Regulating greenhouse gas emissions by an inter-temporal policy mix: An experimental investigation*

Tiho Ancev**,†, Rimvydas Baltaduonis**,†, and Elizabeth Bernold**†

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: optimality of abatement investment, overall regulation efficiency, and permit prices. The effects of the regulation that employs an inter-temporal mix of policy instruments are compared to the effects observable under regulation using a 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 on an outright tradable permit scheme.

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), in Northeast and Mid-Atlantic US states (Ruth et al., 2008), 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, the literature does not provide unequivocal evidence that 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 impels 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 an attractive alternative. 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 1). A key benefit of this policy design is that the temporary emissions tax could reduce the uncertainty about future compliance costs by providing a price signal during the initial stages of regulation implementation. 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

¹See Appendix 1 for a brief overview of the recent events around the GHG emissions reduction policy (and politics) in Australia.
long-term.

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 an outright tradable permit scheme. The performance of the regulation is evaluated along key criteria of interest, such as optimality of investment in abatement technology and emission permits 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 reported in the literature (e.g., Roberts and Spence, 1976; Pizer, 2002; Krysiak and Oberauer, 2010; also Shobe et al., 2014 write about a ‘hybrid approach’ implemented in California), but an 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 findings from laboratory economics experiments that were 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: next section outlines the theoretical underpinnings of the experiment, which is 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 offering 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 standard theoretical framework of environmental economics. Let us assume that a benevolent regulator representing societal preferences for environmental quality aims to regulate emissions of GHGs. It is assumed that an objective of the regulator is to regulate emissions at lowest overall social cost. Incentive based regulations are consistent with that objective, with some of the specific regulation choices being: a tax per unit of emissions imposed on individual emitters; a tradable permit scheme, where an overall cap is imposed on emissions and tradable permits are distributed among emitters in some way;\(^2\) or a tax for a specified initial period followed by a tradable permit scheme.

The ensuing empirical study is focusing on the effects of alternative types of regulation on optimality of 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:

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\(^2\) 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 has not been 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).
\[ \max \pi_i(T_i, q_i, e_i) = pq_i - C_i(T_i, q_i, e_i) - k_i(T_i)T_i - te_i \] (1)

where \( \pi_i \) denotes profit to emitter \( i \), \( T_i \) denotes a technology available to emitter \( i \) that could be deployed in order to reduce emissions \( e_i \); \( q_i \) denotes the level of output chosen by emitter \( i \); \( p \) is an exogenous output price, as it is assumed that an emitter cannot influence the price in the output market; \( C_i(T_i, q_i, e_i) \) is a joint cost of production and abatement cost function; the product \( k_i(T_i)T_i \) is the cost of investment in abatement technology, where \( k \) denotes the marginal cost per unit of increment of deployed technology; \(^3 t \) denotes the ‘price’ on emissions, which is equivalent to the marginal tax rate under an emissions taxation policy. In this case, the price on emissions is completely exogenous to each emitter as it is set by the regulator. However, when the policy is based on a tradable permit scheme, the price on emissions is endogenous, in a sense that it is determined by the level of emissions by individual emitters within the cap on emissions set by the regulator. The cap is exogenous to the emitters, but the price on emissions is not. In that case, the price on emissions should be denoted as \( t(e_j, T_j) \), where \( j = 1, \ldots, i, \ldots, N \), is an index of emitters.

This is a fundamental difference between an emissions tax regulation, and a tradable permit scheme regulation. Under a tax regulation, and given the tax rate set exogenously by the regulator, each emitter has an optimal response, 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 optimal response is independent of the actions of any other emitters. Every individual emitter only interacts with the regulator, and not with any of the other emitters.

