Abatement Investment Decisions under Alternative Emissions Regulation: Preliminary Findings from an Economic Experiment[1]

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Abstract

Through laboratory experiments, we study the impact that emissions-regulating scheme design has on electricity generators' emissions-reducing investment decisions and on market efficiency. In particular, we study the impact of uncertainty of investment returns (in the form of endogenously-defined carbon offset permit price) on the magnitude and timing of these investments. We examine whether a well-designed tax, temporarily enforced for several periods prior to a cap and trade system's implementation, smooths the transition to cap and trade and increase overall market efficiency.

1. Introduction

As concern about the dangers of anthropogenically-induced climate change grows, there is increasing pressure on political leaders throughout the world to be more active in putting forth policies designed to combat rising greenhouse gas emissions. The question of which particular policies to implement still generates heated public debate (Kelly 2009; Drape 2012). The economics profession has since at least the 1980s agreed that incentive-based policy instruments are superior to standards-based instruments (Downing and White 1986; Tietenberg 2006; Aldy and Stavins 2012). This preference is now widely, if not uniformly, accepted by governments and by the public at large. There is

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still, however, a notable debate among economists and policy practitioners as to which specific instrument from the group of incentive-based policy instruments to choose. In particular, the question of whether it is best to implement price-based policy (e.g. a carbon tax) or quantity-based policy (e.g. an emissions trading scheme) is still largely unresolved.

One of the most important criteria when rating emissions control policies is the extent to which they motivate firms to adopt low-emissions technologies (Kneese and Schultze 1975). Emissions trading schemes (ETS) have become the norm in most countries aiming to regulate emissions, due in part to the business sector's perception that the direct market-based nature of an ETS would be preferable to a tax. However, there is insufficient evidence to conclude that an ETS actually yields a superior overall result compared to a carbon tax.

The theoretical foundations of incentive-based emissions policies suggest that when several assumptions hold, firms will achieve the emissions cap at least cost under a cap and trade regime. However, the least-cost outcome based on an ETS relies on strong assumptions of no transaction costs, perfect information, no market power and agents' risk neutrality in the face of uncertainty. These assumptions may be too strong to be realistic (Betz and Gunnthorsdottir 2009; Hahn and Stavins 2011). It is known from decision theory that the high uncertainty with regards to the future prices for tradable permits (i.e. future return on investment in abatement) significantly affects firms' incentives to invest (Kahneman and Tversky 1979). The distorted investment patterns that arise from the inherent uncertainty about future prices of permits in an ETS can result in inefficient market outcomes (too much or too little investment; too-high, too-low or unstable trading prices for permits over the long term), thereby raising the overall compliance cost for the market (Malueg 1989; Aldy and Stavins 2011; Hahn and Stavins 2011).

On the other hand, a revenue neutral tax that does not alter the distribution of taxation burden or taxation income in a society and that is set by a benevolent regulator, presents itself as a potentially simpler and more attractive mechanism to induce emission reduction. Compared to an ETS, a tax carries greater certainty about returns on investment in abatement, which should result in less distorted investment patterns. Recent experimental and theoretical findings evidence that priced-based policies (taxes) better motivate optimal investment patterns due to the greater certainty in the investment returns (Requate and Unold 2003; Requate 2005).[7] In spite of greater certainty that a tax instrument could achieve, new taxes (particularly those with no appointed end-date) consistently suffer strong political opposition. This has been most recently evidenced with the fierce political and public backlash to the imposition of a carbon tax in Australia (Shanahan 2012).

In light of the problems associated with an ETS and with a carbon tax, a 'hybridization' of the two policies could be a helpful compromise between the two systems. While installing a perpetuating tax on emissions is an unappealing or perhaps impossible venture for most politicians, a finite tax that would convert to an ETS at a pre-specified

[7] See Requate 2005 for a more comprehensive overview of adoption and implementation incentives resulting from environmental policy instruments.

time might pass more easily through a legislature. An ETS would proceed once the tax expires, providing a longer-term, direct market-based incentive for firms to continue to emit at the target level. Since a tax would precede the ETS, the uncertainty with regard to future return on investment could be reduced, conceivably resulting in an optimal investment pattern and a target-abiding emissions level.

The objective of this paper is to test the effect of the design of a regulatory scheme on emissions-reducing investment decisions. In particular, we study behavioral responses to a newly-implemented taxation regime on CO_2 emissions versus an ETS regime with tradable permits for CO_2 emissions. These two well known regulatory designs are then contrasted to a third, so called "hybrid," design that involves an initial period of a taxation regime, followed by an ETS-like regime. This hybrid design is motivated by the current policy in force in Australia.

We ask whether a well-designed tax, temporarily enforced for several periods prior to an ETS system's implementation, might smooth the transition to an ETS and increase overall efficiency of the regulation. As far as the authors are aware, this is the first study that explicitly examines this type of hybridized design in which a price-based instrument is sequentially followed by a quantity based instrument over time. The combined use of price and quantity instruments in a static sense (at a single point of time) is widely known in the literature, but the dynamic combination of the two instruments has not yet been studied.

