Title: The problem of uncertain non-point pollution credit production in point and non-point emission trading markets

Short Title: Point and Non-point Emission Trading

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This paper explores the issue of non-point pollution credit production in the context of water quality in rivers and streams. Such trading depends on emission reduction cost differential between point source polluters, such as publicly owned treatment plants and industrial sources, and non-point polluters, such as farms. In previous studies of emission trading markets, polluter production decisions are either treated outside the market analysis (see Cason and Gangadharan, 2006) or made on the basis of emission credits as an input to production (see Godby et al. 1998). In water quality emission markets there is a clear link between non-point (farm) production activities and non-point emission credits, although this is often difficult to quantify accurately in advance. The problems associated with linking cause and effect gives the non-point emission credit its unique non-point characteristic. As water quality is a significant issue in many catchments throughout the world, further experimentation seems warranted. This paper presents the results of a series of experiments in which players face imperfect knowledge of abatement outcomes associated with non-point (defuse) sources of emission credits.

Key words: emission trading, diffuse source pollution, uncertainty, experiments.
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Introduction

Point and non-point pollution in rivers and streams is a major problem in many developed and developing countries. Runoff from farms is often laden with sediment and chemicals such as nitrogen and phosphorous which result in decreased water quality downstream. Changing land use practices and constructing riparian buffer strips between the farming lands and watercourses are seen as effective ways of reducing the loads reaching the streams during major rain events. Giving tradeable credits for emission reductions and allowing trade provide financial incentives to undertake such activities. Such market based approaches to pollution control will in theory achieve pollution reduction targets at least cost. Emission reductions from non-point polluters undertaking land use change and the construction of riparian buffer strips, however, are by no means certain. Defining credits for non-point source improvements depend on localised features such as land uses, climate and geology. Estimating the contribution of non-point sources to pollution loads is often based on hydrological models which, by their nature, carry a level of model error and uncertainty. The randomness of non-point source loads associated with large storm events, for example, makes them difficult to predict accurately in advance. It is only with the passing of time and measurement that actual loads are realised. In essence, non-point source loads are less predictable temporally and spatially than point source loads. While spatial differences can potentially be overcome with trading ratios (see Horan, 2001; Hung and Shaw 2005), how to manage the uncertainty of non-point loads necessitated further research, in order to realise fully the gains from trade. Historically, such uncertainties in pollution trading markets have resulted in significant price volatility and undesirable emission levels. Designing well crafted market instruments which account for these uncertainties is vital if active and efficient market outcomes are to be achieved[1].

This paper examines institutional design alternatives for overcoming these uncertainties in non-point emission estimates. These include the government taking full responsibility for discrepancies between modelled and realised loads, allowing point sources to bank realised credits as a means of offsetting future risk, and the use of reconciliation markets to reassigned credits once actual non-point credit production is realised.

The paper begins with a review of literature on the development of point/non-point pollution markets and how the current study builds on existing knowledge. This is followed by an outline of experimental designs and treatments used and the finding of the experiments. The paper concludes with a summary of the main findings and suggestions on how to create better trading institutions to resolve pollution problems.

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[1] This is becoming even more important in many catchments where non-point sources of pollution, such as sedimentation and nutrient enrichment because of farmland runoff into rivers and streams, are the main source of pollution.

Review of literature

The development of point/non-point markets is often underpinned by biophysical modelling. Such modelling is in most cases conducted by the government agency issuing the permits or offsets. It could therefore be argued that the government issuing credits should take responsibility for any discrepancies between the notional credits issues on the basis of modelled data and realised emissions levels. This approach has the benefit of promoting trade in certain property rights since the government shoulders responsibility. Society, through the government, takes responsibility for modelling uncertainty but in response gains the socialised benefits of reduced pollution levels.

A counter argument to socialising the uncertainty is that the players in the market are the direct beneficiaries from trade and so should carry the burden of the uncertainties of trade. In this study, the liability for credit uncertainty lies with the point source buyers, as is often the case in field point/non-point pollution markets. To assist players to manage the uncertainties associated with trading in pollution markets, banking and reconciliation market options are often available and will be included as options in this study.

Banking allows firms to make one-way intertemporal trades and in the process balances their credit production and trading decisions (Cronshaw and Kruse, 1999). With banking options, the benefits of abatement activity in the current period can be counted towards offsetting future emissions. Previous research has suggested that banking has the potential to reduce price volatility, particularly in the initial periods when there is significant emission target uncertainty in the market (Cason and Gangadharan, 2006; Cronshaw and Brown-Kruse, 1999; Godby et al. 1997; Mestelman et al. 1999)[2].

[2] Cason and Gangadharan (2006) point out that the adoption of banking varies greatly from unlimited banking in the federal sulphur dioxide trading program in the United States to limited banking in the Ozone Transport Commission option in the Eastern United States to no banking options in the RECLAIM program of Southern California.

