expected to make use of this power by submitting bid/offer schedules that understate their costs if the region is a buyer or overstate their costs if the region is a seller. It is important to keep in mind the two factors that determine market share: the shape of the region's MAC curve and the disparity between the market price and the region's MAC. The greater the disparity between market price and MAC, the more a region will gain from trade. The greater the rate of increase of the MAC curve (represented by a higher α), the smaller the quantity required to close the gap between the MAC and market price, meaning the region has less to gain from trade. Consequently, market share is not the only factor that determines the degree to which a region will manipulate its bid/offer schedule. While it seems natural to assume that regions with a large market share will significantly adjust their bid/offer schedules to affect the market outcome, it is incorrect to assume that regions with small market shares are unable to manipulate the market. For instance, a region that has a large abatement requirement but has a MAC curve such that the shadow price of marginal abatement is close to market price will have a small market share. The "shallow" shape of the MAC curve, however, implies that small changes in market price result in large changes in trading volume, amplifying the region's potential to capture significant gains from trade (see Figure 12). The increase in market share for purchasing region *i*, $q_{i_0} - q_{i_1}$, resulting from a decrease in market price from P_0 to P_1 is much greater than the increase in market share for region *j*, $q_{j_0} - q_{j_1}$. The differential between these market share changes can be seen to be a result of the relative shape of the MAC curves and the abatement requirements, q_i and q_j. This result reveals that a region's ability to manipulate the market and increase gains from trade is not proportional to its market share but is a function of the shape of the region's MAC curve and its abatement requirement. While no region has the extreme characteristics of the example diagrammed in Figure 12, this concept encourages downplay of the relationship between market share and market power, an important consideration when analyzing the results of the full-strategizing runs.

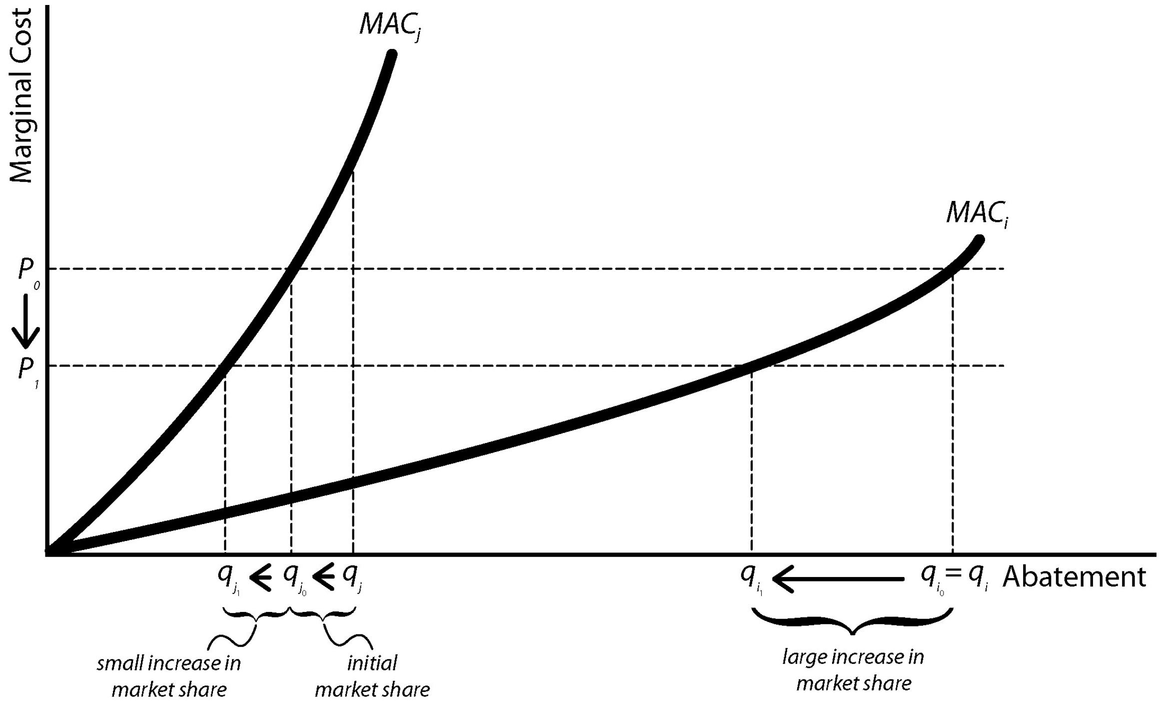

Figure 12. Effects of the abatement requirements and the shape of the MAC curve on market share changes.