The paper is organized as follows: the next section will refer to some related experimental literature. Section 3 will outline the theoretical underpinnings of our model and experiment. Section 4 will include a description of the experimental methods and procedure. Section 5 will convey the results. Section 6 discusses some implications carried by the results and suggestions for future research, and concludes.

2. Previous Literature

From the early 1980s, theoretical, empirical and experimental studies focused on emissions-reducing mechanisms have debated and tested the relative benefits to various design characteristics. While many studies have tested different aspects of emissions-regulating mechanism design (i.e., auction types, permit banking[8]), few have investigated the differences in investment cost patterns that regulations motivate in emitting agents.

Early models, such as the one presented by Downing and White (1986), graded regulations by their resulting aggregate costs on an industry-wide level. Their models suggest that an auction-based tradable permit system would yield more efficient investment outcomes than a tax or non-auctioned (grandfathered) permits.

Requate (2003) deepened the scope of analysis from investment costs on the market level to explore the individual firms' investment decision under specific regimes, and argued that taxes could provide long lasting, stable incentives for investments, while permit

[8] More extensive reviews of the experimental emissions trading literature can be found in Bohm (2003) and Requate (2005).

prices are likely to fall when many firms invest, and eventually yield lower investment levels.

The uncertainty inherent in evaluating the return that an efficiency investment will yield is a key concern when weighing a tax versus an ETS. Hahn and Stavins (2011) draw attention to agents' frequent failure to undertake cost-minimizing investments because they lack the information needed to cost-effectively invest. Pezzey and Jotzo (2012) further explore the implications of this uncertainty in a model that allows for imperfect information and less-than-perfectly rational actors. Pezzey and Jotzo illustrate multiple ways in which the greater uncertainty inherent in ETS regulations could yield less optimal investment by agents than a tax.

Camacho-Cuena and Requate (2012) also relax the perfect-information assumptions. In their model and experiment, liable entities lack perfect information about others' emissions profiles and investment decisions. They use experimental methods to test the investment decisions of individual agents under three different regimes, observing higher overall efficiency under an ETS than under a tax.

3. Theoretical Foundations

The experiment is designed to mimic an industry composed of agents (firms) that emit CO_2 under their initial technology and can upgrade (not overhaul) their production technology in the face of government regulation aimed at curbing aggregate CO_2

emissions.[9] The study's design is motivated by the electricity sector, as it is one of the largest emitters of greenhouse gases in Australia and globally. The study is however, completely decontextualised, and therefore has a significance that goes well beyond the electricity generation sector. We assume that all agents in this market are small, and therefore do not influence the tax rate or price of the units produced and ultimately sold in an external market.

In the model, *n* individual agents maximize profits by optimizing their production technology and producing output in a round of 13 sequential periods. Producing output entails generating emissions, which in this case was articulated to the agents as using inputs. This can be seen as using a credit (or allowance) to emit, as an input in the production activity. An emission restriction is exogenously implemented, e.g. by the government, midway through the round. The agents can choose to abide by the restriction by cutting back production (and commensurately emissions), or by investing in an abatement technology with which they could produce same amount of output but with less associated emissions, or both.

Our designed environment includes 8 agents that are endowed with technology unique to each of them. This asymmetric design was motivated by concerns about coordination problems that arise under firm symmetry (Requate and Unold 2003). The strategic issue of who should invest when, given that if others invest a firm might be better off waiting to buy permits in the market, is not nicely resolved when firms are symmetric. Under

[9] The market here is composed of firms that incorporate new technologies into their original portfolios rather than abandon their old capital for a fully new set of equipment. This feature yields a market of producers with unique emissions efficiencies before and after investment.

market symmetry it doesn't matter which firms invest, but it does matter how many firms invest. The coordination problem means that too many or too few firms invest, yielding sub-optimally high investment costs. Previous similar experimental studies that attempt to create an asymmetric market limit asymmetry to the initial technologies. In these studies, the asymmetry disappears after investment; agents only have the option to upgrade to a single (symmetric) efficient technology. Recently published work suggests that the coordination problem persists in these environments (Camacho-Cuena and Requate 2012).

In the experiment described in this paper Agents *i*, are endowed with one of *n* unique initial technologies A_i = [1, …, *n*], with a baseline emissions profile $e(A_i)$. The profitability of each technology is dependent on the level of production and on each agent's abatement cost structure. From his or her initial technology, an agent may invest in up to four technology upgrades $U_i=[V_i,\ldots, Y_i]$, each of which will increase her emissions-efficiency, i.e. reduce emissions per unit of production by a further 10 percent from the initial level A_i (e.g. $e(U_i) = (1-k)e(A_i)$, $k = 0.1, 0.2, 0.3, 0.4$).

Each upgrade has a positive, increasing investment cost *IC*. The cost for the first investment *V* is greater than zero and less than subsequent investment options (W, X, Y) $IC(W_i) > IC(V_i) > 0$, and all investment costs are specific to an individual agent *i*. The model assumes that the expense associated with improving a more efficient technology (relatively fewer emissions per unit of output) by 10 percent is greater than the expense of improving a relatively less-efficient portfolio by 10 percent. This is operationalised by imposing a restriction that the price to upgrade is lowest for agents with least-efficient initial technology and highest for agents with most efficient initial technology.

