Carbon Emissions Markets: A Simulation Approach

C. Watkins

EcoCarbon Incorporated, Australian CRC for Renewable Energy (cwatkins@acre.murdoch.edu.au)
and
Department of Economics, University of Western Australia

Abstract: Since the advent of the Kyoto Protocol in 1997, increasing international attention has focused on the implications of anthropogenic climate change. In particular, consequences for the economy have dominated national debates in several industrialised countries. If the Protocol is ratified, industrialised nations will face a binding limit on their carbon dioxide equivalent (CO2-e) emissions of six greenhouse gases. National emissions quotas require countries to develop domestic emissions regulation, which, to a large extent, consist of emissions permit trading schemes. The Virtual Emissions Trading Program (VETP) is a simulation model that uses financial models to simulate a market for carbon emissions permits in which participants take on roles as emitters, sequesters, traders, and a regulator. Participants are required to meet emissions targets through investment and trading, with the object of maximising the value of their business within a given policy framework. A number of policy parameters can be manipulated to simulate various scenarios on the domestic rules which may govern a carbon constrained future. The model has implications for: (i) greenhouse gas emission policy analysis; (ii) corporate strategy development for operations within a carbon constrained future; (iii) education in the economics of market mechanisms used in constraining carbon emissions; and (iv) generation of experimental data for academic research. This paper elaborates on the VETP model and its relationship to the complex and evolving policy environment surrounding a carbon constrained future. Preliminary results from a simulation conducted with industry participants are reviewed.

Keywords: Emissions trading; Market mechanisms; Experimental economics; Greenhouse gas; Emerging markets

1. INTRODUCTION

International concerns over anthropogenic climate change have mounted substantially over recent years. In 1992, the United Nations Conference on Environment and Development, known as the Rio Summit, resulted in the United Nations Framework Convention on Climate Change (UNFCCC). The primary intent of the UNFCCC is to stabilise greenhouse gas concentrations at levels that would prevent dangerous anthropogenic interference with global climate, and it has now been signed by 186 governments. Subsequently, the third Conference of the Parties (CoP3) to the UNFCCC was held in Kyoto in 1997, and adopted the Kyoto Protocol. Under the Protocol, parties included in Annex 1 to the Convention (industrialised countries) must, overall, reduce emissions of six major greenhouse gases (GHG) by about 5% from 1990 levels by the commitment period, 2008 to 2012. Industrialised countries accepted different targets of emission reduction in order to achieve the overall emissions reduction target. The Protocol allows three flexibility mechanisms, international emissions trading, Joint Implementation (JI) and the Clean Development Mechanism (CDM), with the aim of allowing industrialised countries to achieve their emission limit at least cost to their economy. Emissions trading, particularly, is expected to reduce the cost of greenhouse gas reduction due to the large international range in marginal abatement cost curves, and the prospects for comparative advantage.

Australian negotiators successfully argued for special consideration due to the energy intensive nature of the economy and the land use implications of the Protocol for the country. Australia's target is 8% above 1990 levels, which is argued to be a substantial reduction on business as usual emissions forecasts. Presuming legally binding national carbon constraints do come into effect, Australia must deal with major greenhouse issues.

In early 2001, the Protocol's future was put in doubt by the US Government's decision not to ratify the treaty. However, the outcome of the recent resumed COP6 meeting in Bonn reflected the political will of European and other governments to progress the Kyoto Protocol despite the US withdrawal. The Bonn Agreement deals with key points of contention in the international negotiations, relating to financial issues, the flexibility mechanisms, compliance provisions, and land use, land use change and forestry (LULUCF). Although many details are yet to be finalised, the Agreement is likely to encourage ratification by sufficient Annex 1 countries for the Protocol to come into force, albeit without the USA.

Although some still believe the Protocol will not be ratified in its present form, the general consensus, given mounting scientific evidence of climate change, is that binding limits on emissions are inevitable, and market based mechanisms are the most efficient means of achieving these limits. National emissions quotas require countries to develop domestic emissions regulation, which, to a large extent, will consist of tradeable emissions permit schemes. Several industrialised countries have developed proposals for domestic emissions trading schemes, generally of an allowance-based type, and schemes are being, or have been, established by a number of governments including those of the United Kingdom and Denmark.

2. CARBON PERMIT MARKET SIMULATIONS

Since the inception of the Kyoto Protocol, there has been wide interest in simulating aspects of emerging carbon emission permit markets for a variety of purposes. This work has involved academic experimental economists, national and international policy makers, major national and multinational corporations, and industry groups, particularly those corporations and industries which are large emitters of greenhouse gases.

