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Abstract

Incentive-based policies, such as emissions taxes and emissions permit trading schemes, are increasingly used to regulate greenhouse gas (GHG) emissions in many jurisdictions around the world. Taxes impose a fixed price on emissions, whereas under tradable permit schemes prices emerge in the secondary permit market. The delayed price discovery under tradable permit schemes creates uncertainty about the future cost of compliance that liable emitters will face. To mitigate this uncertainty, some jurisdictions, including Australia, have designed policies to regulate GHG emissions that commence with an emissions tax that is in force for several years, subsequently transforming into a tradable permit scheme. This paper examines the effects that this type of staged transition – from no regulation to a regulation by an emissions tax, to a regulation by tradable permits – has on several criteria of interest: abatement investment, quantity of emissions, permit prices and overall regulation efficiency. The effects of the regulation that employs an intertemporal mix of policy instruments are compared to the effects observable under regulation using single policy instrument: a tax only, and a tradable permit only regulation. Economics experiments in a laboratory were used to study economic behavior under these three types of regulation. The findings suggest that a regulation based on a staged transition from a tax to a tradable permit scheme results in more socially desirable outcomes on a range of criteria when compared to a regulation based solely on tradable permits.

Keywords: Abatement, Cap and Trade, Emission Markets, Environmental Policy, Emission Taxes, Permit Trading.

JEL classification: C92, D47, L51, Q28, Q55

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1. Introduction

Incentive-based policies, such as emissions taxes and emissions permit trading schemes, are increasingly used to regulate greenhouse gas (GHG) emissions in many jurisdictions around the world (Tietenberg, 2006). Emissions trading schemes have been implemented in the European Union in 2005 (Betz and Sato, 2006), in New Zealand in 2008 (Bullock, 2012), and in California in 2013 (Schobe et al., 2014); emissions taxes are in place in Norway (Bruvoll and Larsen, 2004), in several Canadian provinces (Sawyer and Gass, 2014), and in Ireland since 2010 (Conefrey et al., 2013); a contemporaneous policy mix (a hybrid of tax and a tradable scheme existing at the same time) operates in Switzerland since 2008 (IETA 2013), and an intertemporal policy mix with a staged transition from an emissions tax to an emissions trading scheme was initiated in Quebec in 2011 (Sawyer and Gass, 2014) and in Australia in 2012 (Rootes, 2014).

Although the desirability of incentive-based policy instruments is widely documented (Downing and White, 1986, Tietenberg, 2006, Aldy and Stavins, 2012), the choice of which specific incentive-based policy instrument to implement still generates significant debate (Goulder and Schein, 2013). Tradable permit schemes are seen as more popular and politically more palatable regulation compared to a tax, largely due to the business sector's perception that the direct market-based nature of the tradable permits impose lower compliance costs on emitters compared to a tax (Svendsen, 1999). However, there is no clear-cut evidence in the literature confirming this is so. In particular, the argument that tradable permit schemes are cost-effective relative to taxes relies critically on the assumption of the absence of transaction costs and market power, and of risk-neutrality and availability of full information. These assumptions have been shown to be untenable, particularly because of the effects that market uncertainty has on abatement investment decisions (Betz and Gunnthorsdottir, 2009; Hahn and Stavins, 2011). Uncertainty about future emissions permit prices can lead firms to invest more or less than the optimal levels of abatement (Malueg, 1989); thereby raising the total social cost of regulation (Aldy and Stavins, 2012; Hahn and Stavins, 2011).

On the other hand, a tax presents itself as a potentially simpler regulation for emissions reduction. An emissions tax could be set at a rate that would impel polluters to curb emissions to the target level (Milliman and Prince, 1989). The steady price signal provided by a tax lends emitters a greater certainty about future compliance costs and the benefit of undertaking investment in abatement. Under certain conditions, an appropriately set tax could result in lowest cost of compliance (Requate, 2005). However, a GHG emissions tax can prove to be extraordinarily unpopular, as testified by the recent political events in Australia, where the parliamentary elections in 2013 revolved heavily around the so called 'Carbon Tax', and the incumbent government that instituted the tax was subsequently voted out (Rootes, 2014).[1]

In light of the drawbacks associated both with emissions trading and with taxing emissions, a mix of the two policies could be a helpful compromise. While installing an ongoing tax on emissions in a previously unregulated jurisdiction maybe seen as politically impractical venture, a temporary tax that would subsequently convert to a tradable permit scheme at a pre-specified and agreed-upon time might pass more easily through a contentious political process. Indeed, this type of transitional regulation did become law in Australia (Rootes 2014 and Appendix A.1). A key benefit of this design is that the fixed temporary tax could reduce the uncertainty about future compliance costs by providing a price signal during the initial tax stage. If set properly, this signal would conceivably lead to production and abatement investment decisions on the part of emitters that are in line with socially optimal outcomes. Once the tax stage expires, an ongoing emissions trading scheme would be implemented over a long-term.

[1] See Appendix A.1 for a brief overview of the recent events around the GHG emissions reduction policy (and politics) in Australia.

The main question pursued in this paper is whether an inter-temporally mixed regulation, comprised of an emissions tax temporarily enforced for several periods prior to an implementation of a tradable permit scheme, would improve the performance of an emission regulation in comparison to a single instrument policy, e.g. an outright tradable permit scheme. The performance of the regulation is evaluated along several key criteria of interest: optimality of investment in abatement technology, quantity of emissions, and permit prices. The overall performance of tested regulation is evaluated by its efficiency in relation to the theoretical optimum.

The use of a mix of policy instruments in a static sense is widely known in the literature (e.g., Roberts and Spence, 1976; Pizer, 2002; Krysiak and Oberauner, 2010; also Shobe et al., 2014 write about a 'hybrid approach' implemented in California), but the inter-temporal mix, or an inter-temporal hybrid of an emissions tax and a tradable permit scheme has not yet been investigated in detail. As far as the authors are aware, this is the first study that explicitly examines this type of inter-temporally hybridized policy design, in which a tradable permit scheme sequentially follows an emissions tax.

This paper reports on laboratory economics experiments that are used to study economic behavior under three types of regulation: tax only, tradable permit scheme only, and an inter-temporal policy mix of a tax followed by tradable permit scheme. Following Smith's (1982) defining work with laboratory experiments as useful test beds for market based solutions as policy alternatives, several experimental studies that focused specifically on emissions regulation emerged in the 1990s (Cason and Plott, 1996; Cronshaw and Kruse, 1999). Muller and Mestelman (1998) provide a comprehensive review of the early experiments related to emissions regulations, which laid a foundation for the contemporary work in the field. The more recent literature reporting on experimental studies in the context of regulation of emissions is reviewed by Cason (2010) and by Friesen and Gangadharan (2013). The work presented in the current paper is most closely related to the experiment reported by Camacho-Cuena et al. (2012), who focused directly on the effects that particular permit allocation schemes have on participants' decisions to abate.

The paper is organized as follows: the next section outlines the theoretical underpinnings of the experiment, followed by a description of the experimental setup and procedures. The discussion proceeds with a section that presents the results, and the ultimate section concludes by discussing some policy implications of the findings and avenues for future research.