The main cited drawback of banking, however, is that it can result in an oversupply of banked credits (Cronshaw and Brown-Kruse, 1999; Innes, 2003; Kling and Rubin 1997). Banking also has some potentially serious biophysical drawbacks. Banking effectively reduces the regulator's control over the temporal distribution of emissions. From a physical management perspective, this means that aggregate emissions each year may not be reduced to target levels. Rather, cumulative emission levels over time will equal cumulative environmental targets. The benefits of banking therefore have to be balanced with the environmental need. If meeting a cumulative target over years is satisfactory, then banking and environmental targets can coexist. If, however, the target is one that has to be met each time-period, a threshold for environmental resilience, for example, then meeting the environmental emission reduction target and the banking option may not be able to coexist. As Cronshaw and Brown-Kruse (1999) point out, banking is likely to reduce emission rates in earlier periods as credits are banked and increase emissions in latter periods as the credits are used as offsets to meet target levels.

Reconciliation markets are often implemented once the actual emission levels are realised and allow traders to potentially balance discrepancies between notional and actual (realised) credits and credit requirements (Carlson and Sholtz, 1994; Tietenberg, 1980). Reconciliation markets have been found to overcome the adverse effects of stochastic credit production in pollution markets (Carlson and Sholtz, 1994) and stabilise market prices (Cason and Gangadharan, 2006). Carlson and Sholtz (1994) argued that an absence of such markets would lead to traders holding excess emission credits or report excess emission levels matching their holdings to ensure they are not later penalised. In this study banking options are explored with and without reconciliation markets.

This study extends knowledge on pollution markets in two different dimensions by incorporating non-point production uncertainty and production decisions into the laboratory settings.

Studies of the point/non-point trading problem to date have largely focused on uncertain emission targets. Having uncertain aggregate targets, however, is not unique to point/non-point markets. While emission targets do vary, such targets are not what make point/non-point pollution markets unique. The core of the point/non-point trading problem lies in determining exact predictions of the impact of a change in non-point polluter activity (often farming activity) on pollution loads so that credits can be issued and traded. In this study, the main source of non-point uncertainty lies in the production of the credit, rather than the emission target.

Godby et al. (1998) were the first to include a production decision phase in their experimental analysis of pollution markets. In their experiments players were issued emission tradeable shares (trading entitlements) which after trade were converted to coupons (banking permits). Depending on the design, there was then a reconciliation coupon market followed by a production decision. In their experiments, production was not connected to the initial allocation of shares. In essence the shares, while stochastic, were exogenously determined and grandfathered to the players.

This paper builds on the original work by Godby et al. (1998) in three ways. First, in Godby et al. (1998) the initial allocation of shares is exogenously determined and trade is based on the need for emission coupons as an input to production. In field markets, a non-point polluter (a farmer with land adjacent to rivers and streams, for example), in order to create credits, has often to choose a more expensive or less productive farming option with the expectation of returns for credit sales. Credits are not an input to production, rather a tradeable output from a change in farm management. In these experiments, players make decisions on emission credit production rather than on input use which requires permits. Uncertainty is created by having only notional (unrealised) credit production before trade.

Second, in Godby et al. (1998) emission targets are varied rather than emission credits. In this study a distinction is made between point source players with certain production/emission credit production and non-point players with stochastic emission permit production. Buyer of credits (point source polluters in this instance) are responsible for any differential between notional and actual credits traded and as such trade with asymmetric risks.

Third, production decisions in Godby et al. (1997) are made each round. Changing land use by non-point sources to establish riparian buffers along the banks of rivers and streams, however, often involves investments which are not easily changed and last through numerous compliance and certification periods. To capture this, production decisions are bound over three rounds.

The study consists of a set of experimental treatments which move from certain trade, in which the government carried responsibility for the stochastic nature of credit production, to a situation in which the point sources carried the responsibility. Issues which have yet to be fully understood include the consequences of credits uncertainty and production decisions on efficiency and the consequences of primary and reconciliation trading with banking in point-non-point trading markets. This study begins to answer some important questions concerning the relationship between stochastic pollution markets and initial credit production, and extends the work done to date on the relationship between banking and reconciliation markets.

Experimental Design

The treatment variables were trade certainty with government liability, uncertain credits with point source liability, the presence or absence of banking and the presence or absence of reconciliation markets. These were combined in the form the four treatment combinations presented in Table 1.

Insert Table 1 here

Each experiment consisted of twelve periods, divided into various phases according to the treatment. These phases included a production decision, trade in non-point emission credits, realisation of non-point emission credits, a reconciliation market, production penalties, and banking.

Treatment #1: Trade certainty

The first treatment consisted of a production decision and trade in certain non-point emission credits and production penalties. As discussed previously, emission trading is an inherently uncertain issue and, as a result, notional credits are often based on government modelling. As the government is often responsible for establishing credits and the associated modelling underpinning them, the argument could be made that society, through the government, should take responsibility for the uncertainty associated with the credits. In this treatment, the government takes on the liability of the modelling error in allocating non-point emission credits. This being the case, players once having made their decision are able to trade in certain property rights which in theory will produce the modelled efficient distribution of credits.