A number of important issues have been investigated in emissions permit markets. In one of the early papers published in this area, a bilateral emissions trading experiment among four Nordic countries, is analysed [Bohm 1997]. The participants were public officials or experts appointed by energy ministries. In this simulation, emissions permit prices were close to competitive equilibrium levels, with a high efficiency of allocation. Muller and Mestelman [1998] and Godley et al. [1998] found that allowing the banking of permits smooths prices over time. The authors also show that a trader who has market power in some market other the emissions market can influence the emissions market, reducing its efficiency. Thus, the introduction of emissions trading reduces the overall efficiency of the economy. However, research by Bohm and Carlén [1999] show the market power problem is not serious since many participants in the carbon market both buy and sell permits. Mizuta and Yamagata [2000] simulate a Kyoto-style international emissions trading market with 12 agents consisting of six Annex 1 countries and six developing countries for the purpose of investigating institutional issues involved in creating an international emissions market.

In an experiment using bilateral trading and double auction markets, Hizen and Saijo [2001] present results showing high efficiency under both methods of trading, and that marginal abatement costs are equalised in both cases. Prices converge to the competitive equilibrium price in the double auction market, and to a limited extent under a bilateral market. Hizen et al. [2001] focus on the effects of a non-compliance penalty, abatement irreversibility and time lags for abatement investment, factors which were precluded from the analysis in Hizen and Saijo [2001]. A new concept, "point equilibrium", is developed by the authors, in which the normative equilibrium price depends on the previous decisions of abatement investment. Their simulations show two significant patterns of price dynamics. The first pattern involves relatively low prices for emissions permits in early periods which lead to insufficient emissions reduction on behalf of suppliers of permits. Agents demanding permits conducted excessive emissions reductions immediately before the end of the simulation. This is termed the constant point equilibrium case. The second price dynamic observed arose due to the fear of non-compliance, and is referred to as the early point equilibrium price decrease case. Some subjects conducted excessive internal emissions reductions at an early stage in the simulation, and the point equilibrium price fell substantially.

A number of large scale international simulations have been conducted. The International Energy Agency (IEA) held an international simulation using 24 participants, involving representatives of 16 countries, the IEA and the European Commission [see Baron, 2000]. EcoCarbon coordinated the Australian involvement, which consisted of three private sector players and one government participant. The simulation was conducted in eight trading sessions over four weeks. A series of simulations have been conducted by Eurelectric (a union of European electricity utilities), with participants from 40 electricity utilities from 16 European countries. The Greenhouse gas and Electricity Trading Simulations 1 and 2 (GETS1, GETS2) demonstrated that the joint trading of electricity and carbon emissions instruments in a market can shift electricity production towards existing low carbon-intensity generators.

3. THE VIRTUAL EMISSIONS TRADING PROGRAM (VETP)

VETP was jointly developed by the Commonwealth Bank, IT+e, and EcoCarbon as a tool for education, corporate strategy development and research into greenhouse gas emissions permit trading. For these purposes, the emissions trading simulation model aims to provide valuable information in maximising corporate profitability under regulated emission constraints; the identification and analysis of alternative corporate strategies; the efficacy of internal abatement and external abatement via permit trading; the operational processes of allocation systems, auctioning of permits and secondary market trading; the characteristics of alternative regulatory regimes; the impact of emissions trading system modalities and impacts of intervention by the regulator; and the investigation of price dynamics, and the effect on prices and volatility of "news", alternative regulatory regimes and various permit instruments.

The model simulates a domestic emissions trading market and is based on the interaction of four types of agent under the control of a games-master. The four types of agent are the emitter, sequester, intermediary and regulator. Participants are required to meet emissions targets through investment and trading, with the object of maximising the value of their business within a given policy framework. Simulation participants take on the role an agent, however the games-master controls the regulator. A simulation will comprise of numerous emitters, a small number of sequesters, at least one intermediary, and only one regulator. Agents operate within a particular regulatory regime, and the simulation is controlled by the games-master (who is also the workshop facilitator). Participants make decisions based on the characteristics of their agent, their expectations on the behaviour of other agents and the regulatory regime, and news sent out by the games-master.

The simulation is based on a Kyoto Protocol-type carbon constrained economy and international policy environment. Generally the use of the Protocol's names for instruments and permits has been avoided to so as not to create confusion, particularly as the rules governing flexibility mechanisms are far from decided.