The results of full-strategizing with all six regions, hot air excluded, for an ε value of 10%, which were very similar to the 20% case, show that neither buyers nor sellers were able to achieve monopolistic or monopsonistic goals (see Table 7). The most apparent indicator of this was that the market price, while dropping by 5.4% in the second period, increased in the subsequent five periods for a negligible overall increase of 0.6% (see Figure 13). The fact that the market price did not change significantly does not suggest that the market was unaffected by strategizing. While the price manipulating objectives were not achieved by either side, divergence from efficiency was significant with volume declining in each of the first six periods for an overall decrease of 18.8%. This resulted in an aggregate cost increase of 2.6% as all players, with the exception of EET, incurred losses from strategizing. It seems that the sellers' (primarily FSU) effort to raise the market price was almost perfectly offset by the buyers' (primarily USA, JPN, and EEC) effort to lower the market price. With all regions having misrepresented their costs, trading no longer equalized their true MACs. While regions were obviously better off than before trading, the result was not as cost-effective as it was with perfect competition.

Table 7. Effects of strategizing within a full-trade, full-strategizing market with no hot air.

Market Price	150.45	Market Volume	219.77

	Increase from perfectly competitive case					
	α (%)	**β (%)**	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
USA	3.4	-86.5	25.6	41.0	213.5	0.6
JPN	5.7	-20.5	5.6	6.4	127.2	0.8
EEC	0.7	-57.3	16.2	18.5	223.3	0.9
OOE	-12.5	102.2	3.5	10.8	38.7	0.3
EET	2.7	0.2	-1.3	-8.1	-11.0	-0.3
FSU	55.4	0.2	-49.6	-19.5	1173.2	4.6
Total					**1764.9**	**2.6**

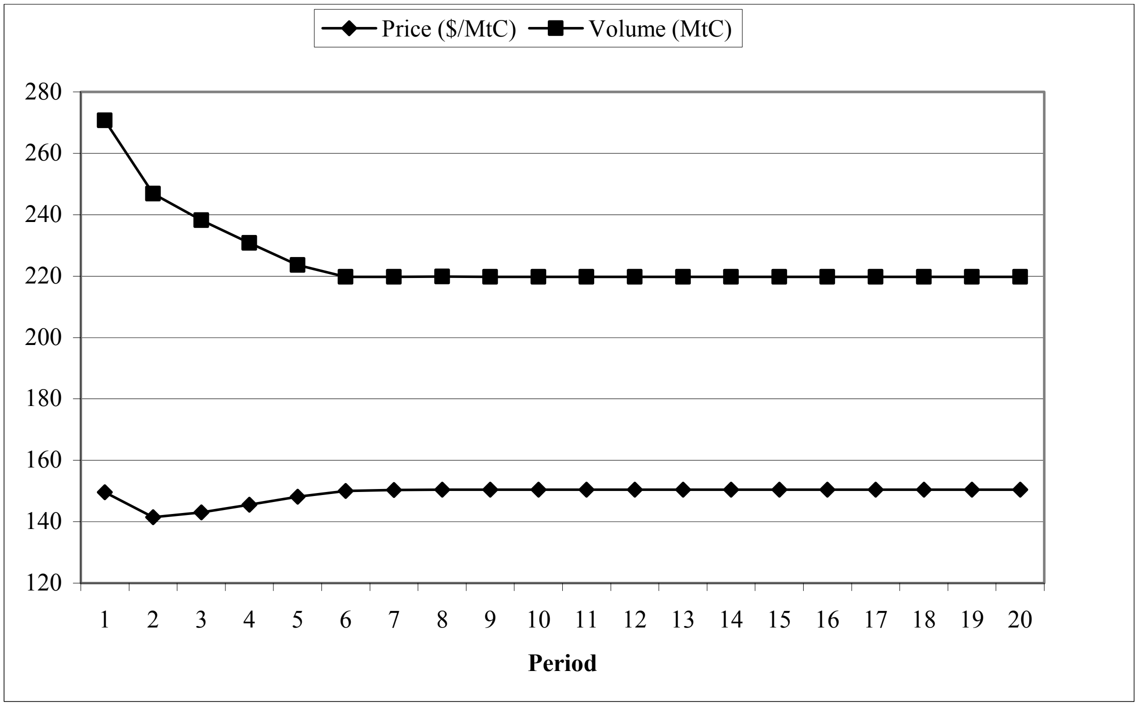

Figure 13. Market price and volume evolution with full-trade, full-strategizing, with no hot air.

As this study has investigated trading scenarios resembling monopoly and monopsony, it seems appropriate in the full-strategizing case to address the theory underlying their amalgamation: the bilateral monopoly. In a bilateral monopoly, a monopoly seller faces a monopsony buyer. Unlike a monopoly or monopsony, which are termed ultimatum games where the dominant player announces a price and the price taking counterpart makes sale or purchase decisions accordingly, a bilateral monopoly relies on a bargaining process to determine market outcome (Wolfstetter, 1999). The most common example, and the application receiving the most analytic attention, is labor negotiations between a major employer and a labor union. When each party has equal market power but neither party has the ability to make an ultimatum, the result is an infinite-horizon bargaining game in which offers and counter-offers are made until an agreement is reached (Wolfstetter, 1999).