This model includes upgrade opportunities that maintain technology asymmetry through the duration of the session. The added complexity allowed by the proportional upgrades also allows for clearer application of this study's findings. Since each agent type maintains a unique value for a permit under this setup, the market provides a greater opportunity to transact more efficiently.

In the experiment, some information about aggregate outcomes in individual periods is provided to participants (the agents). Importantly, and in a departure from previous studies (e.g. Camacho-Cuena & Requate, 2012) at the end of each period participants were provided with information on the total number of upgrades (effectively units of investment) that have been undertaken by all participants in that period. This design choice was made to improve transparency in the lab (in the real world, firms are likely to know once another firm has undertaken a large upgrade) and to minimize the magnitude of the described coordination problem that has been found in previous studies (Requate and Unold 2003; Camacho-Cuena and Requate 2012).

An aggregate desired emissions level E^* is exogenously imposed by a regulator. The regulator chooses either the emissions cap directly, or imposes a corresponding emissions tax rate to ensure (at least in theory) that E^* is attained. The aggregate emissions level E is the sum of individual firms' emissions, $E = \sum_{i=1}^{n}(e_i)$. In this asymmetric market, the theoretical setup was that some portion of the firms *j* (n – j, …, n) should upgrade their technology, while the remaining firms (1, …, n-j-1) should not invest in abatement. A regulator with full information can determine the minimum abatement costs and the optimal upgrades for each agent according to the defined cap level or tax rate.

An agent with original technology *i* has an incentive to upgrade their technology until the level at which the incremental upgrade costs (marginal abatement costs) equal the price of emitting or the price of an input (either the tax rate or the equilibrium permit price). If maximum profit with initial technology A is the production income less the cost C of emitting with the initial technology at that level: $\pi_i^{A_i} = Y_i - C(A_i)$, and maximum profit with upgraded technology production income less the cost C of emitting with the upgraded technology less the investment costs *IC*: $\pi_i^{U_i} = Y_i - C(U_i) - \sum_A^U IC(U_i)$, agent *i* should upgrade until the investment costs equal the difference in the cost of emitting $\sum_A^U IC(U_i) = C(A_i) - C(U_i)$.

In the model, agents know with full certainty the future tax level (when applicable), the number of permits that they will be allocated once the cap is put into place (when applicable), and the time at which the regulation with be implemented.

Under a tax, agents should invest until marginal investment costs equal the (known) marginal tax rate. Under an ETS, future permit prices are unknown, so agents should wait for information about other agents' investments before executing their own investments. Individuals' optimal investment decisions depend on the emissions price (the tax, or a permit's traded price). In the theoretical parameters used in this study, the marginal tax rate is within the range of equilibrium permit prices obtainable from an optimal aggregate and individual investment behavior.

Theoretically, and as is the proclaimed policy objectives of cap and trade systems, agents with the highest potential returns to investment relative to their investment costs (i.e., lower abatement costs) should move first and invest. Their early investment will provide a signal to agents with higher abatement costs that there may be opportunities to purchase permits at prices that are likely to be lower than their own abatement costs. Under perfect information, the equilibrium level of investment and production theoretically converges to the one under the tax regime. This design results with optimal investment levels that are equivalent for each of the eight agents under all of the three regimes in a Nash equilibrium. For each agent, the Nash equilibrium abatement investment and production decisions are the same in all treatments.

4. Experimental Design and Procedure

We compare agents' behavior under the three regulatory regimes (treatments) via an economic experiment. The experiment was programmed and conducted with the software z-Tree in an experimental laboratory at the University of Sydney (Fischbacher 2007).

Parameters and treatments

The participants' (Agents') task was to earn as much profit as possible during the experimental session. Each Participant faced a unique linear production function, unique investment costs and finite production capacity. Participants selected a production level to maximize their income each period. They could invest in upgrades to increase their efficiency. Participants played four rounds in a session. All rounds in a session were of the same treatment, and participants maintained the same character endowments for the four rounds.

A round consisted of 13 periods. Each period included three stages:

1. Investment Stage (60 seconds). At the start of every period (except for period one), participants could invest in an upgrade that would reduce their emissions (represented by their production costs) by 10 percent each. Emissions were referred to as Inputs, and each production level required a certain number of Inputs. An upgrade reduced the number of Inputs required per production level by 10 percent. Participants could select up to four incremental upgrades (one upgrade per period). The maximum four upgrades would carry a cumulative 40 percent reduction. Any upgrade was irreversible and lasted for all the remaining periods in the round.
2. Production and Trading Stage (60 seconds). Participants selected a Production Level between 0 and 10 each period. The costs (emissions) and profits associated with each production level were known to participants. In the treatments with an ETS, a single unit double auction was also active during this stage.
3. Summary Stage (15 seconds). Participants were shown a summary of their personal performance for the previous period and the cumulative number of investments undertaken by all participants in that period.