2. Conceptual framework

To set the stage for the experimental economics work presented in the subsequent sections, we rely on a theoretical framework based on standard premises of environmental economics. Let us assume that a benevolent regulator representing societal preferences for environmental quality aims to regulate emissions of GHGs. The objective of the regulator is to regulate emissions at lowest overall social cost, so that the sum of the cost of reducing emissions (cost of abatement) and the cost of damages from remaining emissions is minimised (Freeman et al., 1973). This can be represented by:

$$\min_{L^*} \sum_i AC_i(l_i) + DC(L^*) \tag{1}$$

where L^* is the socially optimal level of aggregate emissions; AC_i is the cost of emissions abatement incurred by the i^{th} emitter as a function of their individual emissions l_i; and DC is the overall damage cost associated with the optimal level of emissions L^*. All of the above quantities are assumed to be known with certainty to the regulator. Consequently, the regulator is able to implement a regulation that will result in an optimal level of emissions. The regulation can be a tax per unit of emissions imposed on individual emitters; it could be a tradable permit scheme, where a cap of L^* is imposed on emissions and tradable permits are distributed among emitters in some way;[2] or it could be a tax for a specified initial period followed by a tradable permit scheme. Under each of these three regulations, it is assumed that the regulator can set an optimal tax rate or an optimal cap on emissions, which will satisfy equation (1).

The ensuing empirical study is focusing on the effects of alternative types of regulation on production and investment decisions of emitters. Each emitter could be seen as aiming to maximise their profit from producing goods/services subject to the particular type of regulation on their GHG emissions:

$$\max \pi_i(T_i, q_i) = NR_i(q_i) - IC_i(T_i) - CC_i[l_i(T_i, q_i)] \tag{2}$$

where π_i denotes profit to emitter i, T_i denotes a technology available to emitter i that could be deployed in order to reduce emissions; q_i denotes the level of production chosen by emitter i ; NR_i denotes the net revenue from that production (revenue net of production costs); IC_i denotes the cost of investing in abatement technology; and CC_i denotes the cost of compliance with the emission regulation, which is a function of the emissions by emitter i that are in turn determined by the abatement technology used and the production level chosen. Under an emissions tax regulation, compliance costs are simply determined by $CC_i = l_i \times t^*$, where t^* is the tax rate per unit of emissions. Under this regulation, there is a unique Nash equilibrium. Given the tax rate set by the regulator, each emitter has a best response strategy, which is to invest in abatement technology and/or to adjust its production plan, up to the point where the cost of reducing an additional unit of emission is just equal to the tax rate. Moreover, this response strategy is independent of the actions of any other emitters. Every individual emitter effectively plays a game only with the regulator, and not with any of the other emitters.

[2] Initial distribution of permits can be conducted by 'grandfathering' or by auctioning permits off in a primary auction market. Auctioning permits is likely to lead to a more efficient outcome than grandfathering (e.g. Thaler, 1980; Cramton and Kerr, 2002; Camacho-Cuena et al., 2012), in particular because it might provide the desired initial signal about abatement costs of various emitters (Betz et al., 2010). However, auctioning of permits is not very popular in practice. In this paper, we assume proportional permit 'grandfathering' since many newly-implemented emissions trading schemes grandfather initial permit allocations. For example, California GHG emission regulation allocates significant amount (but not all) of permits based on grandfathering (Shobe et al., 2014).

Things are very different under a regulation based on a tradable permit scheme. In this case, the cost of compliance for each emitter is determined by the opportunity cost of using permits to fulfil requirements for own production activities (i.e. producing certain level of output requires certain amount of permits to be held and to be surrendered to the regulator at the end of the accounting period), and by the direct cost of purchasing permits on the secondary permit market when the amount of permits held is less than what is required.[3] Both the opportunity cost – the foregone benefit of selling permits on the secondary market –, and the direct cost of purchasing permits that each emitter faces are explicitly determined by the market price of permits in the secondary market. In turn, this price is determined by the amount of abatement that emitters undertake, which is defined by their production choices and abatement investment decisions.

It is apparent from the above that under tradable permit scheme, the abatement decisions of each emitter has bearing on the permit market that affects all other emitters. This is particularly significant when the emitters are heterogeneous in their production and abatement cost structures, as is normally the case in practice. Under these circumstances, a socially optimal allocation of abatement across individual emitters can only materialise if each emitter has full, complete and certain information about every other emitter's production and abatement cost structures. In this case, those emitters who have low cost of abatement will abate more and will offer permits for sale in the secondary market, and those who have higher costs will abate less, and will buy permits in the secondary market. Equilibrium in the secondary permit market will ensure that abatement is allocated optimally among emitters.

However, in practice there is seldom full and common information about the cost structures of the possibly very many emitters that are regulated by a tradable permit scheme. In the absence of full information, a socially optimal allocation of abatement across emitters is not likely to

[3] In addition to the opportunity cost of using permits in own production and the direct costs of purchasing permits, compliance costs under tradable permit scheme also comprise any penalties that emitters have to pay to the regulator if they fall short in permits, i.e. have emitted more emissions than the permits that they hold.

materialise. The reason is that in the absence of full and common information about abatement cost structures of all emitters, there is no mechanism for an individual emitter to recognise whether their own abatement cost are high or low relative to the others. As a consequence, individual emitters are not able to correctly calibrate their abatement decisions. Some emitters will invest in abatement technology when they should not, and others will not when they should.[4] One way to rectify this problem is via primary auction of permits, when the prices achieved in the primary market for permits can provide signals about relative abatement costs of individual emitters (see footnote 2), and consequently help emitters to correctly calibrate their decisions to invest in abatement technology.

Another regulatory approach is to implement a temporary tax prior to the implementation of a tradable permit scheme. Given that under a tax there is a strategy for each individual emitter that leads to a Nash equilibrium, and that under a tradable permit scheme without full information there is no such strategy, a regulator might consider using a mix of instruments: start with a tax to provide a signal to emitters about their cost of abatement relative to other emitters, and after a period of time transform it into a tradable permit scheme. Theoretically, the policy design consisting of an intertemporal mix of a tax on emissions followed by a tradable permit scheme should provide additional information signals to emitters that should help induce optimal abatement behaviour.

This theoretical expectation has so far not been tested empirically, and the aim of the current study is to do exactly that. We conducted experimental economics study in the laboratory for this purpose. The experimental treatments were commensurate with the three types of regulations of interest: emissions tax; tradable permit scheme; and an inter-temporally mixed regulation comprising of an emissions tax followed by a tradable permit scheme. These three regulations

[4] Shobe et al. 2014 discuss the same phenomenon in the sense that inability to correctly calibrate abatement investment decisions '…harms the market's price discovery function', and sends '… incorrect signals about which units of abatement are worthwhile and which ones are not.' (p. 408).

were compared based on total emissions, optimality of investment in abatement technology and permit prices. They were also compared using an overall efficiency metric, which corresponded to the societal objective of achieving emissions reduction at lowest cost. The representation of the efficiency metric was articulated as an optimal total surplus (*TS**), calculated as follows:

$$TS^* = \sum_i NR_i(q_i^*) - \sum_i\{IC_i(T_i^*) - CC_i[l_i^*(T_i^*, q_i^*)]\} + GR^* - MDC \sum_i l_i^* \quad (3)$$

where the first term on the right hand side constitutes the net revenue from production, and is used here to represent the social benefit associated with the production (and consumption) of goods and services; the second term (in parenthesis) represents the abatement cost; the third term accounts for the government revenue, comprised of receipts from emissions taxes, or penalties for insufficient permits, as applicable; and the last term represents the cost of environmental damage, where *MDC* is the marginal damage cost. The subscript *i* denotes an individual emitter. The asterisk on the production quantity (*q*), abatement technology (*T*), and emissions (*l*), denotes that these are at their theoretically optimal level.