Treatments #2: Point source liability

The second treatment consisted of a production decision, trade in uncertain non-point emission credits, realisation of non-point emission credits and production penalties. In this treatment, non-point emission credits are uncertain and the liability is vested with the point source buyers. Point source polluters can purchase uncertain credits from non-point sources. Once the market closes, actual credits are realised using a conversion factor ranging from 0.8 to 1.2. The range of the conversion factor was known to the players at the start of the game. The liability of any shortfall in traded credits was assumed to reside with the point source players in this and Treatment 3 and 4 experiments. The production penalty for any shortfall in credits was additional point source production.

Treatment #3: Banking

The third treatment consisted of a production decision; trade in uncertain non-point emission credits, realisation of non-point emission credits and production penalties and banking. This treatment extends treatment 2 by allowing point source players to bank surplus credits across rounds. Any point source credit surpluses after the reconciliation market could be banked for use or trade in following rounds. This differs from banking in the Cason and Gangadharan (2006) case where banked credits were not tradeable in future periods.

Treatment #4: Banking and Reconciliation Markets

Treatment 4 included a production decision, trade in certain or uncertain non-point emission credits, realisation of non-point emission credits, a reconciliation market, production penalties and banking. In the final treatment, players traded potential credits in a primary market. Once the actual credits were realised, a reconciliation market would commence. Any point source credit surpluses after the reconciliation market could be banked. Credit deficits following the reconciliation market are either accounted for from previously banked credits or by additional point source production.

Each of the 4 treatments consisted of three experimental sessions. Each session consisted of eight (8) subjects; four (4) subjects were randomly allocated to be point source players and four (4) subjects were randomly allocated to be non-point source players. The experiments were conducted at the Griffith University Experimental Economics Laboratory[3] using The Experimental Software System, (TESS) and students at Griffith University, Brisbane Australia. The students were recruited using an on-line registration system and posters located across the campuses[4]. Sessions consisting of only one market each round, lasted approximately 1 ½ hours. Sessions with primary and reconciliation markets lasted approximately 2 ½ hours. Students were given $A10[5] as a turn up fee and

[3] See http://www.economicexperiments.com/
[4] See http://www.ens.gu.edu.au/johnt/registration/
[5] 5 $A1 = $US0.80.

could earn additional income according to their farm or firm's income. Students earned between $A13 and $A48 and were paid in cash at the end of each session.

On arrival at the session, the students signed in and were directed to a computer where they viewed a set of PowerPoint instructions and associated quiz prior to commencing the session[6]. The complexity of the issues explored and the need for external validity with policy stakeholders required some level of contextualisation[7].

In common with all the treatments, players made production decisions prior to trade. Point source players were provided with a production target and three production possibilities with increasing costs of production. Non-point players had the option of producing two different types of products, one with a higher return but no credits, the other with a lower return but credits. The players' characteristics are summarized in Table 2 below.

The non-point players choose the amount of a fixed quantity of resources they wish to be used on product A with the balance being used to produce product B and the associated credits. The point sources choose the total quantity of credits they wish to produce prior to trade. The credits are automatically produced from the cheapest option upwards. Credits bought in the market are used to offset the most expensive credits. Should a deficit occur, production above current levels is made to meet the deficit.

Insert Table 2 here

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[6] A set of instruction files and quizzes are available at http://www.ens.gu.edu.au/Johnt/Instructions/papers/eeps/

[7] Roth (1987) refers to such policy analysis as "whispering in the ears of princes".

By this logic, the optimal strategy for point source polluters is to produce no credits until after trade has occurred. The choice between producing product A (with no credits) and B (with credits, but a lower marginal value) depends on the player's attitude to risk and uncertainty[8].

Point source investment in abatement technology is often costly and long-lived. Similarly, changes in farm practices can often involve long term investment decisions. As a result, production decisions, once made, were fixed for three rounds. Production decisions were made in rounds 1, 4, 7 and 10 and carried over into the following two rounds. Once the decision was made (or carried over from previous rounds), players traded credits in a real time multiple unit double auction market[9]. The rules of trade followed the bid/ask reduction rule, as defined by Plott and Gray (1990).

Results and discussion

This study extended knowledge on pollution markets by incorporating production decisions and non-point production uncertainty into the laboratory settings. This section reports and discusses the results of incorporating production decisions into experiments and the ability of the participants in the experiments to coordinate production and trade to achieve competitive equilibrium outcomes. The consequences of non-point production uncertainty in markets with banking and reconciliation market options are then compared with markets with certain non-point credits.

[8] Unfortunately, we did not play a risk game with the subjects. Measuring individual preferences in individual decision-making under risk and uncertainty enables further comparisons between individual and market behaviour (Camerer, 1998; Sarin and Weber, 1993; Holt and Laury, 2002; Di Mauro and Maffioletti, 2004;). If we had played a risk game, we could have explored possible correlations between the risk game decisions and their decisions in the emission trading game. This is certainly an important area for further research.