To find an efficient outcome in the simple bilateral case, the point that maximizes joint profit is chosen. Joint profit is maximized at the quantity where the buyer's marginal cost function, $\frac{dC}{dQ}$, intersects the seller's marginal revenue function, $\frac{dR}{dQ}$, where C is the supplier's cost, R is the demander's revenue, and Q is quantity (Siegel, Fouraker, 1960). This quantity is denoted by Q^* in Figure 14. The profit-maximizing quantities for monopoly, Q^{MP}, monopsony, Q^{MS}, and perfect competition, Q^{C}, are also included for comparison. Although for these latter three cases the resultant market price is known, in the bilateral monopoly case the price is indeterminate because variability in price is simply a profit tradeoff between players, falling somewhere between P_1 and P_2. The socially common and "fair" solution is one in which a price is chosen such that the joint payoff is split equally between the two players.

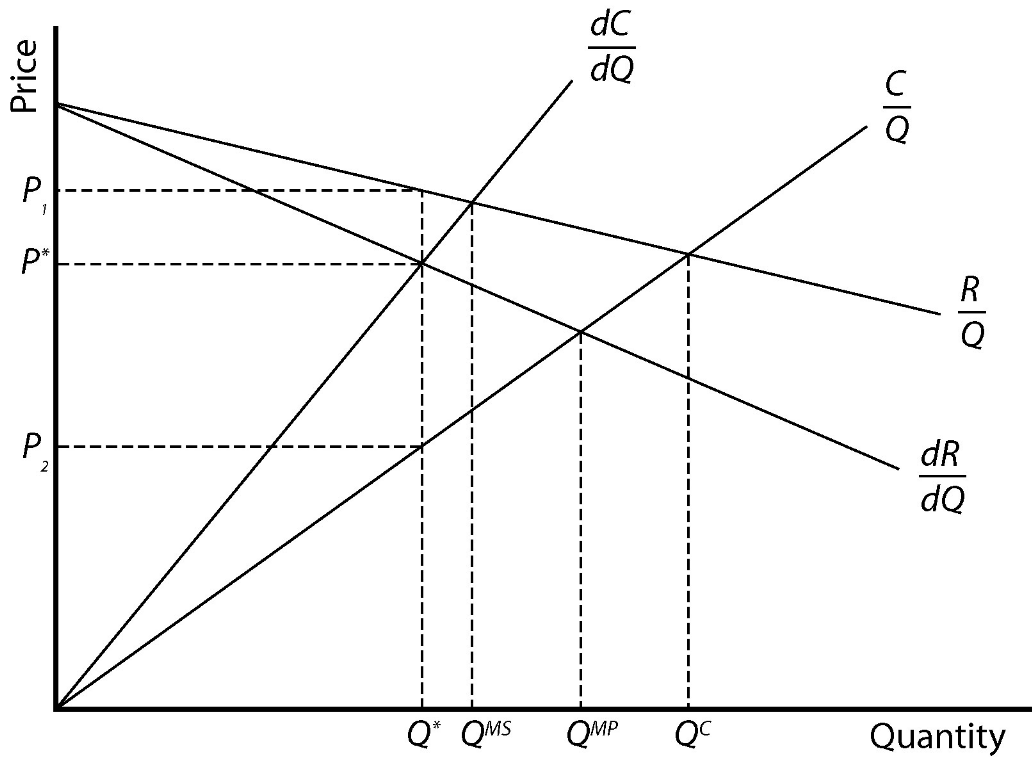

Figure 14. Market structure within a bilateral monopoly.

The applicability of the theory of traditional bilateral monopoly to this simulation is supported by the results of the full-strategizing outcome. Market supply was restricted and market demand was lowered, resulting in an inefficiently low trading volume. The upward and downward pressures on price caused by the manipulation of the sellers and buyers, respectively, counter-balanced each other and price remained fairly constant. Even though there was no single monopsonist, as is the case for a true bilateral monopoly, and the buyers acted in a non-cooperative manner, the results suggest that they were still able to combat successfully the supply-restricting monopolist FSU.

While the full-strategizing, no hot air case equilibrated to essentially the same outcome with ε values of 10% and 20%, the market evolved slightly differently in the two cases. As aforementioned, the 10% case experienced a 5.4% drop in market price in the second period before increases in the subsequent five periods, resulting in market stabilization in the seventh period. In the 20% case, market price fell by only 4.0% in the second period, and stabilization was reached in the fifth period. This was an illustrative example of how the bounds on the search for an optimizing α affect market outcome and the speed of approach to convergence. The reason for the price drop in the second period was that FSU was unable to adjust α enough to find its global cost minimization. Instead, the dominant seller was forced to submit a bid/offer schedule that did not restrict supply sufficiently. The buyers, on the other hand, were able to find the submission values that represented a personal global cost minimization because their total market share was distributed over several bid/offer schedules, increasing the flexibility of their aggregate submission. In effect, FSU had to "catch-up" to the more flexible buyers, as was evidenced by the persistent increase of α by the maximum allowable amount in the rounds prior to stabilization. As predicted, a higher value for ε led to a faster market convergence. The assumption that bounds on α are reasonable for risk-averse traders did not have significant effects on the market outcome, when considering the 10% and 20% cases.