Based on the above expression for *TS*, and utilising the data obtained from the experiment, the performance of each of the three tested regulations was compared using the following total efficiency (*TE*) measure:

$$TE^k = \frac{\sum_i NR_i(q_i^k) - \sum_i\{IC_i(T_i^k) - CC_i[l_i^k(T_i^k, q_i^k)]\} + GR - MDC \sum_i l_i^k}{\sum_i NR_i(q_i^*) - \sum_i\{IC_i(T_i^*) - CC_i[l_i^*(T_i^*, q_i^*)]\} + GR^* - MDC \sum_i l_i^*} \times 100 \quad (4)$$

Where the superscript *k* is used to index the observed levels of production, investment in abatement technology, and emissions for each of the three regulations (*k* = 1, 2, 3) that were tested. The higher the observed value of TE^k, the closer the regulation *k* is to the theoretically optimal outcome.

3. Experimental design and procedures

The design of the study was motivated by the electricity sector, one of the largest greenhouse gas emitters in Australia and globally. However, the experiments were conducted without a mention of this particular context. Furthermore, the language used during the sessions was intentionally decontextualized from typical environmental or regulatory vocabulary in order to minimize the chance of association of the experimental environment with the CO2 emissions regulation that was in place at the time. Permits were referred to as *inputs*, and the tax was framed as an *input price*.[5] Technology upgrades were referred to as *investments*.

The experiment was designed around eight heterogeneous emitters whose roles participants took. The task for the participants in the experiment was to make production, investment, and permit market choices so as to maximize profits (Eq.2) with respect to their production characteristics, possibilities to invest in abatement technology, and the regulation they faced. They maximized their profit subject to the cost of complying with the regulation. They could form expectations about the cost of compliance based on a known marginal tax rate, or based on an expected price of a permit. In particular, and crucial for the key research question of this study, in the inter-temporally mixed regulation treatment where the emissions tax and the tradable permit scheme were sequentially implemented, the tested hypothesis was whether the implementation of the mixed regulation improves participant's ability to form more accurate expectations about future permit prices relative to their own cost of abatement, and to consequently better calibrate their abatement investment decisions.

Each participant faced the same linear production function, where a unit of input could produce a unit of output, and implicitly entailed emitting a unit of emissions. The maximum quantity of output that could be produced by each participant in any given period within a round of play was

[5] The *input price* was set to an amount different from the carbon tax that was in place in Australia at the time.

ten units. Participants could invest into upgrades of their production technology in order to reduce emissions. Generating emissions in this setup was articulated as using required *inputs*, as in Gangadharan et al. (2005). Emitters can reduce emissions either by cutting back production, by investing into a less emission-intensive technology, or both.

Participants differed by the net revenues per unit of output, and consequently per unit of emissions (Table 1). Based on these differences, individual emitters were characterized as 'producer types'. For any given value of net revenue to be attained, producer types described on the left hand side of Table 1 had to produce more units of output and thereby more emissions than the producer types on the right hand side of Table 1. For instance, to attain net revenue of 100, producer type 2 had to emit 10 units of emissions (corresponding to 10 units of output that requires 10 units of inputs/permits), whereas producer type 8 would only need to emit 4 units of emissions (corresponding to 4 units of output that requires 4 units of input/permits). Based on this, we can define emission intensity per unit of net revenue, as displayed in the second row of Table 1. Producer types 1, 2 and 3 can be consequently labeled as relatively high emission intensity producers, producer types 4 and 5 as medium emission intensity, and producer types 6, 7 and 8 as low emission intensity per unit of net revenue.

Participants could invest in a single discrete unit of abatement technology upgrade per period, up to a maximum of four upgrades in a given round (13 periods). Each unit of abatement technology upgrade reduces that participant's emission intensity per unit of net revenue by 10%. Participants differed by individual cost structures for abatement technology upgrades (Table 1). The high emission intensity producer types (1, 2 and 3) had relatively low nominal investment cost of technology upgrades. However, given that each technology upgrade only reduces emissions per unit of net revenue by 10%, the investment cost per unit of emission intensity improvement was still fairly high for these producer types. Consequently, it was optimal for these producer types not to invest in abatement technology upgrades.

Producer types 4 and 5 with medium emission intensity had low investment costs for technology upgrades, especially for the higher level of upgrades (the third and fourth upgrade). This makes them the lowest cost producer types in terms of investment cost per unit of emission intensity improvement, which in turn meant that they should invest the most in upgrades out of all producer types, optimally at three technology upgrades each. By the same token, producer type 6 should optimally invest in two technology upgrades, and producer types 7 and 8 in a single upgrade each (Table 1).

The damage cost associated with emissions was set at E$16 per unit of emission. This was not explicitly communicated to participants, but was reflected in the tax rate applied in the tax-only and the intertemporally mixed regulation treatments, which was set at E$16 per unit of input. It was also reflected in the rate of the penalty for not surrendering sufficient amount permits, which was set at double the marginal damage cost, i.e. at E$32 per insufficient permit.

The experiments were programmed in z-Tree (Fischbacher, 2007) and conducted in an experimental laboratory at the University of Sydney in the period 10/2012 - 4/2013. All 144 participants (8 participants per session, 6 sessions per treatment and 3 treatments) that took part in the experiment were students at the University of Sydney who were recruited via the University's ORSEE database of student volunteers (Greiner, 2004). Each of the three treatments was replicated in six experimental sessions; a total of 18 experimental sessions were conducted. Each participant took part in only one session. An experimental session consisted of four rounds. Each of the 13 periods in a round consisted of a series of stages, summarized in Table 2. All rounds in a session were identical in that the same treatment and producer characteristics were induced for the duration of the whole session.

The first five periods of each round comprised the pre-liability phase, in which participants were free to choose a level of production without facing any costs associated with emissions. The emissions regulation was implemented from period 6 onwards in each round (Table 3).[6] In each of the 13 periods within a round, participants selected a production level in order to generate revenue, had an opportunity to invest in abatement technology upgrades, and received information about the total number of technology upgrades undertaken by all participants in that round.

The information given to participants that described their own production characteristics (net revenues, cost of investing in technology upgrades, and their profits) was completely private. On the other hand, the information on the total number of abatement technology upgrades undertaken by all participants, and all the information related to permit trading, such as the best standing bid and ask, and the quantity and price of traded permits, were provided publicly.