[9] For an explanation of the double auction mechanism used in this study please refer to the instruction files available at http://www.ens.gu.edu.au/Johnt/Instructions/papers/eeps/

Incorporating production decisions

This results section will first present a summary of the experimental data from each of the four treatments. Benchmarks for comparison will include the four used by Cronshaw and Brown Kruse (1992), Franciosi et al. (1993) and Muller and Mestelman (1994). The traditional benchmarks include perfect foresight competitive equilibrium (PFCE) and adaptive competitive equilibrium (ACE) introduced by Cronshaw and Brown Kruse (1992).

In this study we introduced the notion of having tradeable yet uncertain non-point emission credits. Where in previous studies certain emission credits were allocated to players and aggregate emission targets were uncertain, in this study non-point uncertain credits were generated by player defined production decisions prior to trade. Uncertainty in catchment modelling rests mainly in estimating the consequences of riparian farmer management actions on non-point pollution loads in rivers and streams. Determining aggregate targets at the end of catchments is a more certain science.

Buyers in the market (point source players) could choose to produce certain emission reductions or trade in these uncertain credits. The dynamics of the markets and player decisions were therefore quite different to those explored in previous studies and so require different definitions of the benchmarks for assessment.

The PFCE represents the performance if the players trade and bank optimally. The ACE is the competitive equilibrium given the current inventory of credits. In this study these criteria are premised on the players making optimal production decisions in the first instance which makes estimating optimal outcomes slightly more complex. Godby et al. (1998, p.71), for example, was able to estimate the ACE by simply "adding the total number of coupons remaining to be distributed to the current inventory, allocating them equally over the remaining periods, and reading the price off the aggregate demand schedule for the coupons in the current period". In this analysis the production decision of each player for each period will need to be used to estimate a set of adaptive supply and demand schedules from which competitive equilibriums can be estimated.

Perfect foresight decision sets and competitive equilibrium

One of the most commonly discussed benchmarks of market efficiency in the experimental market literature is the perfect foresight competitive equilibrium. Due the uncertain nature of non-point credits the notion of perfect foresight is extended to include perfect foresight of the final emissions of non-point polluters. Including uncertain emission levels results in a set rather than a unique PFCE. The PFCE values for conversion ratios 0.8, 1.0 and 1.2 are presented in Table 3.

Insert Table 3 here

The production sets associated with each of the conversion ratios are presented in Table 4. The optimal production decision of non-point players did not change with the level of uncertainty. This was done in order to determine their reaction to the notion of uncertainty. Optimal production for non-point players was to produce only lower value credit producing crops.

Insert Table 4 here

It would be expected that trade in certain credits in a multiple unit double auction environment would produce convergence with the perfect foresight competitive equilibrium. Yet, while there were signs of convergence in two of the three replicate sessions (see Figure 1), overall market prices in markets with certain credits were found to be significantly different to the perfect foresight competitive equilibrium price ($t = 14.68$, $p = 0.000$).

Insert Figure 1 here

An alternative to the PFCE is the ACE. Cronshaw and Brown Kruse (1992) defined ACE as the equilibrium determined by the current stock of credits. In this study the ACE is calculated by deriving the supply and demand schedules for each round based on the non-point production decision of each of the non-point players. Differences between ACE prices and actual trade prices were tested using a paired t-test. The experimental trade price data was not significantly different from the ACE prices ($t = 1.214$, $p = 0.226$).

With perfect foresight, players would not only produce the 'correct' number of credits, but trade them at the competitive equilibrium price. Achieving the perfect foresight competitive equilibrium outcome thus requires two synchronised activities. It is not surprising therefore that the competitive equilibrium was not achieved. It does, however, open the question as to whether field markets given production and trade decisions are likely to achieve the perfect foresight competitive equilibrium predicted by standard economic optimisation models of this type. Given the production decisions of the players ACE was achieved supporting the traditional view that double auctions are efficient. The result questions whether analysis of markets without consideration of the decisions made to establish the market is perhaps partial and may result in unrealised results.

Uncertain non-point pollution credits

The second area of research dealt with uncertain non-point pollution credits. Four formal treatment sets of experiments were conducted: trade in certain credits, trade with point source liability, trade with banking, and trade with banking and reconciliation markets. Differences between the market treatments are evaluated in terms of differences in market prices, quantities traded, allocative efficiency and accordance with emission levels.

Trade price differences between treatments

Table 5 presents the mean trade price by treatment. The trade prices were analysed using appropriate analysis of variance and associated post hoc tests. This analysis will first compare market prices with those observed in the certain treatment. This will be followed by an analysis comparing uncertain credit trade with banking and primary and reconciliation market prices.

Insert Table 5 here

The trade prices across the various treatments are significantly different ($F = 12.571$, $p = 0.0000$). Interestingly, the trade prices given certain credit rights were not significantly different from trade under uncertainty ($p = 0.66$). This result suggests that the level of uncertainty (0.8 to 1.20) was not large enough to produce a significant change in price behaviour.

That said, the trade prices given certain credit rights were found to be significantly higher than trade prices given uncertain trade and banking ($p = 0.000$). Further the variance in market prices in the certainty treatment was less than in the uncertainty treatment with banking. This result suggests that banking allowed traders to balance their demand for credits across periods effectively.