To help test the validity of the assumptive constraint on the variability of α between trading periods, the simulation was run using a large ε of 50%. While the market price and volume were similar to that of the 10% and 20% cases, the behavior of the regions in the approach of this equilibrium was quite different (see Table 8 and Figure 15). One interesting outcome was the extreme reduction of α by the purchasing regions, with USA, JPN, EEC, and OOE reducing the value nearly to zero. This behavior was coupled with a universal increase in β by these same regions, making the result difficult to analyze. Surprisingly, FSU lowered its α value as well while drastically raising its β value. While a pseudo-random selection of an optimal α-β pair was previously assumed, these results suggest that the selection process may have had a random element to it, but it was definitely biased toward a small value for α. Another interesting result of the 50% case was the decrease in total cost resulting from bid/offer schedules that were nearly linear. This may have been a result of the speed at which equilibrium was approached: while stability was not reached faster in this case than the 10% or 20% cases, regions quickly approached and overshot the equilibrium, as is shown by the oscillating price and volume values in Figure 16. This suggests that a large value for ε may result in decreased stability, increasing market fluctuation and increasing time until a strong equilibrium is reached.

Table 8. Effects of a large bound on α (50% value for ε) within a full-trade, full-strategizing market with no hot air.

Market Price	149.47	Market Volume	238.70

Increase from perfectly competitive case

	α(%)	**β(%)**	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
USA	-94.6	578.3	17.4	-28.0	78.5	0.2
JPN	-31.0	5.0	3.1	-3.5	6.5	0.0
EEC	-83.5	272.0	9.5	-10.9	45.5	0.2
OOE	-96.3	-1134.7	1.8	-5.7	-0.1	0.0
EET	-61.7	1371.3	-1.0	-6.3	3.2	0.1
FSU	-94.2	15128.9	-30.9	-12.2	566.7	-2.2
Total					**700.3**	**1.0**

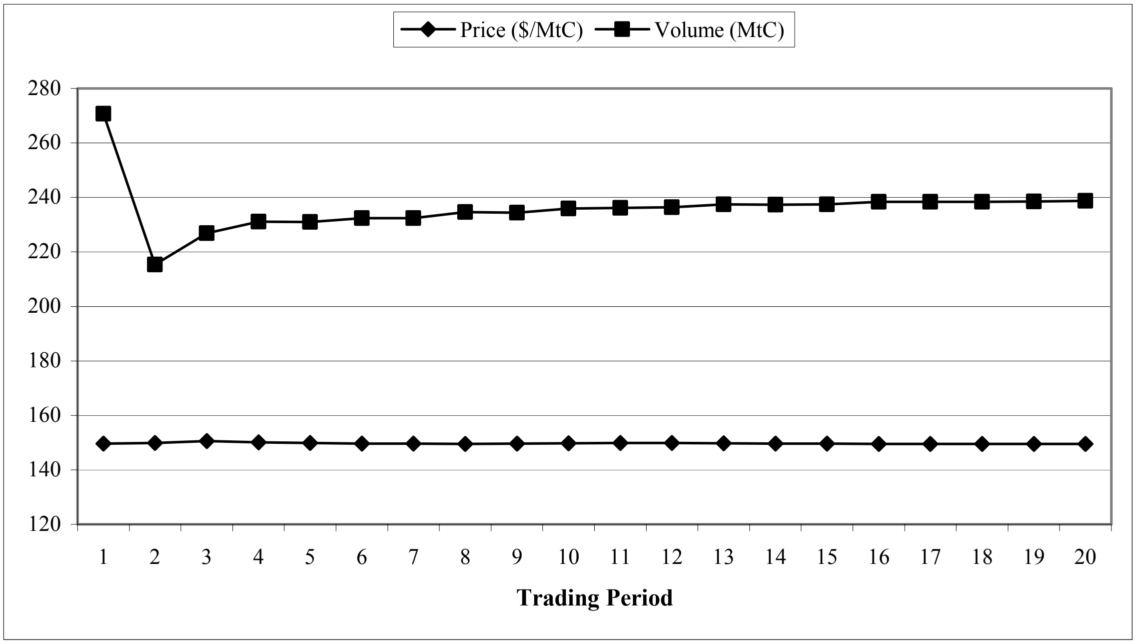

Figure 15. Market price and volume evolution with full-trade, full-strategizing, no hot air, when a large (50%) value for ε was used.