An experimental session consisted of 4 replications (rounds) of 13 periods. Participants could earn income in each replication. Four replications per session were held in order to allow for our observation of participants' behavior before and after learning and to control for noise. All rounds in a session were identical in that the same Treatment and Producer characteristics were imposed for the duration of a round. Treatments were characterized by the regulation type. Treatment 1 was a tax regime, Treatment 2 was a hybrid regime, and Treatment 3 was an ETS regime. The first 5 periods of each round were a liability-free phase, in which participants had the opportunity to produce with no emissions costs, and to invest. The emissions regulation (tax or trading) was implemented at period 6 of each round. Participants knew the sequence and timing of regime implementation within a round in advance of the round's beginning.

In the treatments with trading, emissions permits were symmetrically grandfathered to the participants each period from the first period that trading became active. A single unit double auction was selected as the trading mechanism in the designed environment due to its easily understood and utilized design, particularly the ease of placing and accepting bids and asks. Smith (1962) provides extensive evidence of the double auction's tendency to elicit best-possible market results in experimental environments. The findings presented by Camacho-Cuena et al. (2012) strongly suggest that the type of auction used after an initial distribution of permits does not have a significant effect on the pattern of technology adoption in their environment which is similar to the one reported in the present paper.

In periods with trading, the market for participants to buy and sell Inputs was open for 60 seconds.[10] Participants could submit as many bids or asks (and buy and sell as many Inputs) as they like within the trading period. Each bid or ask was for a single unit (Input). The screen displayed the best current bid and ask at all times. To execute a trade, buyers or sellers had to click on the bid or ask that they were willing to transact for. Each transaction is for one Input. A record of each transacted price from the current period was displayed on participants' screens.[11]

Experimental Procedure

On entering the lab, each subject was randomly assigned a role as one of 8 Participants. Each session was randomly assigned to one of the three treatments. Comprehensive instructions about the game's mechanism were provided in a video.[12] After viewing, participants completed a quiz to demonstrate their understanding of the instructions.

All participants were students at the University of Sydney who were recruited via the University's ORSEE database of student volunteers (Greiner 2004). Payments were in Australian dollars. Each participant was given a A$10 show-up fee and could earn an additional A$30 during the 2-hour session; participants took home an average of A$33.21.[13] Participants were informed of their personal exchange rate before beginning

[10] Screenshots can be found in Appendix 2.
[11] In advance of running the experiment sessions discussed in this paper, we ran a set of trial sessions. The purpose of these trials was to ensure that the software and instructions were robust. In advance of the trials, we considered setting a binding price floor for permits to be traded in the market. Because we observed trading prices in the paid trial were not extremely high or low (and we observed no price bubble or crash), we elected not to include a price floor in the experimental sessions described here.
[12] Video instructions are available from the authors upon request.
[13] This sum (A$20/hour) is slightly greater than a typical student job's pay rate in Sydney.

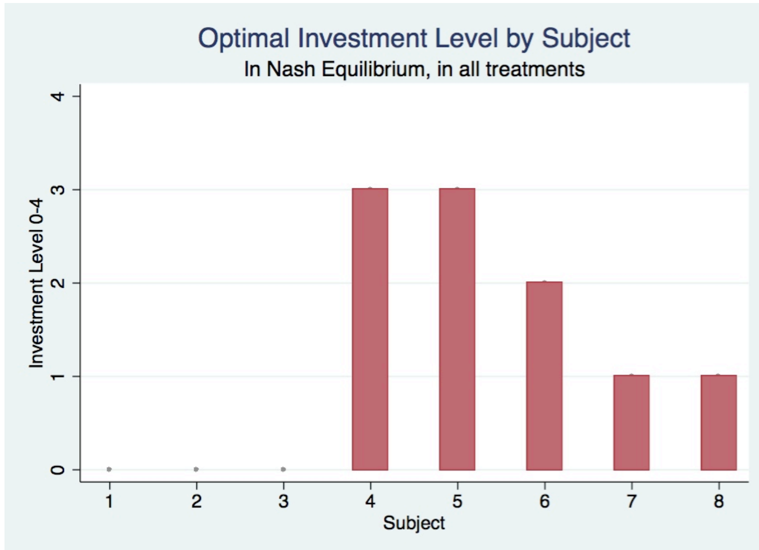
the session. The exchange rates (Experimental dollars to Australian dollars) were adjusted for each Participant's characteristics so that each participant had the opportunity to earn an equivalent payout (see exchange rates in Appendix 1). Each participant participated in only one session.

5. Results

This section presents some preliminary results from the first set of sessions completed. As of January 2013, three sessions per treatment were run (out of planned five). Each session was comprised of four rounds. The behavior in the first round, fourth round and overall is analyzed here to provide a cross-section of responses to the three regulations at the initial experience, and after some learning has taken place. Behavior under the three regulations was easily compared because each participant's optimal behavior (Nash Equilibria for investment magnitude and production level) is the same under each regime (Figure 1).[14]

[14] See Appendix Table 2 for a detailed list of optimal investment levels.