Prices in the primary and reconciliation markets were not as expected. Trade prices in primary markets were found to be significantly higher than those in any other treatment ($p < 0.05$). Once credits were realised, market prices in the reconciliation markets were significantly lower than the trade prices in the primary market ($p< 0.05$) as point source traders balanced differentials between notional and actual credits, but not significantly lower than in single certain markets. In terms of market prices, the option of having primary and reconciliation markets did not produce the expected market efficiencies.

Trade Quantities

Significantly more units were traded when the players held uncertain credits than when the credits were certain ($p < 0.001$). This suggests that, while the uncertainty did not impact on market prices, it did impact on player production decisions. Non-point players chose to trade more credits than risk possible market returns from uncertain credits. Banking, however, overcame these concerns. The quantity traded in experiments with banking was not significantly different from the quantity traded in certain credits (p=0.361). The quantity traded under uncertainty with banking was greater than without banking. The quantity traded in the primary market was significantly less than trade under certainty, but was not significantly different from the quantity traded in the reconciliation market. The quantity traded overall in the primary and reconciliation markets was greater than that traded in any other market, suggesting that a primary/reconciliation market option is not as efficient as other market options. Consistent with the variance in market prices, the variances in quantity traded were found to be significantly higher given certain credits than uncertain credits.

As discussed, Carlson and Sholtz (1994) and Cason and Gangadharan, 2006) found that reconciliation markets overcame the adverse effects of stochastic stocks in pollution markets. One possible explanation for the differences found in this study lies in the combination of events. In Carlson and Sholtz (1994) reconciliation markets were combined with staggering the allocation and expiratory date of tradeable credits. Cason and Gangadharan (2006) combined reconciliation markets with compliance and enforcement consequences. In this study there were no such additional factors. This suggests that perhaps reconciliation markets in isolation - without accompanying incentives such as compliance and enforcement procedures - may not be as effective in stabilizing pollution markets as originally expected.

Allocative efficiency

Allocative efficiency in this study was defined as the ratio of aggregate optimised income and the aggregate incomes of the players in each of the experimental sessions. Table 6 summaries the allocative efficiency of each of the treatments.

Insert Table 6 here

Banking significantly increased allocative efficiency. Experimental markets with banking options (Treatments 3 and 4) exhibited efficiency levels 9-10% higher than markets with certain or uncertain non-point pollution credits without banking. This result suggests that in terms of allocative efficiency, the uncertainty of credits was more than compensated for by the banking option. Introducing reconciliation markets led to lower efficiency than without suggesting that the dual market option may have excessively complicated the market at the expense of cost minimisation.

Consequences of banking

Allowing point sources to bank credits is expected to reduce uncertainty and thus reduce market volatility. Volatility in market prices, quantities and emission levels are expected to fall with banking as players spread their trade and decisions over rounds (see Cason and Gangadharan, 2006). To explore this the consequences of banking were analysed in terms of variance in market prices, quantities traded and aggregate emission levels. Banking occurred in uncertain credit markets with and without a reconciliation market. While banking led to fewer trades and lower average prices, it did not led to reduction in the variance on market prices as predicted by previous studies. When the credits are uncertain, the variance of market prices was found to be significantly greater with banking than without ($F = 1.1299$, $p < 0.01$)[10]. While the variance in the primary market was significantly lower, the variance in the reconciliation market was significantly higher ($F = 1.018$, $p < 0.01$).

Banking also led to a greater variance in the quantity traded in uncertain credit markets ($F= 1.2535$, $p < 0.01$). Variance in the quantity traded in the reconciliation market with banking was significantly less than the other variance in the other market treatments.

Cronshaw and Brown-Kruse (1999) argued that while banking provides traders an opportunity to manage credit demands temporally, it can potentially result in a higher

[10] See Ott, R. Lyman, 1993, An Introduction to Statistical Methods and Data Analysis vol. 4. Duxbury Press, Belmont, California. Section 7.4.

production of credits in the early rounds and a less than emission production target in later rounds. Credit demand and credit production are decoupled by banking. Figure 2 shows the level of aggregate credit production each round of Treatment #3. In all three session replicates of the treatment, there was an oscillating production of credits. In two of the three sessions, credit production was higher in the early rounds and declined in the latter rounds as predicted. As discussed previously, whether banking is a viable option depends on the biophysical consequences of the variance of credit production around the target.

Insert Figure 2 here

Conclusions

In this study we introduced the notion of having tradeable yet uncertain non-point emission credits and production decisions prior to trade. Where in previous studies certain emission credits were allocated to players, in this study non-point uncertain credits were generated by player defined production decisions prior to trade. Buyers in the market (point source players) could choose to produce emission reductions or trade in these uncertain credits. The dynamics of the markets and player decisions were therefore quite different from those explored in previous studies and better reflected the joint production decision and trade environments faced by polluters in point\non-point markets.