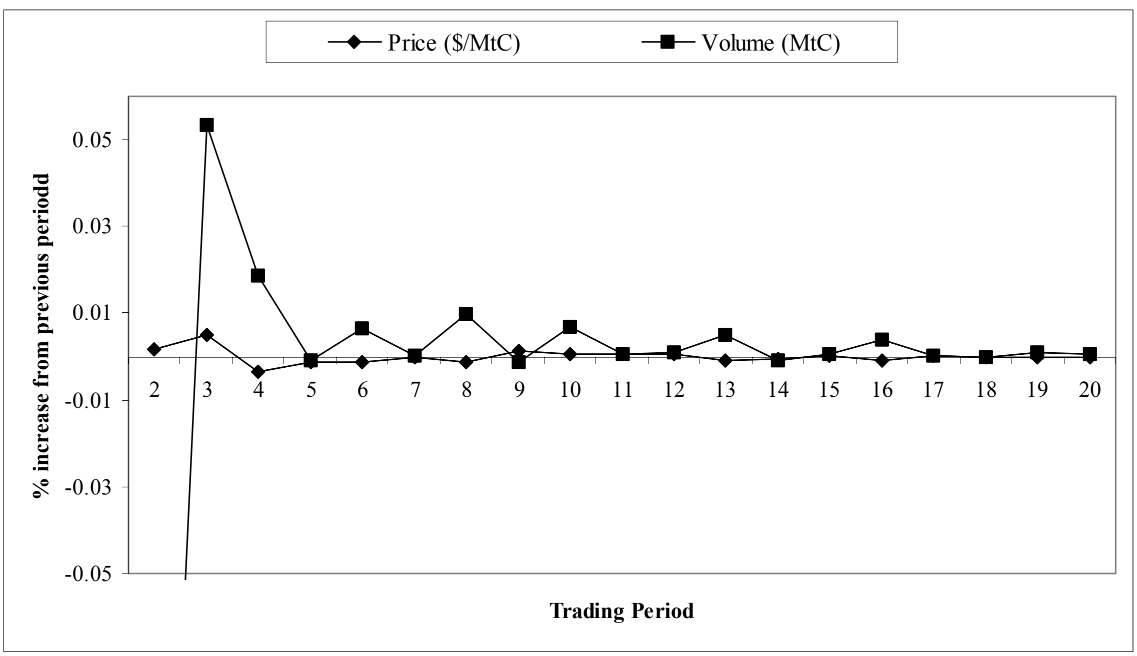

Figure 16. Market price and volume fluctuation between periods with full-trade, full-strategizing, no hot air, when a large (50%) value for ε was used.

4.3.4 Full-Trade, Full-Strategizing without USA Involvement

With the U.S. withdrawal from the Kyoto Protocol because of the “harm that this climate agreement would incur on the U.S. economy” (Buchner, 2003), the market demand for emission rights was significantly reduced. First, the no hot-air case was considered, with an ε value of 10%, and the result of the efficient outcome was as expected: the reduced demand resulted in a significant drop of 14.5% in market price over the same no-strategizing outcome with the inclusion of the U.S. For the full-strategizing case, with one of the top three demanders out of the picture, FSU was able to exert greater influence on the market price, successfully raising the price by 11.3% through strategic manipulation (see Table 9). While FSU did better when no regions were allowed to strategize when the U.S. was involved, the exclusion of the U.S. allowed FSU to increase its gains from trade by 1.6%, an indication of some degree of monopoly power. The inefficiency introduced by strategizing had substantial effects on trading volume, which decreased by 26.5%, and increased total costs by 11.3%. This result was consistent with a market of imperfect competition: the greater the market power of a single player, the greater the deadweight loss.

Table 9. Effects of strategizing on a market without USA and with no hot air.

Market Price	145.01	Market Volume	177.89

	Increase from perfectly competitive case					
	α(%)	**β(%)**	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
JPN	-2.5	-25.0	13.0	13.8	1631.2	18.4
EEC	14.9	-140.7	38.4	36.3	1978.3	16.1
OOE	-15.0	100.5	12.7	30.3	657.1	12.5
EET	5.3	-37.0	5.7	86.3	-167.6	2.5
FSU	-57.6	16888.7	-69.8	-29.7	-328.9	-3.2
Total					**3770.1**	**11.3**

In the context of a bilateral monopoly, the result of U.S. exclusion seemed to cause a divergence from the situation of equal and opposite market powers wielded by the monopolist and the non-cooperative monopsonist. While the previous result suggested that trade negotiations were truly bilateral, the reduction in the power of the monopsony created an imbalance of market power, a situation that affected the bargaining abilities of each side. Even though this scenario is not commonly addressed in the literature on bilateral monopoly, the result of the simulation suggested that an imbalance of market power simply affected market outcome in a way proportional to this imbalance. Because a unique Nash equilibrium was not guaranteed, the outcome of this five player market was difficult to predict and may have been highly sensitive to the initial parameters (Wolfstetter, 1999). In this regard, the usefulness of the bottom-up simulation was pronounced.

As in the case with U.S. involvement, the discrepancy between the runs with an ε value of 10% and 20% was negligible. Again, the value affected the speed at which the market converged, but only slightly affected the actual market outcome. Just as before, FSU increased α by the maximum allowable amount during the initial periods before stabilization was reached. This again resulted in a drop in price in the second period and FSU had to catch up in subsequent periods.