In the treatments with trading, five emissions permits per period were allocated to each participant starting in the initial period when trading of permits became active. This was commensurate with the theoretically optimal level of emissions of 40 per period (eight participants times five permits), which was the same under all three regulations considered. A single-unit double auction was implemented as the permit trading mechanism due to its low transaction costs and easily understood and utilized design, particularly the ease of placing and accepting bids and asks.[7] Figure 1 represents the theoretically predicted permit market equilibrium under the optimal investment scenario. In the event that a participant held less than the required number of permits at the end of a period, it was specified that a fine at a rate that is double the marginal damage costs, i.e. E$32, would be levied for each insufficient permit. This

[6] Five unregulated periods were included prior to the regulation in order to provide the participants with sufficient time to familiarise themselves with the experimental environment and with their own production, abatement and investment possibilities, before the regulation took effect.

[7] Smith (1962) provides extensive evidence that double auctions elicit best-possible market results in experimental environments. However, Camacho-Cuena et al. (2012) 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 an experimental environment similar to the one reported in this paper.

was observed in 14% of permit trading periods, amounting to a shortage of 1.3 and 1 permits on average per period under the trade-only and mixed regulation treatments, respectively.

On entering the lab, each participant was randomly assigned a role of one of the eight producer types (Table 1). Comprehensive experimental instructions were shown in a video and complemented by a hard copy. After viewing the video, participants retained the written instructions and completed a quiz to demonstrate their understanding of the tasks.

Participants' earnings were calculated based on their performance in all four rounds. Participants were privately informed of their personal exchange rates before the beginning of the session. The Experimental dollars to Australian dollars exchange rate was adjusted according to the characteristics of a specific producer type of a participant, so that in equilibrium each participant had equal opportunity to earn the A$30 performance-based payout. In the actual experiment, participants earned an average of A$24.35 in addition to the A$10 participation fee, for a total of A$35.35 over a session that lasted one-and-a-half hour overall.

4. Results

This section reports the results from the experimental sessions that are used to compare the three alternative regulatory treatments: tax-only, tradable permit scheme only, and inter-temporally mixed regulation (staged transition from tax to tradable permits). Comparisons were conducted in terms of overall efficiency of regulation, optimal investment in abatement technology, overall emissions, and prices of permits in the secondary permit market. A standard Wilcoxon–Mann–Whitney two-sample rank-sum test was used to test the significance of the observed differences between treatments. In addition, a regression analysis was used to test whether there is a difference in the level of departure from the theoretical optimum investment in abatement technology upgrades across the production types (high, medium, and low cost of improving emission efficiency) and across the three tested regulations.

4.1 Overall Efficiency

The efficiency measure presented in Eq. 4 was computed using data from the experimental treatments corresponding to the three regulations that were tested. A higher efficiency score indicates a lower total social cost of regulation (the sum of abatement and damage cost). Overall efficiency was consistently higher under the inter-temporally mixed regulation than under trade-only regulation (Figure 2), even though the differences were not statistically significant due to large variation in efficiency scores, especially for the trade-only treatment. These findings conform to the expectations and to the theoretical predictions that the inter-temporally mixed regulation would be at least as efficient as an outright tradable permit regulation.

In addition, nonparametric Wilcoxon–Mann–Whitney tests indicate that under the tax-only treatment participants achieved significantly higher efficiency levels than under the trade-only treatment (one-tailed $p \leq 0.05$ for rounds 1, 2, 3; $p \leq 0.1$ for round 4) and marginally significant higher efficiency than under the mixed regulation (one-tailed $p \leq 0.1$ for rounds 2, 3 and 4).

4.2 Investment in abatement

Comparisons along investment behaviour were particularly important for this study, as the key effect from implementing a tax before rolling out a tradable permit scheme is to induce emitters to more accurately determine their optimal investment in abatement. The effectiveness of investing in technology upgrades was evaluated via the difference between the observed and the theoretically optimal level of investment in technology upgrades. As described in Table 1, the theoretically optimal level of investment implied that some participants – those with high cost of improving emission intensity – should not invest in technology upgrades at all, while others – those with low costs of improving emission intensity – should invest considerable amounts. Theoretically optimal levels of investment were identical for all three types of regulation.

The propensity of participants in economics experiments in laboratory to overact (in the present context, over-invest) as documented by Gangadharan and Nemes (2005) and Camacho-Cuena et al. (2012) was also observed in this experiment. On aggregate, participants invested in abatement more than they should have in all three treatments.

Aggregate number of, and expenditure on, upgrades were consistently higher under the trade-only treatment than under the mixed regulation or tax-only treatments (Table 4 and Table 5). This implies that participants formed expectations for higher permit prices under the trade-only treatment, compared to the expectations formed under the mixed regulation. It is an indication that the mixed regulation that starts with a tax and transforms into a tradable permit scheme could help emitters form more accurate expectations about permit prices, which in turn enables them to make better decisions about investment in abatement technology upgrades.

The technology upgrade choices demonstrate that participants learn with experience. Aggregate upgrades and investment expenditure move closer towards the theoretically optimal level under all treatments over the four rounds of the experiment (Table 4 and Table 5). Nevertheless, the expenditures are considerably higher than the theoretical optimum even in the tax-only treatment, which was closest to the optimum in the final round. Learning, if measured by participants' propensity to invest closer to theoretical predictions, occurred faster in the tax-only and mixed regulation than in the trade-only treatment. There was a marginally significant difference in aggregate technology upgrade expenditures between the first two rounds in the tax-only (two-tailed $p \leq 0.1$) and in the mixed regulation ($p \leq 0.1$), but no significant reduction in expenditure under the trade only regulation ($p \geq 0.1$). Overall, the variability in investment expenditures is notably lower under the mixed regulation than under the trade-only regulation.

Participants with high costs of improving emission intensity (those who should not have invested at all in order to maximize their profits, i.e. producer types 1, 2, and 3 in Table 1) invested significantly more in abatement technology upgrades under an outright tradable permit regulation relative to the mixed regulation (two-tailed $p \leq 0.01$) (Figure 3). The investment decisions of participants with moderate costs of improving emission intensity (producer types 6, 7 and 8 in Table 1) did not vary significantly across treatments. The participants with lowest cost of improving emission intensity (producer types 4 and 5 in Table 1) invested closest to the optimum, and their investment decisions did not vary significantly across treatments. This is an important result as it indicates that a tax predating a tradable permit scheme is particularly beneficial for adjusting expectations of emitters with high emission intensity who face high costs of improving that intensity, and less useful for those emitters who have lower emission intensity and can improve that intensity at low cost. In combination with the finding that overall investment activity is closer to the optimum under the mixed regulation than under the trade-only regulation, it suggests that the benefits to the high emission intensity emitters from the extra information carried by the tax predating a tradable permit scheme are substantial.