The research found that allowing players to make production decisions is unlikely to result in the perfect foresight competitive equilibrium results predicted by traditional economic optimisation models. The double auction market did however work efficiently in achieving adaptive competitive equilibriums once the decision of the players were realised. Introducing uncertain non-point pollution credits let to asymmetric uncertainty as point sources purchased uncertain credits from non-point source polluters. This uncertainty led to lower quantities being traded and a higher number of trades. Having options to bank credits significantly reduced the number of transactions and market prices and greatly improved allocative efficiency. Introducing primary and reconciliation market options did not perform as well as expected. Market prices were higher than expected in the primary markets. Quantities traded in the primary and reconciliation markets individually were not significantly different and overall let to a larger number of credits being traded than under any other treatment. A proposed explanation is that reconciliation market only operates well when they are complemented with other mitigating strategies, such as staggered credit releases and expiratory dates or well defined enforcement and penalty consequences for non-compliance.

The research indicates that the performance of non-point/point pollution markets is highly dependent on the production decisions of those producing credits. Previous research has evaluated trade on the basis of players being allocated credits or producing the optimal number. It is unlikely that such markets will achieve the perfect foresight competitive equilibrium outcomes estimated by traditional economic models. The research also found that uncertainty in non-point pollution credits adversely affect pollution markets and the assumed benefits of having primary and reconciliation markets may not be realised.

Banking greatly improved the ability of the players to meet the emission target at least cost. In one session players overproduced and banked credits which were then used to meet later round emission requirements. While this helps to overcome credit uncertainty it results in greater than target reductions in farm runoff in earlier periods and greater than target runoffs in the later periods when banked credits are cashed in. While overall the target is met the ecological consequences of exceeding targets needs further exploration. Currently the nexus between banking and round by round physical targets is not considered. An institutional design with banking may elegantly elevate player concerns about credit uncertainty, but not meet the physical objectives which the mechanism was originally proposed for. There is no point having an elegant policy which does not achieve its purpose: to ensure that pollution loads do not exceed ecological limits.

Previous studies have focused on uncertainty in aggregate targets (see Cason and Gangadharan 2006). The results of this study suggest that the institutional design of pollution markets also need to account for uncertainty in non-point credit production and the nexus between production and trade to produce an optimal number and distribution of pollution credits. The results suggest that reconciliation markets, which have been effective in overcoming uncertainty in aggregate targets, may not be as effective in dealing with non-point credit production uncertainty. Second, the nexus between production decisions and trade in notional credits is unlikely to result in perfect foresight competitive equilibrium outcomes. Given production decisions, the markets operated efficiently. The challenge therefore is to design institutions which provide mechanisms for optimal production discovery.

Appendix A.

$$\max \sum_{i=1}^{m}\sum_{j=1}^{n} mr_{ij}x_{ij} - \sum_{k=1}^{p} mc_k xc_k$$

$$st$$

$$\sum_{j=1}^{n} x_{ij} \leq np_i \forall i \in m$$

$$xc_k \leq p_k \forall k \in p$$

$$\sum_{k=1}^{p} xc_k + t_k \geq tc_k \forall k \in p$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} npt_{ij}x_{ij} = \sum_{k=1}^{p} t_k$$

Where

x_{ij} quantity of production option *j* produced by non-point source *i*.

xc_k quantity of credits produced by point source *k.*

mr_{ij} marginal revenue of production option *j* produced by non-point source *i.*

mc_k marginal cost of producing credits by point source *k*.

np_i maximum aggregate production for non-point source *i.*

p_k maximum aggregate production for point source *k.*

t_k credits traded by point source *k.*

tc_k total number of credits held by point source *k.*

npt_{ij} Conversion ratio of non-point source production *j* by non-point source *i* into tradable credits.

Where perfect foresight is not achieved in both the decision and trade a conditional competitive equilibrium is still possible based on actual player decisions. Conditional competitive equilibriums can be estimated by including the players' actual production decisions (X_{ji} and XC_k):

$$x_{ji} = X_{ji}$$
$$xc_k = XC_k$$

In principle, with perfect foresight players should not need a reconciliation market or associated banking. Conditional competitive equilibrium can be estimated for the reconciliation market by including the actual players' decisions and traded quantities in the primary markets (T_i and T_k), where Tk is exogenously determined from a fist run solution.

$$\sum_{k=1}^{p} xc_k + t_k + T_k \geq tc_k \forall k \in p$$
$$\sum_{i=1}^{m} \sum_{j=1}^{n} npt_{ij} x_{ij} = \sum_{k=1}^{p} t_k$$

References

Camerer, C. (1998). Bounded rationality in individual decision making. *Experimental Economics,* 1, 163-183.

Carlson, D.A. and Sholtz, A.M. (1994). Designing pollution market instruments: Cases of uncertainty. *Contemporary Economic Policy*, 12(4), 114.

Cason, T.N. and Gangadharan, L. (2006). Emissions variability in tradeable permit markets with imperfect enforcement and banking. *Journal of Economic Behavior and Organisation*, 61, 199-216.

Cason, T.N., Gangadharan, L. and Duke, C. (2003). A laboratory study of auctions for reducing non-point source pollution. *Journal of Environmental Economics and Management*, 46, 446-471.