The simulation consists of several rounds, which may include rounds before the Kyoto Protocol's 2008 to 2012 first compliance period, five rounds over the five years of the compliance period, and the option to continue to further compliance periods. Each individual round, representing one year, consists of three periods that may be distinct and separated, or continuous. A preparatory period allows participants set their production levels, decide whether to undertake any emission reduction investments (ERI) available, and develop their strategy with respect to production, emissions, and the emissions permit market. Once this has occurred, there is an auction of permits by the regulator. Following the auction, there is an open trading period. Trading may be either by submitting bids and offers to a carbon permit exchange (the emissions trading market), or by bilateral negotiation and agreement between agents.

Three types of emissions permit instruments exist within the emissions trading market of the simulation. Domestic emissions permits (DEP) are part of the national assigned amount of carbon emissions permits. These are allocated to agents by the regulator, either by grandfathering or by auction. Sequestration activities give rise to carbon sequestration credits (CSC), which may be sold into the emissions trading market by sequesters at their discretion. Clean development mechanism (CDM) credits arise from international emissions mitigation projects, similar to those allowed under the Kyoto Protocol. The games-master may make CDM projects available to participants though an auction, and determines the cost of the project, the amount of CDM credits that result from the project, and when those credits will be available.

The regulator represents government in the simulation, and the regulator's actions are driven by the requirement to limit national GHG emissions to an exogenously determined cap. The regulator sets the regulatory framework, and the policy assumptions upon which the simulation will be conducted. Activities of the regulator include allocation of permits by grandfathering or auction, and the enforcement of penalties under the compliance regime assumed.

An emitter represents a carbon emitting company. Several types of business activity are included in the set of emitters, such as cement manufacture, electricity generation, petroleum refining, textile manufacture, and waste disposal. Each emitter has a predetermined relationship between greenhouse gas emissions and output (or revenue), and an absolute emissions cap. Figures 1 to 4 show the stylised emissions curve, the relationship between output (or revenue) and GHG emissions in tonnes for a firm from the petroleum, electricity generation, waste disposal, and textiles industries, respectively. The level of output may only be adjusted one period in advance. Emitters have the choice to undertake ERIs when these are made available by the games-master. An ERI consists of a percentage improvement in the emissions to output (or revenue) relationship, and it requires a capital investment on behalf of the emitter. This can be thought of as, for example, the availability of new, lower carbon-intensity technology. The games-master determines the cost of the investment, and the improvement that the investment makes to the emitter's emissions to output function. ERIs may be made available to all emitters, or selectively. Participants playing the role of an emitter have the objective to maximise the value of the company over the period of the game, within a carbon constrained economy where there are monetary penalties for non-compliance with the emitter's carbon emissions cap.

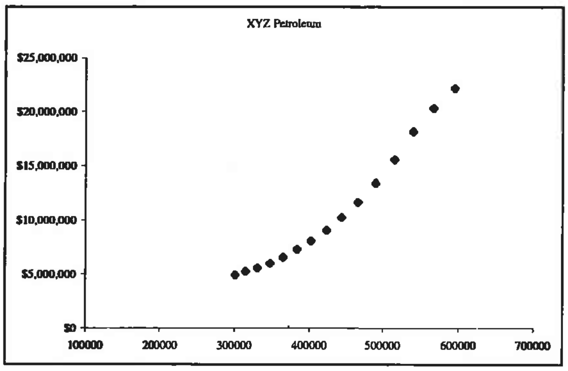

Figure 1. Emissions Curve (tonnes): XYZ Petroleum.

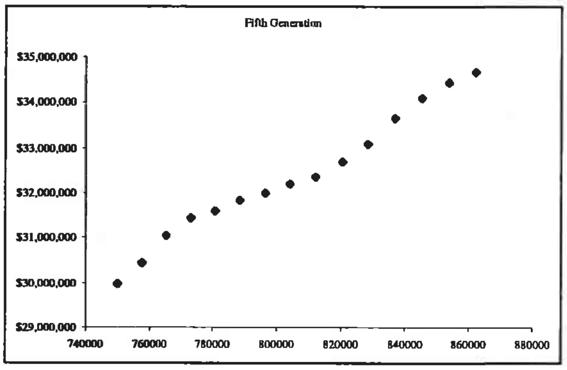

Figure 2. Emissions Curve (tonnes): Fifth Generation.