Figure 1 Optimal Investments



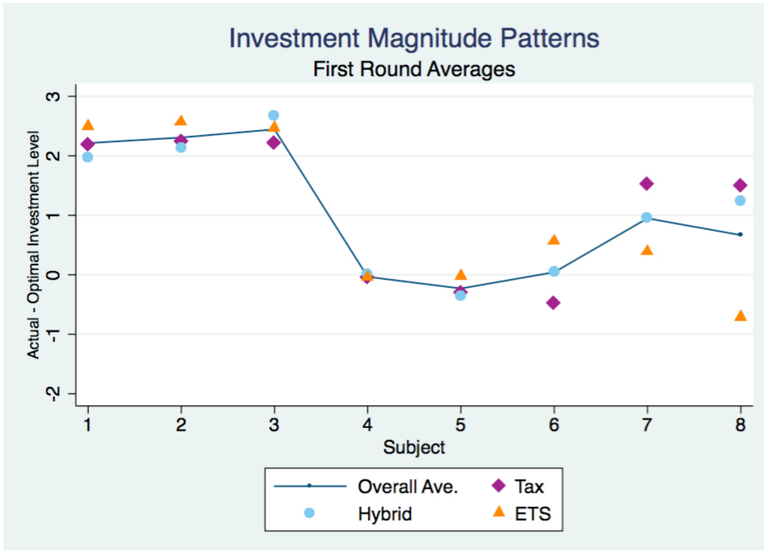
Investment cost efficiency

We measure investment cost efficiency as the actual costs incurred for efficiency upgrades (investments) relative to the minimal (optimal) costs to be incurred under the defined tax rate or a specified emissions cap: $\frac{\min \sum_{i=1}^{n} IC(U_i)}{\sum_{i=1}^{n} IC(U_i)}$.

We found that on average, participants overinvested most under the tax and least under the ETS under the initial round of play (Figure 2).[15]

[15] This result may be attributable to a tax aversion. The difference between treatments is not significant at a 90 percent significant level.

Figure 2 Investment Levels (Round 1)



Learning demonstrated in investment costs patterns

Overinvestment is found at different magnitudes in all treatments, but the extra costs incurred by investing more heavily than necessary to achieve the defined cap are highest in the initial round and decrease significantly (at a 99% confidence level) from Round 1 to Round 3 and 4 (Table 1).

Table 1 Comparison of total investment costs by Round (Bonferroni)
** p-value shows a difference between rounds at a 99% significance level

Round	1	2	3
2	-566.833		
	0.119		
3	-1036.28	-469.444	
	p: 0.001***	0.303	
4	-1107.17	-540.333	-70.8889
	p: 0.000***	0.154	1.000

As seen in Figure 3, excess investment costs (meaning costs incurred by overinvestments) clearly converge to zero (i.e., investment costs converge to the optimal) under the tax and the ETS treatments (Figure 3). Excess investment costs do not follow this trend under the hybrid treatment. Specifically, none of the hybrid observations achieve as optimal investment patterns as do the two lowest ETS and tax sessions. Excess costs decrease most in the tax treatment, second in the ETS and least in the hybrid. The decrease in costs between Rounds 3 and 4 is not significant in any treatment, or overall. The differences between treatments illustrated here are not significant at a 95% confidence level. However, more sessions' worth of data may yield greater insight in terms of this measure.

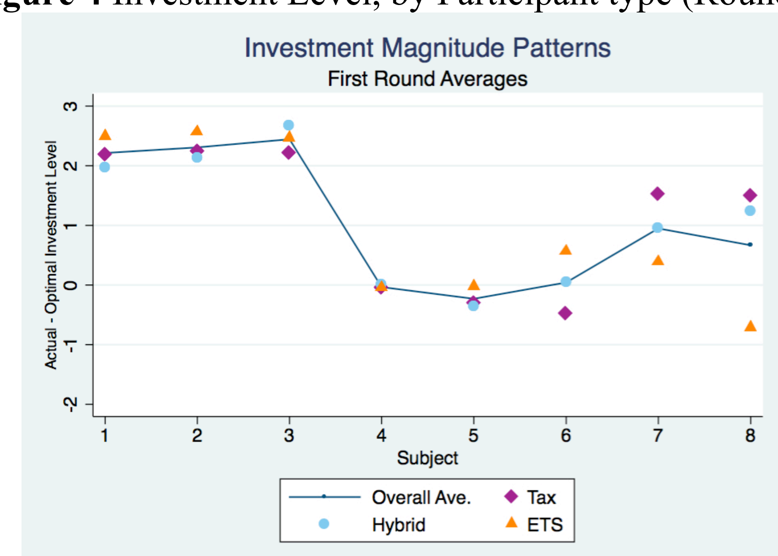
Figure 3 Comparison of Extra Investment Costs incurred, by Round and Treatment

Differences in Investment, by Participant type

The parameters used in this experiment endow Participant 1 with the least efficient initial technology (*A_i*) and Player 8 with the most efficient initial technology. Players 2 through

7 fall in a continuum from less to more efficient. In the first round, the participants with the most extreme cost structures of initial technologies (highest and lowest efficiency) consistently made significantly different investment decisions under the ETS than under the tax or hybrid treatments. Specifically, Participant 8 underinvested under the ETS, and overinvested under the tax and hybrid treatments. In the first round, the least efficient participant (Player 1[*]), who should not have invested at all, overinvested in all treatments. The magnitude of Player 1's overinvestment was greater under the hybrid and ETS treatments than tax (Figure 4).