Without the ratification of the Kyoto Protocol by the U.S., a country creating 35% of all GHG emissions, the future existence of this international environmental treaty is contingent on ratification by Russia; Russian support is required to meet the emissions baseline of 55% specified in the Protocol. Russia has exploited this fact in the bargaining process at the Conference of the Parties in the construction of the Marrakesh accords, securing the right to sell its hot air (Elzen, Moor, 2002). The simulation was run using a hot air allotment of 111 MtC for FSU, as is estimated by the EPPA model (Ellerman, Decaux, 1998).

In the efficient, no-strategizing case, with the supply of permits higher compared to the case without hot air, the resultant 26.1% decrease in market price from the no hot-air case was as expected[22] (see Table 10). With the allowance for full-strategizing, the expectation that the increase in allotment to FSU would increase its market power and profits was met with a 19.8% increase in market price and a 3.2% increase in profits. While the inclusion of cost-free abatement resulted in a significant drop in market price because of the dramatic shift in the market supply, FSU was still able to increase profits by 17.5% over the no hot air case through a combination of increased revenues from sales and an increased ability to manipulate the market. The results were consistent with the predictions of a market with greater market power given to the monopolist.

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[22] As the 10% and 20% values for ε yielded very similar results, the 10% case is analyzed.

Table 10. Effects of strategizing on a market without USA and with hot air.

Market Price	114.86	Market Volume	217.99

	Increase from perfectly competitive case					
	α(%)	**β(%)**	**Quantity**	**Quantity (%)**	**Cost**	**Cost (%)**
JPN	6.9	-33.7	15.3	14.6	2148.5	10.9
EEC	11.8	-150.0	51.3	37.2	3096.8	8.5
OOE	-11.2	7.3	17.8	30.1	1125.2	6.2
EET	-48.3	922.0	10.9	96.4	115.5	-3.6
FSU	-50.9	22586.8	-95.4	-30.4	-737.8	-1.6
Total					**5748.3**	**27.3**

5 CONCLUSION

Many studies have focused on the long-term effects of market manipulation by a monopolist, but this research assumed that the rest of the market players were unable to respond and were simply price takers (Bernard, et al, 2003; Löschel, Zhang, 2002). This study relaxed this assumption by allowing all market players to strategize and submit bid/offer schedules that minimize their costs. With all players possessing some degree of market power, the result seemed to be indicative of a bilateral monopoly, where the buyers acted non-cooperatively as a monopsony power facing off against the primary seller, FSU. Further evidence suggesting this notion of dueling powers was found when the USA was excluded from trading.

Although the socio-political bargaining that is traditionally associated with a bilateral monopoly seems inapplicable within the context of Annex-I trading (Siegel, Fouraker, 1960), iterative strategizing can certainly be seen as analogous to infinite-horizon bargaining (Wolfstetter, 1999). A strategizing scenario involving six players is not guaranteed to equilibrate, but all scenarios showed market price and volume stability within six to ten trading periods. Interestingly, the strategic α and β values continued to vary for some regions several periods after the market stabilized. One explanation could be that regions' bid/offer schedules oscillated in such a way that the aggregate effect on the market was negligible. The fact that the simulation unconditionally resulted in market stability in spite of continuing bid/offer schedule variability suggests that the market equilibriums obtained in these trading scenarios were not overly sensitive to initial conditions, indicating a fairly strong equilibrium.

5.1 Policy Implications

The results of this study indicated that while FSU would have considerable effect on market outcome, especially without U.S. involvement, the combined power of the demanding countries had nearly as much manipulative ability. Previous research emphasized that FSU will be the only major seller, able to monopolize the market and dramatically reduce cost-effectiveness. With powerful buyers in the market, however, the power of the monopolist was dramatically reduced, but significant inefficiency still existed. Policy may be able to combat this inefficiency by changing the structure of the market. The allowance for hot air significantly increases supply, thus lowering the market price and total implementation costs. In effect, it increases the cap on pollution. If hot air were excluded, the effects would be twofold: 1) supply would be reduced, resulting in upward pressure on market price, and 2) FSU's market power would be reduced, resulting in a lower equilibrium market price. While the first effect reduces pollution at the price of an increase in implementation costs, the second effect increases efficiency and thus lowers implementation costs, causing a reduction in FSU's profits. Because hot air is cost-free abatement, a major player can gain significant market power with this allowance. A more cost-effective distribution of pollution permits would be to allocate this hot air to regions that have high MACs, thus reducing the market power of both the buyer and seller.

Because the results of the simulation show that significant inefficiency was introduced through market manipulation, this model should be compared with other possible distribution mechanisms. If trading were not allowed and the Kyoto Protocol acted as a

Command-and-Control (CAC) mechanism, the current specification of abatement requirements would be much more costly than any of the imperfect trading scenarios investigated in this study. Even while wielding significant market power and restricting supply, FSU still increased efficiency within the market compared to the no-trading case. Because trading is voluntary and done only when mutually beneficial to both parties, each transaction represents progress toward equalization of the trading regions' MACs. Thus, while FSU increased its own profit at the expense of raising total implementation costs, the outcome is still radically more cost-effective than the Kyoto-defined CAC allocation (see Table 11).