\(^3 \) This expression models the possibility of varying levels of abatement technology being deployed. The level of technology deployment can be continuous, or discrete as modelled in the empirical work below. The cost varies with the increments of deployed technology.
Things are very different under a regulation based on a tradable permit scheme. In this case, the price on emissions, while appearing to be exogenous to individual emitters, is in fact determined by the amount of abatement that each individual emitter undertakes, which is defined by production choices and by decisions about how much to invest in abatement technology made by each emitter. Consequently, the abatement decisions of each emitter under a tradable permit scheme have bearing on the permit market price 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. Given this heterogeneity, it is difficult for an individual emitter to have a good *ex ante* assessment of the abatement cost of others, and the position of their own abatement cost relative to those of others.

The conventionally advanced argument addressing this problem is that permit markets are reasonably competitive and that over time participants in an emissions trading scheme will gain some sense about the abatement cost structure of others by observing the market price for permits. This will allow them to adjust their own production and abatement decisions efficiently without directly observing the production and abatement cost structures of other emitters, but by making implicit inferences on the basis of the observed permit prices.

This view that relies on the permit market as a signalling device ignores two important features of actual markets. One is that for there to be a permit market, some emitters have to make their abatement and production decisions before they observe any market prices for permits. In other words, there have to be some ‘first movers’. Unfortunately, there is no guarantee that these first movers are going to be making optimal abatement and production decisions, given that they have not observed any permit prices, and therefore cannot accurately assess their abatement cost structure relative to that of others. Another feature is that abatement decisions are often irreversible, and cannot be reverted back in response to the observed permit price. This means that those ‘first movers’ that perhaps should have not invested in abatement, are likely to be
stuck with an irreversible investment. The disadvantage that ‘first movers’ have in this kind of contexts has been discussed in the literature (Dosi and Moretto, 2010).

When these two features of actual permit markets are taken into account, it becomes likely that a socially optimal allocation of abatement across emitters is not going to materialise. The reason is that abatement and production decisions have to be made, by at least some emitters, prior to the market prices of permits becoming observable. As there is no mechanism for an individual emitter to recognise whether their own abatement cost are high or low relative to the others, individual emitters are not able to correctly calibrate their abatement decisions. Some emitters will invest in abatement technology and undertake substantial abatement 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 possible regulatory approach is to implement a temporary tax prior to the implementation of a tradable permit scheme, to provide an initial price signal to the emitters. Suppose that the regulator decides to use a mix of instruments over time: start with a tax and after a period of time switch to a tradable permit scheme. Let us assume that emitters could observe each other’s levels of emissions, but only know their own cost of abatement, and have no knowledge of the abatement cost of others. Further, assume that at the start of the temporary tax regulation prior to the implementation of a tradable permit scheme, the regulator sets an initial tax rate per unit of emissions. Under those circumstances, consider an individual emitter who observes the tax rate, and has to decide what to do in response. Given that they know their own abatement cost, their decision can be only based on that knowledge and on the knowledge

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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).
of the tax rate. No other information is needed. Given the tax rate and their own abatement cost, they can optimally decide on the level of abatement, if any, that they are going to undertake.

This is in contrast to a situation under an outright tradable permit scheme, where no initial signal exists that can suggest to the emitters where they might stand in terms of abatement costs relative to others, creating the ‘first mover disadvantage’ as discussed above. Under a grandfathered tradable permit scheme, an emitter would know the quantity of emissions that they will be entitled to, and their own abatement cost, but this is not sufficient information to make an optimal decision about how much to abate, if any. Additional information about where own abatement costs stand relative to that of others is needed, but is not available \textit{ex ante}. That information starts becoming available once trading in permits commences, however for there to be trading in permits, some emitters would need to have made abatement decisions in the first place, without having sufficient information. Those decisions are not likely to be optimal.

In this light, a policy design consisting of an inter-temporal mix of a tax on emissions followed by a tradable permit scheme should provide the needed additional information signal to emitters that should help induce more optimal abatement decisions. 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 were compared in terms of optimality of decisions made by emitters to invest in abatement technology, and in terms of realised permit prices in the experiment. They were also compared using an overall efficiency metric, articulated as an optimal surplus ($S^*$), calculated as follows:

$$S^* = \sum_i \pi^*_i + GR^* - MDC \sum_i e^*_i$$  \hfill (2)
where the first term on the right hand side is the aggregate profitability across all emitters, with \( \pi_i \) defined in Eq.1; the second 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 denotes a theoretically optimal level.