Figure 4 Investment Level, by Participant type (Round 1)

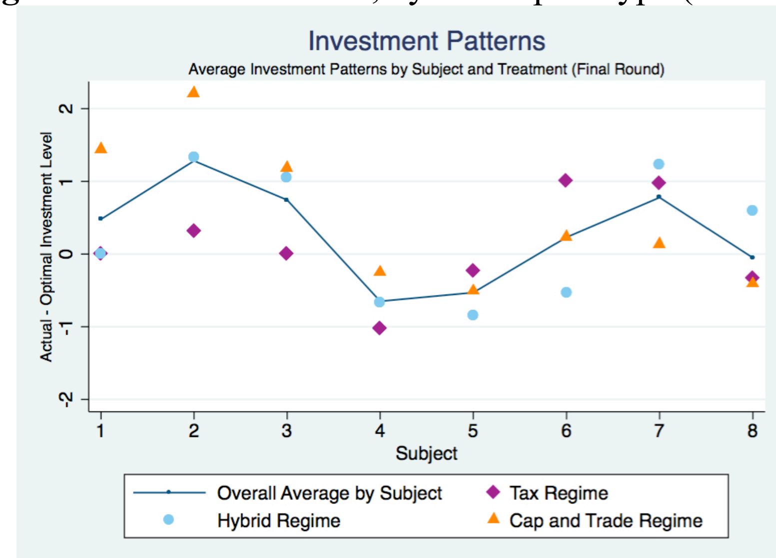


Participants' 1, 2 and 3, the low-efficiency participant types, are best off not upgrading their technologies under Nash Equilibrium. In all treatments, these participants tended to overinvest in early rounds, but invested closer to the zero (optimal) level in later rounds. Later round investments patterns by low-efficiency players were closest to optimal (zero investment) under the tax and furthest from optimal (most overinvestment) under the ETS. Overall (and in Rounds 3 and 4), Players 1, 2 and 3 overinvest significantly more under hybrid and ETS treatments than they do under the tax treatment ($F = 8.06$, $p > F$: 0.0006). Notably, even after upgrading, the efficiency of Players 1-3 was still so low that their final opportunity cost of using a permit for production was lower than the price for which they could sell it in the market.

The participants who start with moderately efficient technology (Participants 4 and 5) underinvested overall and in the final rounds. Their investment levels did not significantly differ across treatments.

The participants who start with the most efficient technologies (Participants 6, 7, 8) overinvested overall and in the final rounds. Overinvestment levels were more equivalent for the less-extreme participants (6 and 7) under the three treatments. This result (underinvestment by less efficient participants and overinvestment by the more efficient) is in line with the findings presented by Camacho-Cuena (2012) and Ganghadharan et al. (2010). Participant 8 (very efficient) invested much closer to the optimal level under ETS and tax than under hybrid in the fourth round (and underinvested under ETS overall) (Figure 5).

Figure 5 Investment Level, by Participant type (Round 4)



Trading Efficiency

We define efficiency in trades as the difference in permits' trading prices P to the equilibrium price given the actual investment pattern, P^*.

$$\textbf{Trade Efficiency in a Period } \frac{1}{1-mean(QP-QP^*)}.$$

We observe lower trading prices for permits, higher trade efficiency, and lower volatility in permits' trading prices in the Hybrid treatment than ETS. Trade prices were significantly less optimal (higher than the equilibrium) in the ETS than prices for permits in the hybrid. Per the above definition, this means that trading efficiency is higher under the hybrid regime than under the ETS. Overall, permits under the hybrid regime were traded at prices significantly closer to the upper bound of the equilibrium price range than were permit prices in the ETS treatments (p = 0.0391**).[16] Trading prices observed under

[16] We do not observe a significant difference in individual rounds, though this result may change with more observations.

the hybrid were significantly lower than ETS prices at a 95 percent significance level in the initial two rounds. Higher volatility in trading prices during the initial period of first round trading, and the overall volatility in the entirety of the first round of trading, was greater in the ETS than the hybrid. We do not observe significant speculative trading in either treatment.