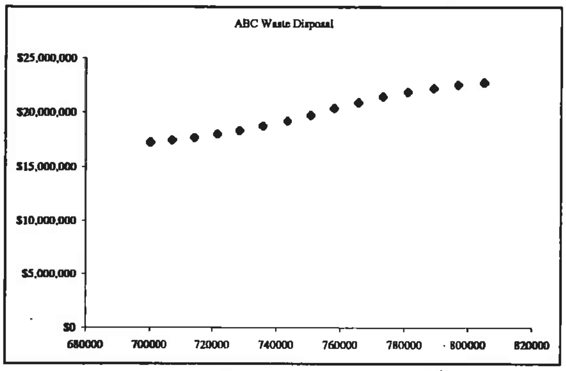

Figure 3. Emissions Curve (tonnes): ABC Waste Disp.

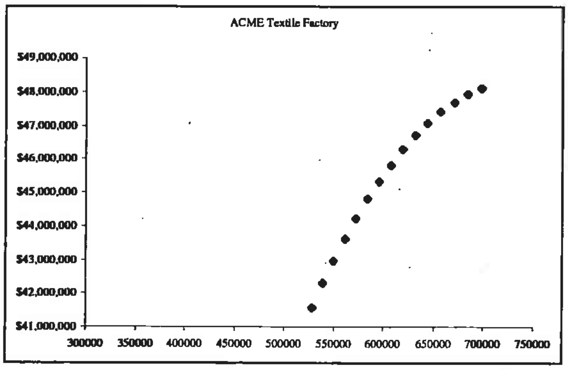

Figure 4. Emissions Curve (tonnes): ACME Textiles.

Sequesters represent a forest industry company that plants trees in order to produce timber, and sequester carbon. The sequester can generate CSCs for sale in the emissions permit market. While revenue for the sequester can be generated by the sale of CSCs there is also the imperative to harvest timber for sale, which is predetermined by harvesting schedules. Harvesting of timber gives rise to carbon emissions. A sequester may alter their production level, and has some discretion over the timing of forest harvesting, however the carbon sequestration properties of the forest over time cannot be changed. Sequesters can also participate in ERI-type investments. However for the sequester, the ERI represents an investment that reduces the measurement error, over the amount of carbon sequestered in the company's forest plantation. Participants playing the sequester also aim to maximise the value of their business over the period of the game.

Intermediaries, representing banks and financial institutions, participate in the carbon permit market with the aim to make profits on the arbitrage of carbon emission permits. The intermediary itself does not have a carbon emissions constraint, as its activities are deemed to be carbon neutral. Like the sequester and the emitter, the intermediary aims to maximise their company value over the simulation.

The games-master controls the simulation, and within a certain compliance regime enforced by the regulator, has the ability to impose a framework on the simulation by controlling the supply of DEPs through the allocation and auction process, controlling the availability of CDM opportunities, their cost and the amount of emissions credits produced, controlling the availability, cost and emissions mitigation nature of ERIs, controlling the non-compliance penalty level, intervening in the carbon permit market through buying or selling permits via the regulator, and the release of news to participants. Using these means, a variety of experimental conditions can be created. Several aspects of the simulation are not under the games-master's control, and there include the production level choices of emitters, sequesters and intermediaries, emitters' choices over the implementation of ERIs, the secondary carbon permit market trading behaviour of agents, the forester's decision whether or not to sell CSCs, and the "rationality" and risk aversion of the agents.

4. PRELIMINARY RESULTS FROM A SIMULATION

Preliminary results are presented for a simulation workshop run for an EcoCarbon member, Woodside Petroleum. The simulation involved participants from a wide variety of business units within the company, who's primary business activity is the extraction and sale of liquefied natural gas. The aim of the workshop and simulation was to educate participants on concepts and strategies for operating within a carbon constrained economy.

Prior to the simulation, participants engaged in a workshop to establish an understanding of the principles and practices of emissions trading, including recent national and international developments; develop knowledge of the options available to participants to manage risks and capitalise on opportunities to optimise corporate returns; and demonstrate the functionality, features, information displays, analytical routines and processes of the VETP simulation software. An important governing principle of the corporate education simulation workshop is that participants need to be sufficiently briefed in order that they can actively and fully engage in the simulation, however also allowing the latitude for experiential knowledge discovery while undertaking the simulation. After applying their knowledge in real-time simulation runs, a post simulation de-briefing session allowed participants to discuss and analyse their strategies and experiences during the simulation.

A number of assumptions were made regarding various parameters of the simulation, emissions trading system, and the compliance regime. The simulation was held in real terms, the interest rate was set to zero and there was no inflation. If an agent became bankrupt, they were not excluded from the simulation. There were no limits on trading, and there were no risk management rules for agents. Full one-to-one fungibility was allowed between CDM credits and CSCs for DEPs. Banking of permits and credits was allowed, credits earned in earlier years could be used in later years. A constant lead time of one year was required for participants to change an agent's production level. The compliance period spanned 2008 to 2012, with end of period penalties. Surplus permits held at the end of the compliance period would hold no value. Permits were allocated by grandfathering and by auction. The grandfathering regime consisted of allocation at the rate of 50% of current emissions for first year. The grandfathered allocation declined to 25% for the second year and 0% for the third and subsequent years.