Based on Eq. 2, and utilising the data obtained from the experiment, the performance under each of the three tested regulations was compared using the following total efficiency (TE) measure:

\[
TE^k = \frac{\sum_i \pi_i + GR - MDC \sum_i e_i}{\sum_i \pi_i^* + GR^* - MDC \sum_i e_i^*} \times 100
\]

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 emitting sectors 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 in Australia 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.

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\(^5\) The input price was set to an amount different from the carbon tax that was in place in Australia at the time.
The experiment was designed around eight hypothetical heterogeneous emitters. Each participant in the experiment was assigned a role of one of those eight emitters. The tasks that participants faced were to make production, investment, and permit buying/selling decisions so as to maximize their profits (Eq.1), and accordingly their own actual payoff. These decisions were to be made taking into account individual production characteristics, possibilities to invest in abatement technology, and the regulation that participants faced. Participants could form expectations about the cost of complying with particular regulation 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 the tested hypothesis was whether the sequential implementation of an emissions tax and a tradable permit scheme improved participant’s ability to form more accurate expectations about future permit prices relative to their own cost of abatement, as compared to an outright tradable permit scheme treatment.

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 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 their net revenues per unit of output, and consequently per unit of emission (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 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.

[Table 1 here]

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 their 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 (Table 1).  

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

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6 The theoretically optimal investment in abatement technology in terms of optimal number of upgrades and optimal expenditure on upgrades is given in the last two rows of Table 1.
upgrade each (Table 1).

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 four rounds in a session were identical in that the same treatment and producer characteristics were induced for the duration of the whole experimental session. The reasons for conducting four identical rounds per experimental session were to allow for sufficient time and repetition of tasks so that participants become proficient in performing the tasks they were required to perform. In addition, the repetition of four identical rounds allowed the researchers to observe the effects of learning over consecutive rounds, and to discern these effects from the treatment effects. This is discussed in more detail in section 4.4 below.

[Table 2 here]

The first five periods of each round comprised a pre-liability phase, in which participants were free to choose a level of production without facing any costs associated with emissions. Participants could also make investments in technology upgrades in anticipation of regulation on emissions that takes effect in subsequent stages of the experiment. This pre-liability phase was designed so that participants can become familiarized with their production and emissions characteristics (i.e. how much input is needed to produce output) and with their investment options in abatement technology (i.e. how much it costs them to undertake technology upgrades,
and by how much incremental upgrades reduce emissions). This allows participants to carefully consider the decisions about production and investment in abatement without the pressure of being exposed to a regulation. The experimental environment was relatively complex, and these five ‘training’ periods were introduced as a pre-liability phase in order to avoid participants making erroneous decisions in the regulatory phase due to unfamiliarity with the characteristics of the roles that they are playing.

The emissions regulation was implemented from period 6 onwards in each round (Table 3). In each of the 13 periods within a round, participants had the task of selecting a production level in order to generate revenue. The choice of production level directly implied a given level of emissions (articulated as an input use). In addition to the task of choosing a production level, from period 2 onwards participants had an opportunity to invest in abatement technology upgrades. At the end of each period they received information about the total number of technology upgrades (investments) undertaken by all participants in that round. During the regulated phase of the tax-only treatment (periods 6-13, Table 3), a tax on emissions was applied, articulated as a ‘price for insufficient inputs’. Participants could see this information and the corresponding reduction of their balance due to emissions taxation, but there were no additional tasks that they could undertake in this regard (Appendix 2, screenshot 2). The same occurred in the mixed-regulation treatment during the tax component of the regulated phase (periods 6-8, Table 3). Participants faced an additional task of trading permits (inputs) in the trade phase of the mixed-regulation (periods 9-13, Table 3), and during the whole regulated phase of the trade-only treatment (periods 6-13, Table 3). This task involved participating in the single-unit double auction for permits by placing bids to buy permits or ask price to sell permits (Appendix 2, screenshot 3).