Regression analysis was used for further evaluation of the treatment effects on participants' abatement investment decisions. The difference between the observed investment in abatement technology upgrades made by participants and the theoretical optimum was the dependent variable in the regression analysis. The dependent variable was regressed on the characteristics of the production, investment and emissions profile of participants that served as explanatory variables. Indicator variables were created for a regulation type (tax-only, trade-only, and mixed regulation); and for the cost of improving emission intensity: high costs (producer type 1, 2 and 3); low costs (producer type 4 and 5); and medium costs (producer type 6, 7 and 8). An interaction term between these two indicator variables was also estimated. The mixed regulation and the medium cost producer types were treated as baselines. Another explanatory indicator variable was created for the conducted experimental rounds (round 1, 2, 3 and 4), with round 1 being the designated baseline. The regression model was estimated using maximum likelihood estimation procedure using clustered standard errors estimator, where the errors were clustered by an identifier for the experimental session. The results from the regression are reported in Table 6. They are in line with the findings reported above based on comparisons using the non-parametric tests, as they confirm the previous finding that producers who faced high costs of improving emission intensity made investment decisions closer to the optimum under the mixed regulation, as opposed to the trade-only regulation. This is evidenced by the magnitude of the estimated coefficient on the interaction term between the trade-only regulation and high cost indicator variable, which is also highly statistically significant (Table 6). This result further strengthens the finding that implementing an inter-temporal policy mix of a tax followed by tradable permit scheme is likely to help high intensity emitters to correctly calibrate their expectations about permit prices, and to consequently more accurately calibrate abatement technology investment decisions.

4.3 Emissions

Since emissions were represented as permits (*inputs*), they were used by participants during both the pre-liability and regulated phases. During the pre-liability phase, the amount of permits available to participants at no cost was not constrained. During the regulated phase the target emissions level was set at 40 units per period. This corresponded to the optimal level of emissions under a tax-only regulation, given the marginal tax rate of E$16. It also corresponded to the theoretically optimal cap on permits under a trade-only and mixed regulation treatments.

The findings from the regulated phase of the conducted experiments indicate that aggregate emissions were very similar under the tax-only and the mixed regulation treatments (Figure 4). Emissions were higher in the trade-only treatment. Overall emissions in the trade-only treatment were significantly higher compared to the mixed regulation (one-tailed test $p \leq 0.01$) and marginally significantly higher than the tax-only regulation ($p \leq 0.1$). This may be attributed to the endowment effect (Requate, 2005) that may compel participants to use all of the grandfathered permits given to them for free under a tradable permit scheme regulation, as opposed to an emissions tax that requires explicit payment to be made for each unit of emission. Within the context of our experiment such endowment effect is the strongest in the trade-only treatment, hence the highest emissions under this treatment.

4.4 Permit Prices

Mean transaction prices observed in the permit market (Table 7) were within the theoretically predicted permit price range (Figure 1) under both regulations that involved permit trading. However, transacted prices for permits were significantly higher on average in the trade-only treatment than in the mixed regulation treatment (one-tailed $p \leq 0.05$ for round 1) (Table 7). As is evident from Table 7, participants had formed expectations of significantly higher permit prices under the trade-only regulation compared to the mixed regulation. This is most evident in round 1, when the difference in permit prices between trade-only and mixed regulation is some 3-4 experimental dollars. With participant learning, this difference reduced to only one experimental dollar in round 4. This discrepancy indicates that initial expectations about permit prices tend to be much more inflated under the trade-only regulation, and that the tax component of the mixed regulation helps participants to form more accurate understanding about the relative position of their own costs of improving emission intensity and the expected permit price.

4.5 Learning

Participant learning featured strongly in the conducted experiments as evidenced in Tables 4, 5 and 7 and in Figure 2. The experimental design provided ample opportunity for learning and information gathering over the four rounds in which individual participants took part. It was expected that learning would occur in all treatments, but the extent and speed of learning was expected to vary across the three treatments. The experimental results are in line with these expectations. Observed learning occurred faster in the tax only and mixed regulation than in the trade only regulation. Case in point is the aggregate number of average technology upgrades (Table 5), where the observed behaviour was very similar in the first round across all three treatments (around 26 upgrades). However, the behaviour changed significantly in the subsequent rounds for the tax-only and the mixed regulation, moving quickly in the direction of the theoretically optimal behaviour (i.e. 10 upgrades). This change occurred much more slowly under the trade-only regulation, where average aggregate number of upgrades remained high in the second and third rounds, and did not approach optimum even in the fourth round. This is likely due to the permit price uncertainty that participants face in the trade-only regulation, and their inability to correctly calibrate investment decisions in abatement technology under this regulation, consequently slowing down their learning process.

5. Conclusion

In the light of the potentially strong political backlash associated with an emissions tax, and the uncertainty associated with tradable permit schemes, a new type of inter-temporally mixed GHG emissions regulation consisting of a staged transition from a tax to a tradable permit scheme has been proposed, and indeed partially implemented in Australia. This paper evaluates this new regulatory approach *vis-a-vis* the more traditional tax-only and tradable permit-only regulations on a range of criteria of interest, including overall regulation efficiency, optimality of investment in abatement technology, overall emission levels, and prices in permit markets. The comparisons were undertaken through economics experiments conducted in a computer laboratory. The results indicate that a mixed regulation may bring about greater overall efficiency, lower overall emissions and lower permit prices, as well as aid investment decisions in abatement technology, when compared to a tradable permit scheme implemented outright.

The overall efficiency under the mixed regulation was greater than the efficiency under the trade-only regulation, although statistical significance was absent. The key driver of this are the non-optimal investments in abatement technology made by participants/emitters. Emitters with high costs of improving emission intensity were found to invest heavily in abatement when they should not have, especially under the trade-only regulation. This is adversely affecting the permit market, eliminating the opportunities for low cost emitters to abate the most. In turn, total welfare is reduced.

The findings under the mixed regulation treatment were an improvement on the trade only regulation. The existence of an emission tax prior to the introduction of a tradable permit scheme significantly improved the ability of the participants to make abatement investment decisions that were more in line with the theoretical optimum. This subsequently resulted with lower emissions, lower permit prices, and higher overall efficiency under the mixed regulation when compared to the trade-only regulation. The mixed regulation is particularly beneficial to those emitters that have relatively higher costs of improving emission intensity, as it helps them to better calibrate their decisions about investment in abatement technology.

The fundamental reasons for this superior overall performance of the mixed regulation relative to the trade-only regulation are more profound. They are related to the differences between an emissions tax regulation and a tradable permit scheme regulation in terms of the strategic interactions among emitters. Under a tax-only regulation, there are no strategic interactions among emitters – the behavior of one emitter does not affect the outcomes that other emitters face. This is very different under a tradable permit scheme regulation, where if the decisions of some individuals are not optimal, it affects the outcomes for the other emitters irrespective of the optimality of their own actions. This situation is apparent in our experiment, where overinvestment by high cost emitters significantly affects the outcomes for all. The strategic difference between an emissions tax regulation and a tradable permit scheme in the context of optimality of investment in abatement has not drawn much attention in the literature thus far, but in the light of the findings of the current paper, further investigations in this direction are warranted.

The findings in this paper suggest that the use of a fixed price instrument – an emissions tax–, prior to the introduction of a tradable permit scheme is likely to be a good policy, as it is likely to reduce the total social costs of regulation. The benefits of this policy are particularly apparent in the short run, as it provides signals to emitters about the adequacy of investment in abatement technology and about expected permit prices in the future. In the long run, a tradable permit scheme may well be the optimal regulatory instrument, but the inefficiencies in the early stages of the implementation could be alleviated by an introductory emissions tax.