The compliance period simulations consisted of 5 rounds representing each year of the 2008 to 2012 compliance period as defined in the Kyoto Protocol. The early rounds featured a distinct and generous segmented timetable of activity between the preparatory period, the permit auction period and the open trading period, but as the rounds progressed, the timetable became less discreetly defined, which, it can be argued, would be a closer approximation to reality.

The games-master intended to manage the simulation to create volatile and wide-ranging permit prices in order to force active responses from participants, and generate a wide range of experiences and learning. Prior to the commencement of the simulation, the games-master mapped out a plan having regard to the known emission intensities of the players; the scenarios for compliance at different permit price levels, the availability and efficacy of ERIs, and contingent upon an expectation of rational behaviour by the players. The intent of the plan was to create high permit prices over the first two years of the commitment period to force players to radically alter their production levels, implement appropriate ERIs and create a sense of panic in the carbon permit market. Over the subsequent three years of the commitment period, the games-master was to induce lower permit prices, with the aim of encouraging agents to again alter their production levels. This is analogous to change in technology and improvements to energy efficiency that are expected once emissions have a cost, and relative prices adjust, leading to the elimination of market imperfections that had previously prevented these emission reduction opportunities being exploited. Further, a fall in permit prices would highlight downside risk to those holding large stocks of permits. A number of key points are emphasised below based on observations made during the simulation.

This simulation introduced the concept of permits for early abatement action, that is, an allocation of permits on the basis of emission abatement actions undertaken prior to the commitment period. This was a "surprise" event. Participants were not given prior notice that there would be a credit for early action scheme. Limited time was available to assess the opportunities and determine a bidding strategy. Principles for the early credit scheme were based on those described by the Australian Greenhouse Office [2000]. A pre-commitment period allocation of a portion of national assigned amount units (AAUs), the permits available to the nation under the international emissions limit, was made by competitive bidding. Participants were offered an early action ERI to be undertaken prior to the commitment period. Participants were to place a bid for a number of emissions permits to be pre-allocated prior to the commitment period. Bids were ranked by the ratio of the quantity of ERI abatement to number of permits sought in the bid. For example, a bid of 4 meant that the participant was bidding for 1 emissions permit to every 4 tonnes of ERI abatement. The higher the ratio of the bid, the "cheaper" the outcome for the regulator. Partial bids were not accepted, and on the assumption that the ERI projects under early action were "additional", the participant could not proceed with the ERI if the bid was unsuccessful. The auction of early action credits was readily accommodated within the VETP software by utilising existing auction and allocation functions.

The bids received by the regulator ranged from 1.6 to 8. Only the highest bids that could be completely fulfilled with the limited number of DEPs available were accepted, and several participants were unsuccessful. Participants who placed the higher bids recognised a dual benefit in emissions avoidance through both investing in the ERI, and receiving an allocation of permits at no additional cost, which effectively reduced their overall cost of abatement. These factors determined their bid. Whereas, participants who made the lower bids commented that their bidding strategy simply reflected an expectation of others' bids being higher than 1. An understanding of the firm's relationship between emissions and revenue, and the opportunities for abatement that receive recognition before the commitment period begins, is important.

The first auction of permits within the commitment period saw a wide range of bids submitted by participants. Several bidders were unsuccessful. The first auction appeared to establish a lower limit for bids. Subsequent auctions invariably saw higher bids made. The spread in bids narrowed through successive rounds of the game within the commitment period as participants became better informed and appreciated the relationships between emissions, revenue and the primary and secondary markets for permits. An implication is that, initially, a domestic market for emissions permits may well be inefficient, and significant opportunities for arbitrage may exist. From a national viewpoint, the introduction of a domestic emissions trading scheme should address capacity building issues for firms participating in the market, and be conscious of structuring a market and a tradeable permit instrument that will eventuate in an efficient outcome. Permit acquisition success in auctions, particularly the first auction, clearly benefited the successful participants. This appeared to be especially true for those who bid aggressively and acquired permits in excess of their own emission requirements, becoming sellers in the secondary market at higher prices. These participants also eliminated their exposure to what was an uncertain compliance penalty regime.