Table 2 **Summary of Mean Permit Prices and Standard Deviation by Round, Test for Equal Trade Efficiency**

	Hybrid R1	Hybrid R2	Hybrid R3	Hybrid R4
ETS R1	Hybrid: 19.61 (6.23) ETS: 23.90 (7.66) F: 20.82 p: 0.0000***			
ETS R2		Hybrid: 19.32 (7.35) ETS: 20.75 (3.95) F: 4.65 p: 0.0319**		
ETS R3			Hybrid: 17.79 (4.63) ETS: 20.18 (11.08) F: 0.18 p: 0.6695	
ETS R4				Hybrid: 19.98 (3.05) ETS: 19.74 (4.74) F: 0.33 p: 0.565

Overall Efficiency

We measure the overall efficiency of a market under a new regime as the minimum total abatement cost divided by the actual total abatement cost $\frac{TAC^*}{TAC}$. Total abatement costs (TAC) are made up of aggregate investment costs (IC), reduction in production income at the profit-maximizing production levels from a restriction-free period (0) to the regulated period (R) and taxes due. The optimal total abatement cost, TAC^*, can be denoted:

$\sum_{i=1}^{n} IC(U_i) + (Y_0 - Y_R)$ + Tax, and overall efficiency:

$$\text{Overall Efficiency: } \frac{\min \sum_{i=1}^{n} IC^*(U_i^*) + (Y_0 - Y_R^*) + Tax^*}{\sum_{i=1}^{n} IC(U_i) + (Y_0 - Y_R) + Tax}$$

Overall efficiency is highest in the tax treatment and lowest in the ETS treatment. We observe a significant difference between the overall efficiency in the tax versus ETS treatments in all periods (p=0.0537*) and in the last two rounds (p = 0.0317**).

6. Discussion and Conclusion

The objective of this study was to investigate and compare efficiencies under different regulations via experimental methods. Strategic uncertainty under a new cap and trade (ETS) is known to motivate suboptimal investment patterns (both over and under-investment) among liable firms, and potentially inefficient and volatile trading in a permit market. We developed an economic experiment to test whether there would be a difference in the behavioural responses to three different regimes, with all characteristics of the environment held constant except for the nature of the regulation.

It has been suggested that a temporary tax, in place for some time in advance of the ETS system, might reduce strategic uncertainty enough to elicit significantly more optimal investment patterns. In this study, we were interested in exploring whether use of a tax as an introduction to a cap and trade regime would motivate more efficient investments and behavior in the permit market than would a simple cap and trade (ETS) regime during the implementation period.

Specifically, we hypothesized that the higher certainty characteristic of a tax would yield more efficient decisions under a full tax than the other two regimes, and that implementing a temporary tax in advance of a trading system would result in higher efficiency under a hybridized regulation than an ETS regime.

Preliminary results suggest that both the hybrid and ETS systems have relative strengths and weaknesses in the laboratory environment. These results show that as expected, participants invest more efficiently under a tax regime than under an ETS regime. However, early tests of the results do not show a significant difference between investment efficiency under the hybrid system to ETS. Contrary to our hypotheses, we observe that participants overinvest at a slightly higher magnitude under the hybrid system than under a simple ETS regime. We hypothesize that the relatively suboptimal decisions may result from the added complexity of the regulating rules.

The hybridized system does not always perform worse than the ETS. Specifically, use of a tax as introduction to an ETS seems to result in more efficient permit market behavior than does a simple ETS (permits are traded at prices that are lower and closer to the upper bound equilibrium price level in the hybrid treatments than the ETS). These results indicate that a greater certainty with regards to return on investments in abatement ultimately informs a more efficient market. This result warrants further study, with particular attention to be paid to how much the tax rate acts as a strong price anchor. In the current parameters, the tax rate equals the equilibrium price under a perfect investment pattern, and there is no price ceiling. A reasonable next step would be to investigate how behavior would react under a suboptimal (too high or too low) short-term tax rate, or within a market with a price floor or price ceiling.

We plan to next explore the effect of an additional layer of political uncertainty on these behaviours. We are in the process of developing additional treatments that will allow us to further investigate whether less certainty about future regulations results in a significantly less-efficient market than do the full-certainty treatments. Specifically, we plan to introduce uncertainty about the implementation, or timing of an implementation of a planned future ETS, and then study the effect of this additional uncertainty on investment and market efficiency.

It should not be overlooked that due to the limited number of observations, the results presented in this version of the paper are preliminary. We plan to gather additional observations from the same setup and treatments that we have presented here in order to test the treatments more thoroughly.

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Appendices

Appendix 1: Tables

Appendix Table 1: Exchange Rates (E$ to AU$1)

Subject	Treatment 1 (Tax)	Treatment 2 (Hybrid)	Treatment 3 (Cap and Trade)
1	E$50	E$103	E$135
2	67	120	152
3	83	137	169
4	111	164	195
5	154	207	239
6	190	243	275
7	226	280	312
8	263	316	348

Appendix Table 2: Optimal Investment Level and Cost, by Participant Type

Participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Optimal Upgrade Level	0	0	0	3	3	2	1	1	10
Optimal Investment Cost (E$)	0	0	0	225	225	150	75	125	800