Table 11. Total implementation costs without trade and for various trading scenarios, all with USA involvement.

Hot air included		**Hot air excluded**	
Market type	**Total Cost**	**Market type**	**Total Cost**
Perfect Competition	53847.5	Perfect Competition	69172.2
Monopoly	54074.7	Full-strategizing	70937.1
Monopsony	54417.9	No trade	119666.5
No trade	119666.5		

One seemingly elegant method of pollution control is governmental taxation. This method relies on a bureaucratic agency to assess a fee for the use of the atmosphere as a pollution sink. While taxing marginal emissions is a theoretically efficient control mechanism, which works by charging a tax commensurate with the marginal social cost of pollution, the practical issues are insurmountable. Finding the marginal social cost of pollution, most likely an increasing, non-linear function, is impossible within our world, and thus policy makers cannot determine the socially efficient tax rate. If this rate is set too low, pollution levels will be higher than is socially optimal, having dire effects on the environment; if set too high, consumption levels will be inefficiently low. Estimation of a socially optimal total amount of pollution, while no simple task, seems much more tractable than estimating marginal social costs, making the “cap-and-trade” method of pollution control relatively attractive.

5.2 Model Performance

The bound constraints placed on α seemed to be justified both qualitatively and empirically. The results from the runs with ε set at 10% and 20% gave results that were consistent with the underlying theory and seemed more realistic than the results of the 50% case. As a form of risk-aversion, bounding the search space for α was realistic in that decision makers within a region would feel more comfortable submitting a bid/offer schedule that was similar to their MAC curve, and with multiple cost-minimizing optima, α would most likely not have to be varied significantly.

Along the same lines, the results from the 50% case suggested that the selection of an optimal bid/offer schedule was not random but biased toward smaller values for α. One area for this study to explore is an alteration of the algorithm used for determining an optimal bid/offer schedule. To make the choice of an optimal α-β pair truly random, the algorithm could be altered to perform a search for an optimal price and quantity, and then use this information to determine the linear relationship between α and β. Then a random α-β pair could be chosen, or some preference function could be constructed. These methods would not only be cheaper computationally, but would make more in-depth analysis possible.

5.3 Future Research

With the recent ratification of the Marrakesh Accords, further analysis of the market created by the Kyoto Protocol will be based on a better understanding of the market situation than previous research. As Russia's indecision has left the future of the Protocol uncertain, much political and legislative activity will undoubtedly occur between now and the commencement of the First Commitment Period in 2008. A future direction for this study would be to allow regions to further strategize within the market by making decisions about investment in pollution abatement technologies, in effect reducing a region's MAC through expenditure on capital (Castelnuovo, et al, 2003). Including endogenous technological change in this simulation would extend the model to represent a longer-term scenario, as technological change occurs at a relatively slow pace. Research has considered the effects of research and development spending on production technology and the emissions-output ratio, which could be incorporated into a strategic climate model (Zwaan, et al, 2002; Castelnuovo, et al, 2003; Löschel, 2002). Consideration of investment in technology would complicate the strategizing each region would perform, perhaps resulting in a more realistic market model.

Another area for expansion would be to include pollution permit banking within an intertemporal trading framework (Schennach, 2000). While this study focused on the iterative equilibrium of trading within a single time period, allowing countries to save permits for later use, and even borrow permits at a certain interest rate, is an area of research that has significant policy implications. Many environmental and political figures have expressed concern or even outrage at the idea of permit banking because of the possibility of abuse and problems with enforcement. Permit banking was used in the SO_2 emissions market in order to ease the transition between reduction periods.

The allowance for banking, if properly implemented, would allow countries to be more flexible in their response to changing market prices and abatement costs. If a demanding country deemed market prices too high, it would have the option to dip into their savings, or possibly take out a loan. This decision would be based on the rate of change over time of the MAC function and the risk-free interest rate (Schennach, 2000). The simple time-independent MAC functions used in this model would have to be modified to change over time. The increased flexibility afforded by banking could also allow for an increase in market manipulation. For example, FSU could increase domestic abatement and bank the remaining permits, introducing a way in which FSU could intertemporally affect the market. The combined effects of these considerations is a natural extension to this time-static model.

5.4 Final Thoughts

While the Kyoto market has many problems that will need to be addressed before the First Commitment Period, it also holds much potential to be a relatively effective way of distributing pollution rights within a world of disparate marginal abatement costs. Without the allowance for permit transference, the Kyoto Protocol would have undoubtedly higher implementation costs to the world, having undue grievous effects on consumption. The tragedy of inefficiency is unrecoverable waste because of poorly designed or implemented distribution mechanisms. Trading within the Kyoto Protocol significantly reduces this waste.

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7 APPENDIX

7.1 Kyoto Protocol

Table 12. Annex-I Countries.