Figure 5 shows the allocation of permits, in percentage terms among participants, and refers to permits allocated during the commitment period, and also includes permits allocated under the early action scheme prior to the commitment period. Figure 6 provides a percentage breakdown of participants' trading of permits on the secondary market. A multitude of issues that have been discussed at length in the literature surround the allocation of permits, either by grandfathering or auction, or a combination of both as was used in this simulation. The results of this simulation highlight the importance of the design of the allocation system, particularly the design of the auction. Market power in the emissions permit market, as discussed in Muller and Mestelman [1998] and Godley et al. [1998], may lead to detrimental effects on the economy as a whole. It has been suggested that constraints on the auctioning process may ameliorate the effects of market power, by for example requiring pre-bid deposits to limit bid size, allowing bids up to a maximum of 100% of the firm's emissions inventory, allowing post-bid allocation discretion by the regulator, or holding auctions more frequently, such as quarterly.

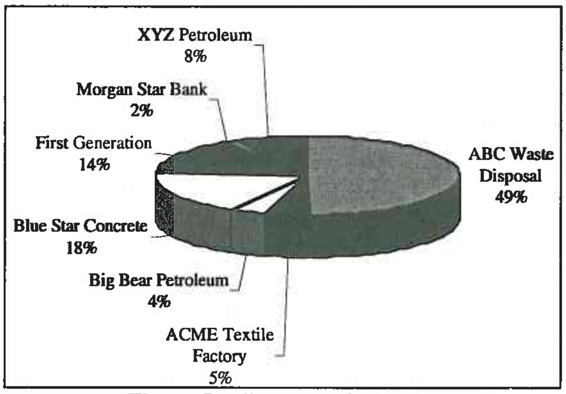

Figure 5. Allocation of Permits.

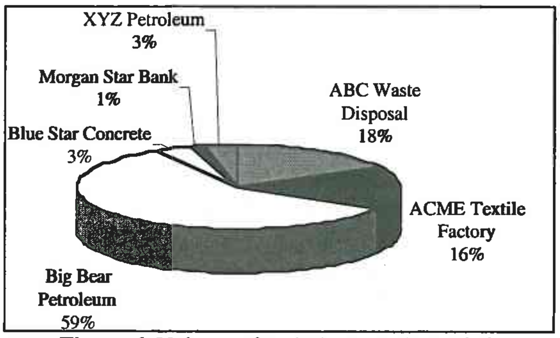

Figure 6. Volume of emission permits traded.

The output and emissions decisions made by participants for each emitter are shown in Figures 7 to 12. Line plots represent the level of output (or revenue), and the vertical bars represent the emissions associated with that level of output. For some emitters, the level of production became volatile during the commitment period. Participants' approaches to risk management varied. No exogenous limitations were placed on decisions regarding output and emissions levels, bidding in auctions and trading in the secondary market, holding stocks of emissions permits, and undertaking ERI and CDM projects. However, it was evident that some participants did not fully understand the risks of their actions in the early stages of the game. Most, but not all, participants adjusted production levels appropriately, and similarly the majority of participants invested in ERIs appropriately. It should be noted that no participants reported inability to understand their net liability position. Apparent irrational behaviour observed for some participants may be an issue of not appreciating the full range of risk management options available. A proper understanding of carbon emission risk management is essential when operating within a carbon constrained economy. To model the behaviour of firms in more detail, risk management constraints on participants' behaviour could be incorporated in the simulation.

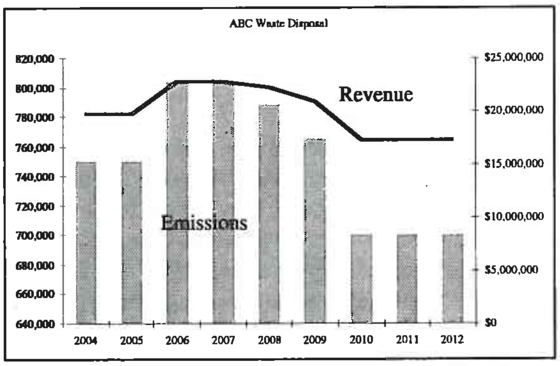

Figure 7. Emissions (tonnes) and Revenue: ABC Waste Disposal.