This study provides useful insights that can be used by pollution regulating agencies, legislators, and businesses, as it sheds light on the benefits that a regulation based on an intertemporal policy mix, consisting of an emissions tax predating a tradable permit scheme, could bring to a wide swath of stakeholders. Curbing GHG emissions effectively on a global scale requires creative solutions: applications of innovative regulatory approaches, such as the inter-temporally mixed regulation investigated here, may be a step forward in that direction.

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Table 1: Production characteristics of participants and theoretically optimal number of abatement technology upgrades

	Producer type assigned to individual participants							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Net revenue per unit of output (or per unit of emissions)*	7.5	10	12.5	15	17.5	20	22.5	25
Emission intensity per unit of net revenue	1/7.5	1/10	1/12.5	1/15	1/17.5	1/20	1/22.5	1/25
Cost of Upgrade 1	12.5	12.5	12.5	25	25	50	75	125
Cost of Upgrade 2	62.5	75	50	75	75	100	150	200
Cost of Upgrade 3	112.5	137.5	150	125	125	200	225	250
Cost of Upgrade 4	162.5	200	250	175	175	250	300	300
Optimal Upgrade Level	0	0	0	3	3	2	1	1
Optimal Upgrade Costs	0	0	0	225	225	150	75	125

* Each unit of output requires using a unit of input, which is equivalent to a unit of emissions.

Table 2: Description of the decision stages within a period in the experiment

Decision stage	Procedures
Investment stage (60 seconds)	Each production level required a certain number of inputs. The inputs are costless in the pre-regulation phase, and costly in the regulation phase. The costs of these inputs represent a component of production costs attributable to the cost of emissions. At the start of the second period, and at the start of all subsequent periods, producers could invest in a technological upgrade that would reduce their emissions intensity by 10%. Producers could select at most one incremental upgrade per period and up to four upgrades in total per round. Choosing the maximum of four upgrades would give a cumulative 40% reduction in required inputs. All upgrades lasted for the remaining periods in the round and were irreversible.
Production and Trading Stage (60 seconds)	Participants selected a production level between 0 and 10 each period. Participants knew their input costs and revenues associated with each production level. In the treatments with trading, a single unit double auction for inputs was also active during this stage. Participants placed bids and asks, and transacted within the trading period. Each bid or ask was for a single input. The best current bid and ask were displayed on the screen at all times. To execute a trade, buyers or sellers clicked on the bid or ask that they were willing to transact for. A record of each transacted price from the current period was displayed on participants' screens.
Summary Stage (15 seconds)	Participants were shown a summary of their personal performance for the previous period and the cumulative number of upgrades undertaken by all producers up to date.

Table 3. Description of experimental treatment

Treatment	**Non-Liability Phase (Periods 1-5)**	**Regulated Phase (Periods 6-13)**	
Tax-Only	Pre-Liability	Tax	
Mixed (Staged transition)	Pre-Liability	Tax (Periods 6-8)	Trade (Periods 9-13)
Trade-Only	Pre-Liability	Trade	

Table 4: Average aggregate expenditure on investment in abatement by round and treatment (standard deviations in parentheses)

Treatment	Round 1	Round 2	Round 3	Round 4	Optimal	Overall Average by Treatment
Tax-Only	3042	2329	1819	1521	800	2178
	(469)	(726)	(707)	(422)		(810)
Mixed (Staged transition)	2979	2304	1738	1592	800	2153
	(663)	(358)	(355)	(553)		(727)
Trade-Only	2933	2373	1821	1667	800	2198
	(649)	(787)	(750)	(814)		(868)

Table 5: Average number of aggregate technology upgrades by round and treatment (standard deviations in parentheses)

Treatment	**Round 1**	**Round 2**	**Round 3**	**Round 4**	**Optimal**	**Overall Average by Treatment**
Tax-Only	26	19.33	15.33	13.83	10	18.63
	(2.9)	(5.4)	(3.4)	(1.5)		(5.9)
Mixed (Staged transition)	25.67	19	14.83	14	10	18.38
	(3.4)	(3.0)	(1.0)	(2.8)		(5.3)
Trade-Only	25.83	21.83	18.83	17	10	20.88
	(2.8)	(5.0)	(5.2)	(5.7)		(5.6)

Table 6. Results from a regression analysis (dependent variable: difference between observed and theoretically optimal number of upgrades in abatement technology)

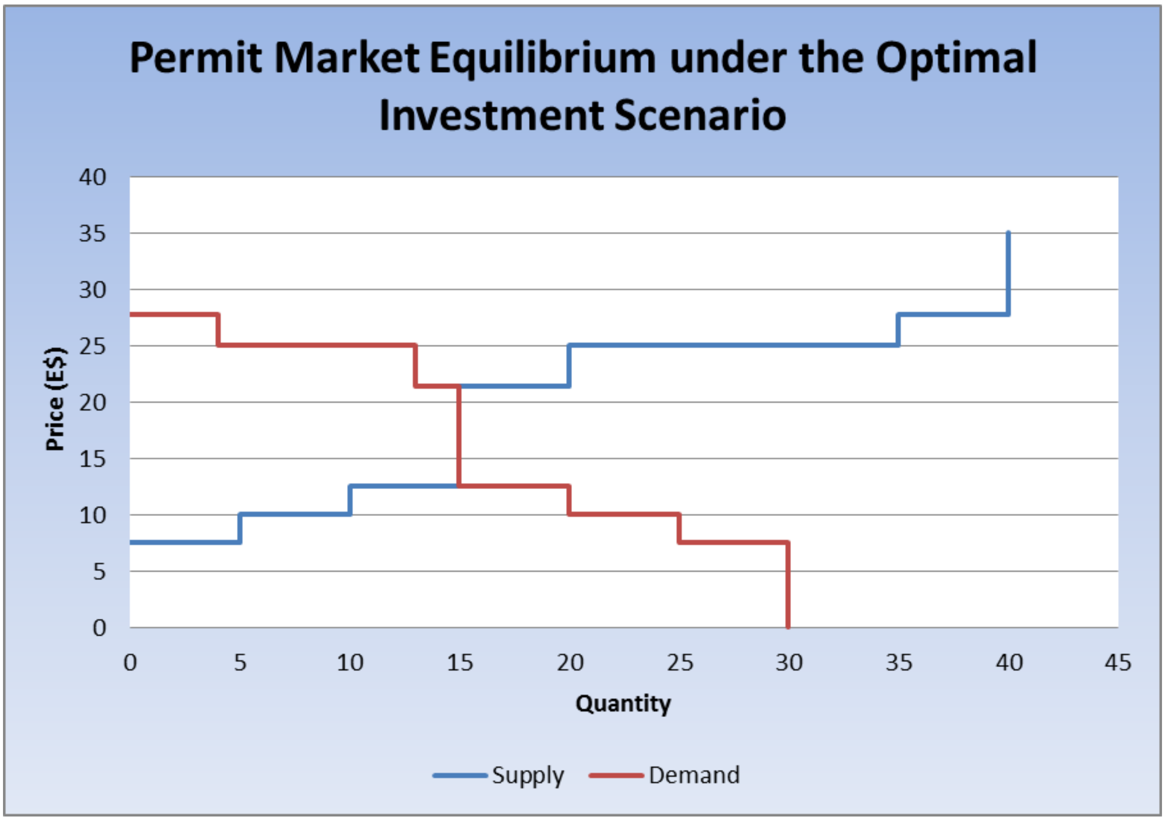
	Estimated coefficients
Constant	1.90***
	(0.22)
Regulation	
Tax-Only	-0.23
	(0.29)
Trade-Only	-0.25
	(0.29)
Cost of improving emission intensity	
High	0.55**
	(0.26)
Low	0.60**
	(0.26)
Cost x Regulation	
High cost	
Tax-Only	-0.104
	(0.37)
Trade-Only	1.29***
	(0.37)
Low cost	
Tax-Only	0.22
	(0.37)
Trade-Only	0.04
	(0.37)
Round	-0.35***
	(0.03)
Log likelihood	-826.7904
n	576