Appendix Table 3: Average Number of Upgrades above Optima

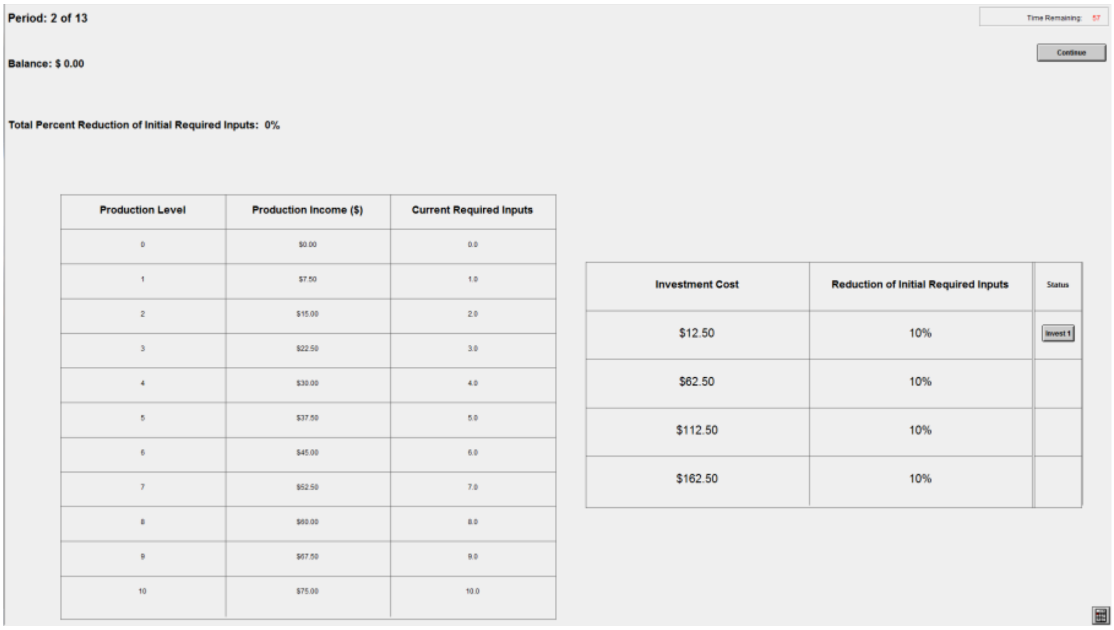
	Round				
Treatment	**1**	**2**	**3**	**4**	**Totals by Treatment**
Tax	48	24	14	12	78
Hybrid	44	33	26	26	129
ETS	45	34	28	26	133

Appendix Table 4: Average Overall Efficiency by Round and Treatment

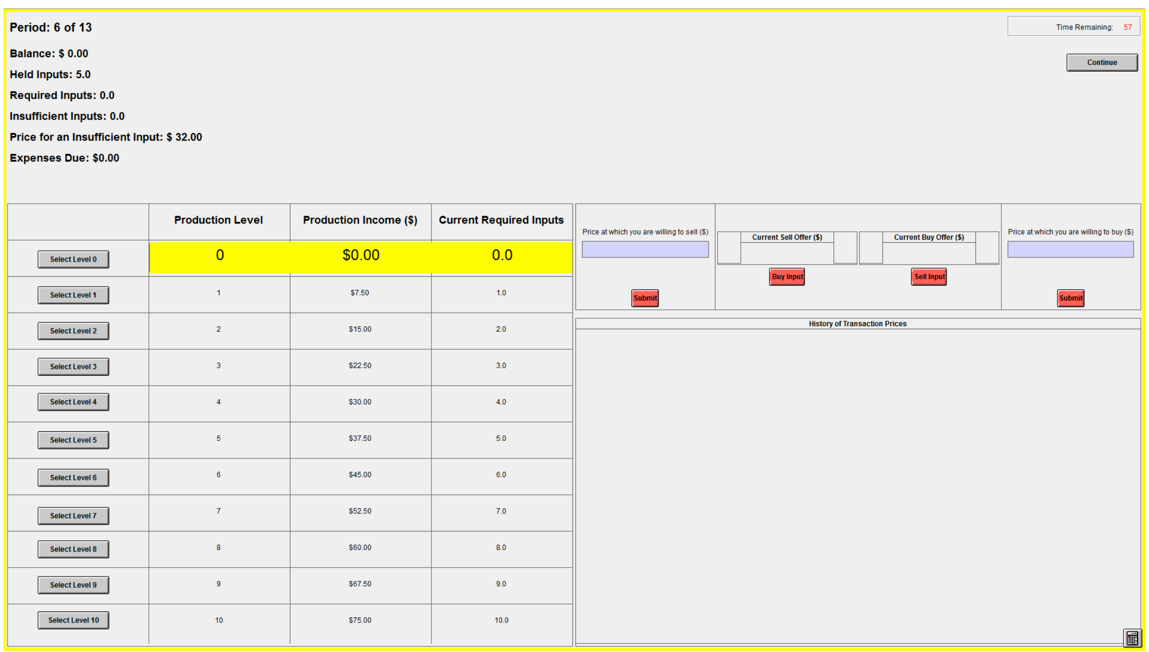
	Round				
Treatment	**1**	**2**	**3**	**4**	**Overall Average by Treatment**
Tax	.593	.785	.812	.825	.754
Hybrid	.535	.607	.721	.763	.657
ETS	.534	.610	.683	.731	.640

Appendix 2: Selected zTree screenshots

Participants' Screen, Investment Stage



Participants' Screen, Production Stage, with Trading



(Bohm 2003)

(Pezzey and Jotzo 2012)

(Smith 1962)

(Fischbacher 2007)

(Gangadharan 2005)