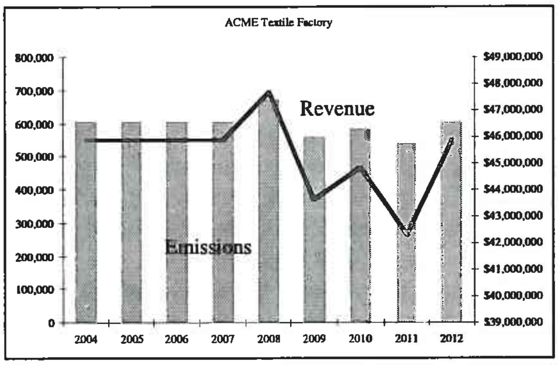

Figure 8. Emissions (tonnes) and Revenue: ACME Textile Factory.

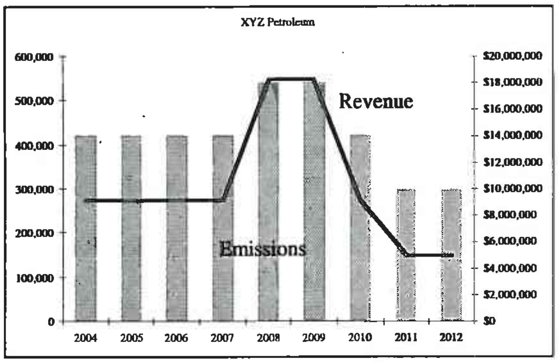

Figure 9. Emissions (tonnes) and Revenue: XYZ Petroleum.

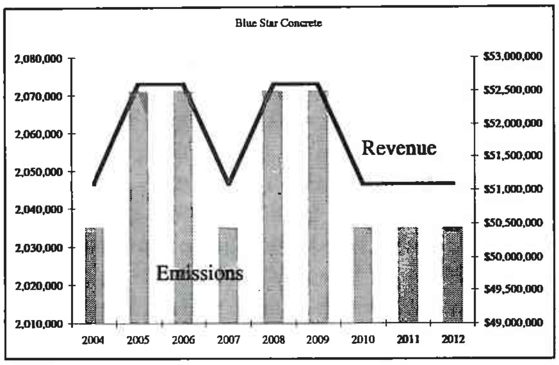

Figure 10. Emissions (tonnes) and Revenue: Blue Star Concrete.

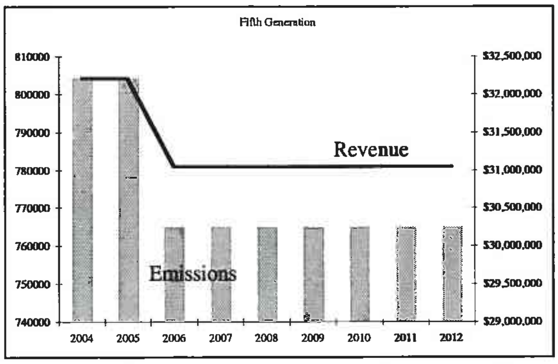

Figure 11. Emissions (tonnes) and Revenue: Fifth Generation.

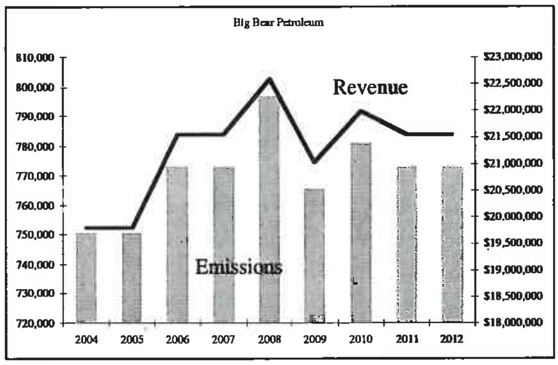

Figure 12. Emissions (tonnes) and Revenue: Big Bear Petroleum.

The games-master aimed to induce lower permit prices over the latter years of the compliance period. However, these efforts were stymied. While the nation was in compliance with its aggregate emissions limit, some participants had a deficit of emissions permits, while others were in surplus. Those holding a surplus of permits did not sell their surplus for a number of reasons. These included hoarding for survival in subsequent periods due to some uncertainty about their future output, and hence emissions, levels. The forester did not sell surplus permits in one period due to the fear of a higher buy-back price when harvesting of the forest was required. Some participants were holding out for higher prices on the secondary market, believing that there would be a substantial shortage of permits within the system at the end of the compliance period. It was expected that an announcement by the regulator informing participants that the system was in overall compliance would lead to a fall in the price of emissions permits. However, this was not the case. Further options open to the games-master included direct intervention in the market by issuing additional permits by auction, seizing permits from bankrupt players, and reducing the non-compliance penalty. None of these options were taken, and participants continued to trade under the prevailing regulatory regime.