Standard errors in parentheses. Significance is identified by asterisks: * indicates $p < 0.1$, ** $p < 0.05$, ** $p < 0.01$.

Table 7. Average permit prices under the staged transition and trading only treatments by round (standard deviations in parentheses)

Treatment	Round 1	2	3	4	Overall Average by Treatment
Mixed (Staged transition)	17.71	17.29	17.04	16.74	17.20
	(3.21)	(3.95)	(3.46)	(3.78)	(3.39)
Trade-Only (All Periods)	21.69	19.97	19.15	17.79	19.65
	(3.30)	(3.16)	(2.69)	(4.09)	(3.44)
Trade-Only (first 5 trading periods)	21.06	20.75	19.65	18.05	19.88
	(3.60)	(3.70)	(2.59)	(3.85)	(3.45)

Figure 1. Equilibrium in the permit market under the optimal investment scenario*



* The market equilibrium price range is in the interval from E$12.50 to E$21.43.

Figure 2. Overall efficiency of the three types of regulation

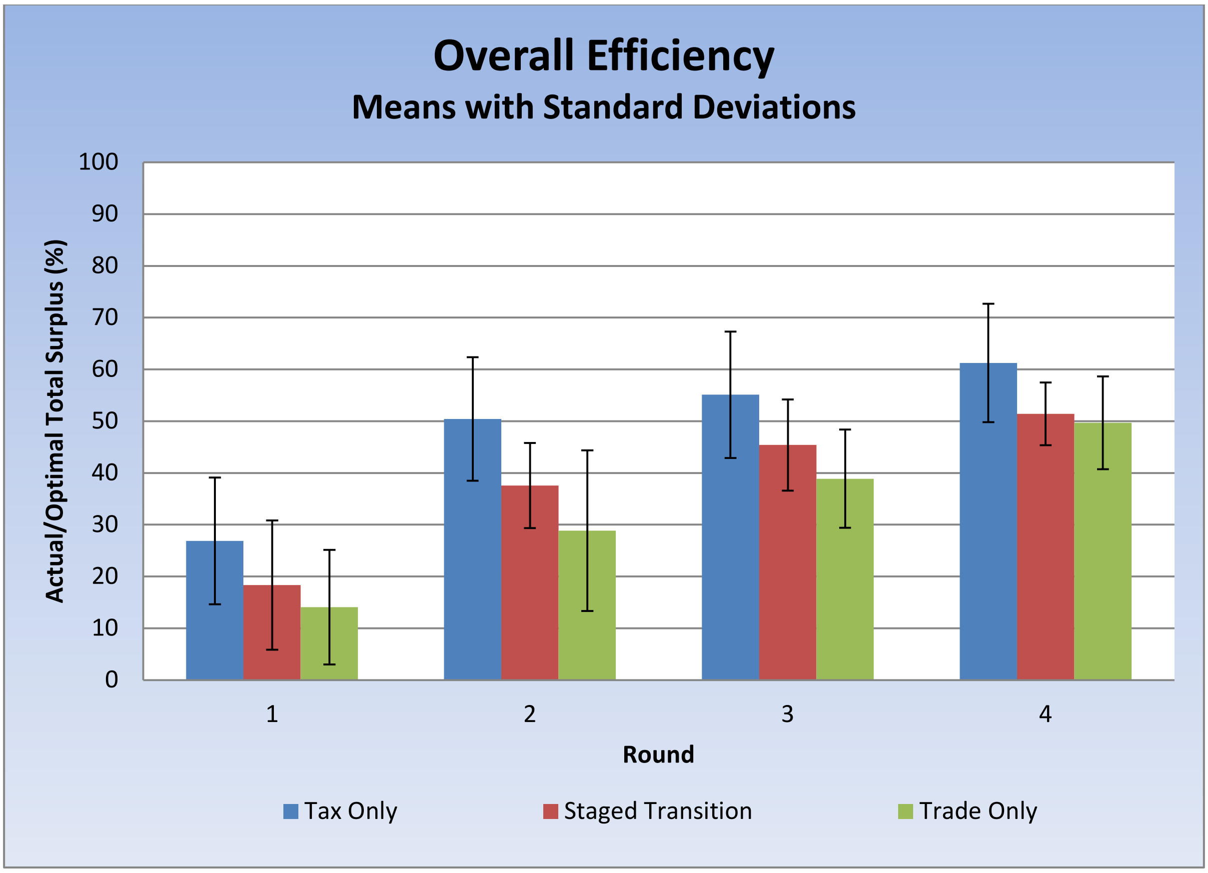


Figure 3. Difference between actual and theoretically predicted number of investment upgrades for the three types of regulation