Australia	Greece	Poland
Austria	Hungary	Romania
Belgium	Iceland	Russia
Bulgaria	Ireland	Slovakia
Canada	Italy	Slovenia
Croatia	Japan	Spain
Czech Republic	Latvia	Switzerland
Denmark	Lithuania	United Kingdom
Estonia	Luxembourg	Ukraine
Finland	Netherlands	United States of America
France	New Zealand	
Germany	Norway	

7.2 Regional Marginal Abatement Costs

Table 13. MAC parameters $\hat{\alpha}$ and $\hat{\beta}$ of the functional form $P = \hat{\alpha}A^2 + \hat{\beta}A$.

Region	$\hat{\alpha}$	$\hat{\beta}$
USA	0.0005	0.0398
JPN	0.0155	1.8160
EEC	0.0024	0.1503
OOE	0.0085	-0.0986
EET	0.0079	0.0486
FSU	0.0023	0.0042

Source: MIT EPPA Model (Ellerman, Decaux, 1998)

8 REFERENCES

Bernard, A., Paltsev, S., Reilly, J., Vielle, M., Viguier, L., 2003. "Russia's Role in the Kyoto Protocol." MIT Joint Program on the Science and Policy of Global Change - Report 98, Massachusetts Institute of Technology, Cambridge, MA.

Buchner, B., Carraro, C., Cersosimo, I., Marchiori, C., 2003. "Back to Kyoto? US Participation and the Linkage Between R&D and Climate Cooperation." Working Paper, Fondazione Eni Enrico Mattei (FEEM), Milan, Italy.

Castelnuovo, E., Galeotti, M., Gambarelli, G., Vergalli, S., 2003. "Learning by Doing *vs* Learning by Researching in a Model of Climate Change Policy Analysis." Working Paper, Fondazione Eni Enrico Mattei (FEEM), Milan, Italy.

Economides, N., Schwartz, R.A., 1995. "Electronic Call Market Trading." Working Paper, Journal of Portfolio Management.

Ellerman, A.D., 2000. "Tradable Permits for Greenhouse Gas Emissions: A primer with particular reference to Europe." MIT Joint Program on the Science and Policy of Global Change - Report 69, Massachusetts Institute of Technology, Cambridge, MA.

Ellerman, A.D., Decaux, A., 1998. "Analysis of Post-Kyoto CO2 Emissions Trading Using Marginal Abatement Curves." MIT Joint Program on the Science and Policy of Global Change - Report 40, Massachusetts Institute of Technology, Cambridge, MA.

den Elzen, M.G.J., de Moor, A.P.G., 2002. "Analyzing the Kyoto Protocol under the Marrakesh Accords: economic efficiency and environmental effectiveness." Ecological Economics 43, 141-158.

Grütter, J.M., 2001. "World Market for GHG Emissions Reductions." World Bank, National AIJ/JI/CDM Strategy Studies Program.

Löschel, A., 2002. "Technological Change in Economic Models of Environmental Policy: A Survey." Centre for European Economic Research (ZEW) and University of Mannheim, Mannheim, Germany. Ecological Economics 43, 105-126.

Löschel, A., Zhang, Z., 2002. "The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakech." Nota Di Lavoro 23.2002, Fondazione Eni Enrico Mattei (FEEM), Milan, Italy.

Parkin, M., 2000. *Microeconomics*. Addison-Wesley, New York.

Schennach, S., 2000. "The economics of Pollution Permit Banking in the Context of Title IV of the 1990 Clean Air Act Amendments." Journal of Environmental Economics and Management 40, 189-210.

Siegel, S., Fouraker, L.E., 1960. *Bargaining and Group Decision Making: experiments in bilateral monopoly*. McGraw-Hill, New York, 1-16.

Tesfatsion, L., 2002. "Agent-based Computational Economics." Iowa State University Economics Working Paper No. 1, http://www.econ.iastate.edu/tesfatsi/ace.htm.

Tietenberg, T., 1985. *Emission Trading, An Exercise in Reforming Pollution Policy.* Resources for the Future, Washington, D.C..

Wolfstetter, E., 1999. *Topics in Microeconomics*. Cambridge University Press, Cambridge, UK, 43-50.

van der Zwaan, B.C.C., Gerlagh, R., Klaassen, G., Schrattenholzer, L., 2002. "Endogenous Technological Change In Climate Change Modelling." Energy Economics 24, 1-19.

ONLINE REFERENCES

"Fair share of atmosphere is only solution to climate change." Institute for Public Policy Research (IPPR) website, August 7, 2003. http://ippr.org/home/index.php?table=press&id=243

"Annan hails EU ratification of Kyoto treaty on global warming." UN News Centre website, May 31, 2003. http://www.un.org/apps/news/storyAr.asp?NewsID=3821&Cr=kyoto&Cr1=

"UN environment agency welcomes Canada's ratification of Kyoto Protocol." UN News Centre website, December 19, 2002. http://www.un.org/apps/news/storyAr.asp?NewsID=5712&Cr=kyoto&Cr1=protocol