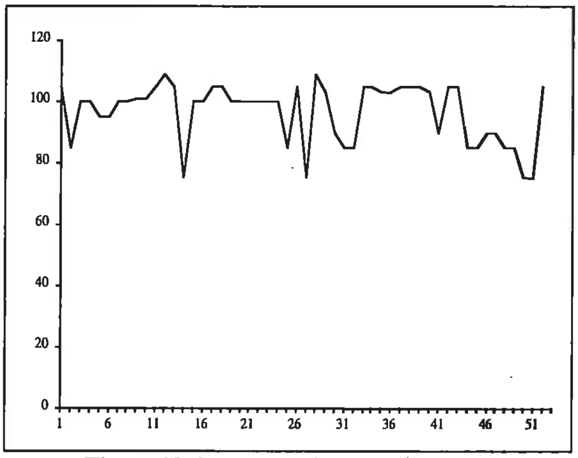

Figure 13. Spot price of carbon ($, trade).

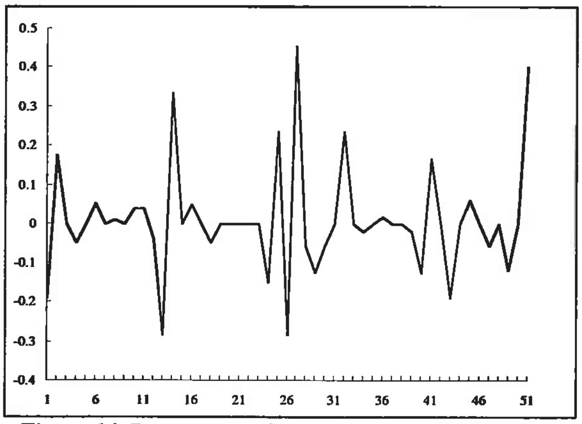

Figure 14. Returns on carbon permits (% return, trade).

Figure 13 shows the spot price of emissions permits over trades, and Figure 14 shows returns on holding permits. Substantial volatility can be seen in the returns, with several large positive and negative observations. Prices eventually declined from trade number 40 (see Figure 1), however the last transaction of the simulation returned the price to higher levels. Intervention in the market proved to be difficult, the implication being that intervention in the emissions market and the management of the price of a permit could be problematic.

5. CONCLUDING COMMENTS

The transition to a carbon constrained economy will be complex and uncertain. Simulation models, such as VETP, provide a valuable means of analysing and learning about carbon permit markets. The VETP model has implications for: (i) greenhouse gas emission policy analysis; (ii) corporate strategy development for operations within a carbon constrained future; (iii) education in the economics of market mechanisms used in constraining carbon emissions; and (iv) generation of experimental data for academic research.

6. ACKNOWLEDGEMENTS

The author would like to thank those associated with the VETP project for assistance, including Steve Becchio, Simon Mathis, Simon Dawkins, and Craig McBurnie; participants in the reported simulation from Woodside Petroleum; Tatsuyoshi Saijo, Hidenori Niizawa, and Yoshiki Yamagata for helpful discussions, and Michael McAleer for helpful comments and suggestions.

7. REFERENCES

Australian Greenhouse Office, Encouraging Early Greenhouse Abatement Action, Ministerial Council on Greenhouse, November, 2000.

Baron, R., Emission trading: a real time simulation, International Energy Agency, 2000.

Bohm, P., A joint implementation as emission quota trade: an experiment among four Nordic countries, Nord 1997:4, Nordic Council of Ministers, 1997.

Bohm, P., and B. Carlén, Emission quota trade among the few: laboratory evidence of joint implementation among committed countries, *Resource and Energy Economics*, 21(1), 1999.

Godley, R., S. Mestelman and R. Muller, Experimental tests of market power in emission trading markets, In *Environmental Regulation and Market Structure*, E. Petrakis, E. Sartzetakis and A. Xepapadeas (Eds.), Edward Elgar, Cheltenham, United Kingdom, 1998.

Hizen, Y., T. Kasukawa, H. Niizawa, and T. Saijo, Two patterns of price dynamics were observed in greenhouse gases emissions trading experiments: an application of point equilibrium, Working Paper, Osaka University, 2001.

Hizen, Y., and T. Saijo, Designing GHG emissions trading institutions in the Kyoto Protocol: an experimental approach, *Environmental Modelling and Software*, 16(6), 533-544, 2001.

Mizuta, H., and Y. Yamagata, Agent-based simulation for economic and environmental studies, Working Paper, National Institute for Environmental Studies, 2000.

Muller, R., and S. Mestelman, What have we learned from emissions trading experiments?, *Managerial and Decision Economics*, 19(4-5), 225-238, 1998.