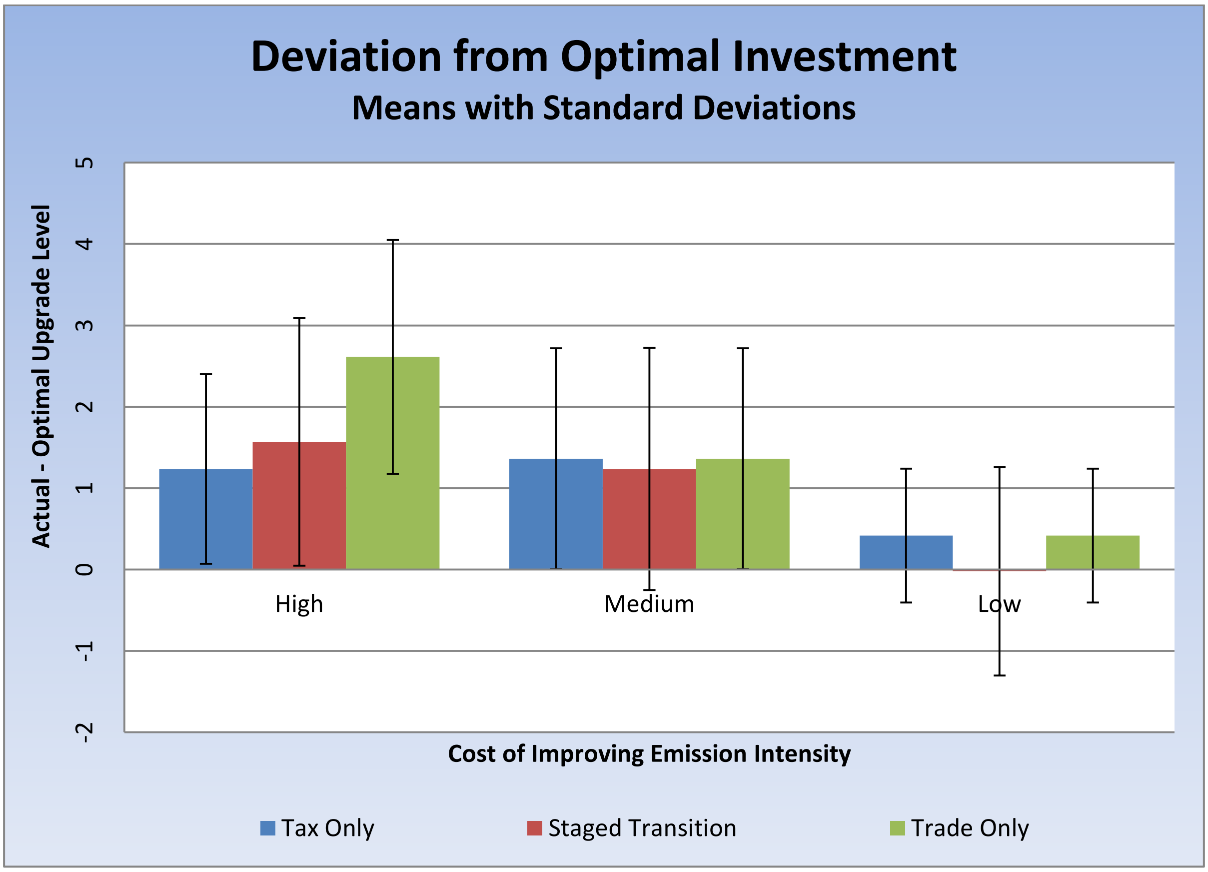
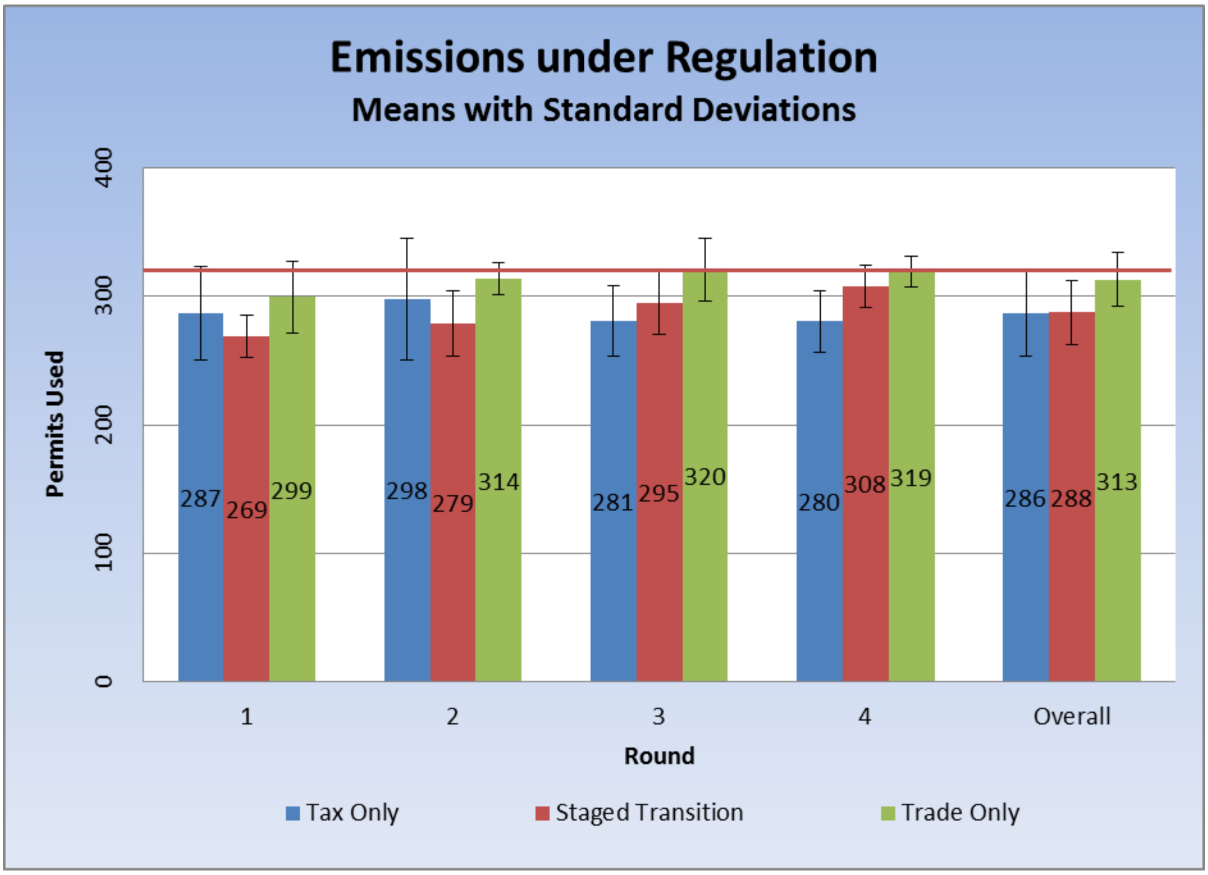


Figure 4. Emissions under the three types of regulation



Appendix A.1

History of recent Australian GHG mitigation policy

1996-2007 Government under PM John Howard (Liberal): limited action on GHG mitigation policy; refusal to ratify Kyoto protocol.

2007-2010 Government under PM Kevin Rudd (Labor): ran an election campaign with a strong commitment for an active GHG mitigation policy; first act of government was to ratify Kyoto protocol; commissioned a report on Climate Change led by John Garnaut; initiated a proposal for a GHG ETS.

2010-2013 Government under PM Julia Gillard (Labor): partly brought to power as a result of strong opposition to the proposed ETS by the Rudd government; modified the proposal into a Carbon Pricing Mechanism (CPM). The CPM instituted on 1 July 2012 and consisted of a fixed fee charged per ton of CO2 equivalent emission. The initial fee of 23 AUD/ton, was set to increase annually based on CPI and on an additional inbuilt rate of increase. The CPM policy explicitly incorporated a transition to an ETS on 1 July 2015. CMP immediately labelled by the opposition as a 'Carbon tax' and strongly attacked and opposed.

2013 (June-September) Government under PM Kevin Rudd (Labor): one of the first acts of government was to move forward the transition to an ETS to 1 July 2014.

2013-2014 Government under Tony Abbott (Liberal): ran an election campaign with a strong emphasis on the commitment of abolishing the 'Carbon tax'. Introduced repeal legislation in Parliament early on in the term. Initially, the legislation could not be passed in the Senate. Subsequently and subject to political negotiations, the legislation repealing the CPM passed Senate, and became a law on 17 July 2014.