Cronshaw, M.B. and Brown-Kruse, J. (1999). An experimental analysis of emission permits with banking and the Clean Air Act Amendments of 1990. In: R. Mark Isaac and Charles Holt (Eds.), Research in Experimental Economics. JAI Press, Stamford, Connecticut, pp. 1-24.

Cronshaw, M.B. and Kruse, J.B. (1999). Temporal properties of a market for emission permits with banking. In: R. Mark Isaac and Charles Holt (Eds.), Research in Experimental Economics. JAI Press, Stamford, Connecticut, pp. 181-203.

Dales, J.H. (1968). Pollution, Property and Price. University Press, Toronto.

Di Mauro, C. and Maffioletti, A. (2004). Attitudes to risk and attitudes to ambiguity. *Applied Economics*, 36, 357-372.

Godby, R.W., Mestelman, S., Muller, R. A. and Welland, J. D. (1997). Emissions trading with shares and coupons when control over discharges is uncertain. *Journal of Environmental Economics and Management*, 32, 359-381.

Holt, C.A. and Laury, S.K. (2002). Risk aversion and incentive effects. *American Economic Review*, 92(5), 1644-1655.

Horan, R.D. (2001). Cost-effective and stochastic dominance approaches to stochastic pollution control. Environmental and Resource Economics, 18, 373-389.

Horan, R.D. and Shortle, J.S. (2005). When two wrongs make a right: Second-best point-non-point trading ratios. American *Journal of Agricultural Economics*, 87(2), 340-352.

Innes, R. (2003). Stochastic pollution, costly sanctions, and optimality of emission Permit banking. *Journal of Environmental Economics and Management*, 45,546-568.

Malik, A.S., Letson, D. and Crutchfield, S. R. (1993). Point/Non-point source trading of pollution abatement: Choosing the Right Trading Ratio. *American Journal of Agricultural Economics*, 75, 959-967.

Mestelman, S.E., Steven R. and van Boening, MR. (1999). A laboratory test of a canadian proposal for an emissions trading program. In: R. Mark Isaac and Charles Holt (Eds.), Research in Experimental Economics. JAI Press, Stamford, Connecticut, pp. 45-92.

Ott, R.L. (1993). An Introduction to Statistical Methods and Data Analysis vol. 4. Duxbury Press, Belmont, California.

Plott, C.R. and Gray, P. (1990). The multiple unit double auction. *Journal of Economic Behavior and Organization*, 13, 245-258.

Roth, A.E. (1987). Laboratory Experiments in Economics. Cambridge University Press.

Sarin, R.K. and Weber, M. (1993). Effects of ambiguity in market experiments. *Management Science*, 39(5), 602-615.

Tietenberg, T.H. (1980). Transferable discharge permits and the control of stationary source air pollution: A survey and synthesis. *Land Economics*, 56(4), 391-419.

Table 1. Experimental Design

	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Nature of credit	certain	uncertain	uncertain	uncertain
Banking	no	no	yes	yes
Reconciliation market	no	no	no	yes

Table 2. Player Characteristics

Point Source Players				Non-point Players				
Player	Target	Product	Cost/Unit	Player	Maximum	Product	Value	credits
1	4500	A	40	5	500	A	100	0
		B	80			B	70	1.10
		C	150	6	400	A	150	0
2	3000	A	50			B	90	1.30
		B	100	7	300	A	200	0
		C	200			B	110	0.90
3	2000	A	60	8	200	A	250	0
		B	120			B	200	0.8
		C	240					
4	1000	A	70					
		B	140					
		C	280					

Table 3. Perfect Foresight Competitive Equilibrium

Notional to realised non-point credit conversion rate	Price	Quantity
1.2	100	1800
1.0	120	1500
0.8	140	1200

Table 4. Perfect Foresight Decisions and Trade

Notional to realised non-point credit conversion rate						0.8				
Competitive Equilibrium						Pr = 140				
						Qty = 1200				
Point Source Players						Non-point Players				
Player	Target	trade	Prodn.	Product	Qty	Player	Product	Qty	Ratio	Credits
1	4500	500	4000	A	3000	5	A		0	
				B	1000		B	500	1.1	440
				C		6	A		0	
2	3000	300	2700	A	2000		B	400	1.3	416
				B	700	7	A		0	
				C			B	300	0.9	216
3	2000	299	1701	A	1500	8	A		0	
				B	201		B	200	0.8	128
				C						
4	1000	101	899	A	600					
				B	299					
				C						

Notional to realised non-point credit conversion rate						1.0				
Competitive Equilibrium						Pr = 120				
						Qty = 1500				
Point Source Players						Non-point Players				
Player	Target	trade	Prodn.	Product	Qty	Player	Product	Qty	Ratio	Credits
1	4500	500	4000	A	3000	5	A	0	0	0
				B	1000		B	500	1.1	550
				C		6	A	0	0	0
2	3000	300	2700	A	2000		B	400	1.3	520
				B	700	7	A	0	0	0
				C			B	300	0.9	270
3	2000	300	1700	A	1500	8	A	0	0	0
				B	200		B	200	0.8	160
				C						
4	1000	400	600	A	600					
				B						
				C						