[Table 3 here]

7 Screenshots of computer screens as displayed by z-Tree software that participants were looking at can be found in the Appendix 2.
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 the information related to permit trading – such as the highest current bid price and lowest current ask price – and the quantity and price of traded permits, were provided publicly.

In the treatments with tax (tax-only and mixed regulation) the tax rate was set at the level of E$16 so as to induce optimal emissions of 320 units on aggregate over the periods 6-13 (8 periods). The optimal aggregate emissions were computed at the point where the sum of the cost of reducing emissions and the cost of environmental damages from emissions was minimized. The environmental damage cost was modeled as a linear function of emissions, ensuring ex-post optimality of the tax rate.\(^8\)

In the treatments with trading (trade-only and mixed regulation), five emissions permits per period were allocated to each participant starting in the initial period when trading of permits became active under the specific regulation. 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.\(^9\) Figure 1 represents the theoretically predicted permit equilibrium price under the optimal investment. Given that a primary aim was to study the efficiency under alternative regulations for controlling emissions, a care was taken not to induce a narrow permit price range, as it could result with inefficient

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\(^8\) We thank an anonymous reviewer for pointing this out.

\(^9\) 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.
outcomes occurring during the emissions permit trading phases. Therefore, a relatively wide permit price range was induced to facilitate efficient exchange of permits at a wide spectrum of prices.

[Figure 1 here]

In the event that a participant held less than the required number of permits at the end of a period, a fine of E$32 was levied for each insufficient permit. This 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 findings 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 optimality of investment in abatement technology, overall efficiency of
regulation, and in terms of observed market prices for emission permits. A standard Wilcoxon–Mann–Whitney two-sample rank-sum test was used to test the significance of the observed differences in these outcomes between treatments. Significance of these results was double checked with a robust Fligner-Policello (FP) test for differences (Fligner and Policello 1981).  

$p$-values reported throughout this section are based on the Wilcoxon-Mann-Whitney tests. Significance refers to $p \leq 0.05$, as validated by the robust FP test, unless otherwise noted.

In addition, a regression analysis was used to test whether there is a difference in the level of departure from the theoretically optimal 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 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 for each producer type, as given in Table 1, were identical for all three treatments.

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10 Asymptotic $p$-value provided by the FP test may not be adequate when the sample size of each treatment is less than 12. In this case, Fligner and Policello (1981) provide critical values of significance. The asymptotic $p$-values generated in Stata 11 using the FPRank module (Benmamoun (2006)) that are presented here have been cross-referenced with these small-sample critical points. Actual values of the conducted Wilcoxon–Mann–Whitney tests are available from the authors upon request.
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, abatement technology upgrades were consistently higher and further away from the optimum 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.

[Table 4 here]

[Table 5 here]

The observed abatement technology upgrade decisions over the four rounds of the experiment demonstrate that participants learn with experience. Aggregate number of upgrades and investment expenditure move closer towards the theoretically optimal level across the four rounds under all treatments (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. As discussed above, this can be attributed to the noted propensity of participants in economics experiments in the lab to overact (Gangadharan and Nemes (2005) and Camacho-Cuena et al. (2012)).

Learning, as measured by participants’ propensity to invest closer to theoretically optimal predictions, occurred faster in the tax-only and mixed regulation than in the trade-only treatment.
(Tables 4 and 5). This is evidenced by the 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 ($p \geq 0.1$) (Table 4). Similar trends are observed between second and third round, and between third and fourth round (Table 4). This indicates that the participants under the trade-only treatment had much greater difficulties in optimally calibrating abatement investment decisions compared to participants under the tax-only and mixed regulation, even after four rounds of repeated play. In addition, the overall variability in aggregate abatement investment expenditures, as measured by the standard deviation, 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 2). 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. 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 could be substantial.
In order to further examine this point, a regression analysis was conducted to evaluate the effects of regulation on abatement investment decisions of participants of particular type. The difference between the observed investment in abatement technology upgrades made by an individual participant and the theoretically calculated optimal number of upgrades for the producer type assigned to that participant (Table 1) was the dependent variable in the regression analysis. The dependent variable was regressed on the following indicator variables: regulation type (tax-only, trade-only, and mixed regulation); 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; and an experimental round (round 1, 2, 3 and 4). The mixed regulation, the medium cost producer type and round 1 were treated as baselines. The regression was estimated using maximum likelihood estimation procedure using clustered standard errors estimator, where the errors were clustered by an identifier for the experimental session, in order to isolate any effects that might have occurred in individual sessions.

The results from the regression estimation 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 emitters 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-temporally mixed regulation comprised of a tax followed by a tradable permit scheme is likely to help high intensity emitters to better calibrate their expectations about
permit prices, and to consequently make more accurate abatement technology investment decisions.

[Table 6 here]

4.2 Overall Efficiency

The efficiency measure presented in Eq. 3 was computed using data from the experimental treatments corresponding to the three regulations that were tested. A high efficiency score indicates an observed outcome that is close to the theoretically optimal outcome, and vice versa for a low efficiency score. Overall efficiency was consistently higher under the inter-temporally mixed regulation than under trade-only regulation (Figure 3). These findings conform well 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.

[Figure 3 here]

In addition, 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 significantly higher efficiency than under the mixed regulation (one-tailed $p \leq 0.1$ for rounds 2, 3 and 4) (Figure 3).

4.3 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. Average permit prices under the mixed regulation and trade-only regulation were somewhat higher than the tax rate under the tax only regulation ($E16$), whereas it is theoretically expected that permit prices should converge to the tax rate given that all the parameters were the same across the treatments. Indeed, we observe such convergence in round 4 of the mixed regulation,
where the permit price is only marginally, and not statistically significantly higher than E$16 (Table 7).

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.

To conduct further comparison on an even more ‘like-to-like’ basis between the mixed regulation and trade-only regulation, we look only at the first five trading periods under the trade-only regulation (Table 7, last row). In this way, we can compare the observations on permit prices in the five initial periods of trading under both mixed and trade-only regulation. For the mixed regulation those are periods 8-13, and for the trade-only regulation those are periods 6-10. This allows us to examine the effects of a tax implemented prior to permit trading taking place, as opposed to implementing tradable permits outright. The results show that average permit prices tended to be significantly higher (i.e. further away from the optimum) in the first five trading periods of the trade-only treatment compared to the mixed-regulation treatment. Moreover, the difference in average permit prices is much greater between the first five trade-only periods and mixed regulation then the difference between the first five trade-only periods and all trade-only periods (Table 7). This is further evidence that the treatment that included a
tax prior to implementing a tradable permit scheme enabled the participants to make more optimal decisions, which resulted in lower permit prices reflecting the overall lower abatement cost.

[Table 7 here]

4.4 Learning

Participant learning featured strongly in the conducted experiments as evidenced in Tables 4, 5 and 7 and in Figure 3. The experimental design provided ample opportunity for learning and information gathering by participants over the four rounds of an experimental session. 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 (investment in 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., investment in 10 upgrades). This change occurred much more slowly under the trade-only regulation, where average aggregate number of abatement technology upgrades remained high in the second and third rounds, and did not approach optimum even in the fourth round. Observing this differential dynamics across treatments allows us to discern the effects of learning from the treatment effects. While the opportunity to learn, in terms of the number of repeated rounds were equal across all three treatments, the learning outcome is much poorer under the trade-only regulation than under the other two treatments.