Notional to realised non-point credit conversion rate						1.2				
Competitive Equilibrium						Pr = 100				
						Qty = 1400				
Point Source Players						Non-point Players				
Player	Target	trade	Prodn.	Product	Qty	Player	Product	Qty	Ratio	Credits
1	4500	500	4000	A	3000	5	A		0	
				B	1000		B	500	1.1	660
				C		6	A		0	
2	3000	400	2600	A	2000		B	400	1.3	624
				B	600	7	A		0	
				C			B	300	0.9	324
3	2000	500	1500	A	1500	8	A		0	
				B			B	200	0.8	192
				C						
4	1000	400	600	A	600					
				B						
				C						

Table 5. Mean Trade Prices and Quantities by Treatments

Treatment	Mean Market Price	Mean Quantity Traded	Total quantity Traded	Number of Trades
1. Certain non-point pollution credits	137.10[e] (1.649)	102.28[a] (5.464)	36514	357
2. Uncertain non-Pollution credits	137.71[e] (0.8067)	83.17[b] (4.199)	39089	470
3. Uncertain non-point pollution credits with banking	131.59 (0.7708)	93.67[ab] (5.457)	29601	316
4A. Uncertain non-point pollution credits, primary market	143.11 (0.9781)	73.28[bc] (5.261)	23011	314
4B. Uncertain non-point pollution credits, reconciliation market and banking options	135.33[e] (1.053)	66.43[c] (3.111)	21323	321

Note: Mean values with the same letter superscript are not significantly different at $\alpha = 0.05$

Table 6. Allocative Efficiency

Treatment	Efficiency
1. Certain non-point pollution credits	79.32%
2. Uncertain non-Pollution credits	78.89%
3. Uncertain non-point pollution credits with banking	88.89%
4. Uncertain non-point pollution credits, primary and reconciliation markets with banking options	86.67%

Figure 1. Market Prices given Certain Non-point Credits

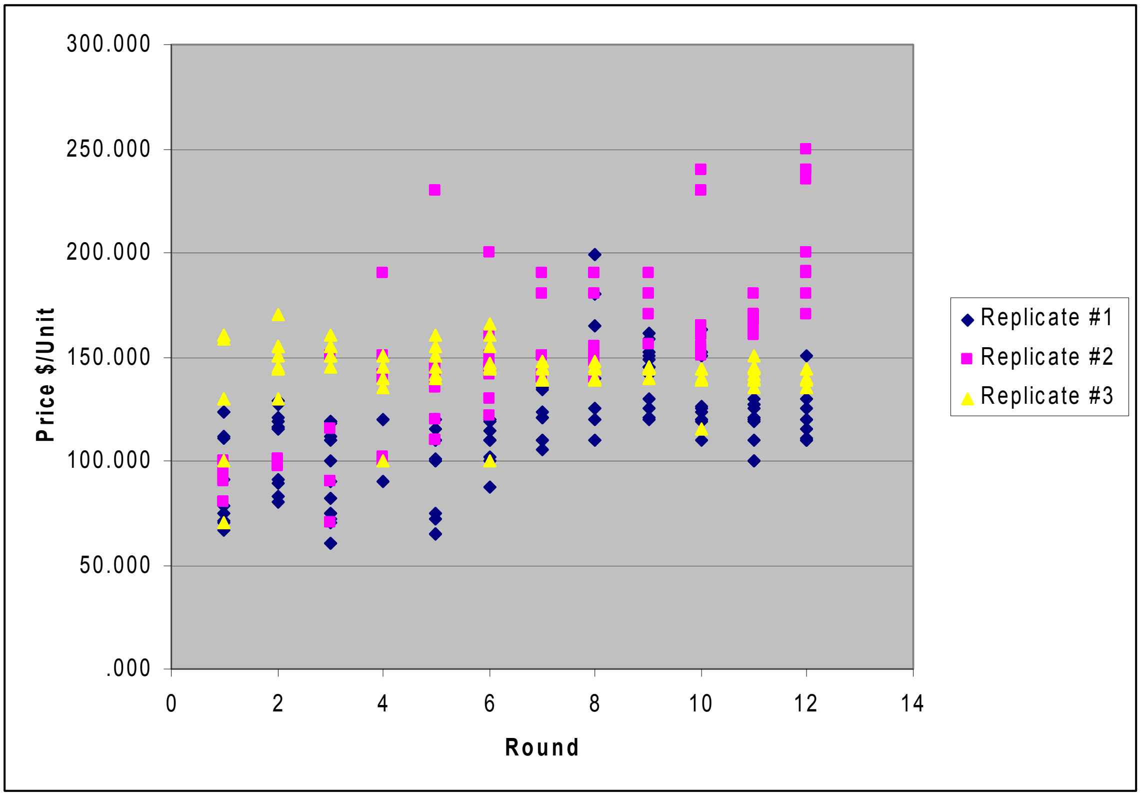

Figure 2. Production of Credits with Banking