This is likely due to the limited capacity of participants to form accurate expectations about permit prices in the trade-only regulation, and subsequently their inability to correctly calibrate
investment decisions in abatement technology under this regulation. This impedes and slows down their learning process. The implication for actual permit markets is significant: the argument that over time participants in emissions trading schemes will be able to work out how does their own abatement cost structure stand in relation to others by observing the market price for permits is supported by the empirical evidence gathered here. However, the empirical evidence suggests that this argument holds much more strongly for an inter temporally mixed regulation, where the exposure to a tax in the early stages of the regulation allows participants to make adjustments much faster, and with much less variability, compared to an outright tradable permit regulation.

5. Conclusion

In 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 optimality of investment in abatement technology, overall regulation efficiency, and prices in permit markets. The comparisons were undertaken through economics experiments conducted in a computer laboratory. The findings indicate that a mixed regulation may enable emitters to make better investment decisions in abatement technology, and may bring about greater overall efficiency and lower permit prices, 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. 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, as their abatement is crowded out by the abatement carried by high abatement cost emitters. The result is the low overall efficiency realized under the trade-only regulation.

Findings from 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 participants to make abatement investment decisions that were more in line with the theoretical optimum. This subsequently resulted with 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. This is significant as under the trade-only regulation, emitters with high costs of improving emission intensity tend to invest in abatement much more than they should, which then creates high cost of permits and subsequently lower efficiency. The mixed regulation rectifies this problem by incorporating a more accurate price-signaling device (the tax rate) in the early stages of the regulation.

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. These differences are general and not specific to the experiment reported in this paper. In general, under a tax regulation, there are no strategic interactions among emitters – the behavior of one emitter does not affect the outcomes that other emitters face. From a perspective of an individual emitter the only strategic interaction is with a regulator. This is very different under a tradable permit scheme regulation in general, where non-optimal decisions of some individual emitters prior to, or in the early stages of, regulation’s
implementation affect the outcomes for the other emitters irrespective of the optimality of those emitters’ own actions. Put differently, under a tradable permit scheme emitters have to form expectations about what other emitters will do, as everyone will be affected by everyone else’s decisions via the permit price. Irreversibility of investment in abatement technology makes this problem even more serious. This general situation is also apparent in our experiment, where overinvestment in abatement 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 a regulatory instrument of choice, but the inefficiencies as a result of non-optimal decisions made prior to, or in the early stages of its implementation could be alleviated by an introductory emissions tax.

Like other empirical studies, and in particular experimental economics studies, the present work has several limitations that should be taken into account when interpreting the findings. Specifically, the results are derived from experiments where there were only few market participants, which might influence the results, even though the relatively large number of replications of individual treatments (six replications) should mitigate this issue to some extent. In addition, some of the design features (e.g. the discrete nature of the abatement cost curve, or the absence of banking of permits) that were implemented in order to simplify the experimental
design might not represent adequately situations in real markets. Also, the dynamics of the sub-optimal outcomes are not further investigated in this paper. There was a global optimum for the experiment *ex ante*, however once participants started to make decisions, some of which are clearly not optimal, the new optimal strategies emerge, which are contingent on those past sub-optimal decisions. Taking into account this iterative optima in a dynamic way would require further careful and extensive modeling, which was well beyond the scope of this paper, but it is something worth pursuing in future research.\(^\text{11}\)

Notwithstanding these limitations, this study provides useful insights that can be used in practical applications 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.

\(^{11}\) Authors thank an anonymous referee for drawing attention to this important point.
References


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

<table>
<thead>
<tr>
<th>Producer type assigned to individual participants</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net revenue per unit of output (or per unit of emissions)*</td>
<td>7.5</td>
<td>10</td>
<td>12.5</td>
<td>15</td>
<td>17.5</td>
<td>20</td>
<td>22.5</td>
<td>25</td>
</tr>
<tr>
<td>Emission intensity per unit of net revenue</td>
<td>1/7.5</td>
<td>1/10</td>
<td>1/12.5</td>
<td>1/15</td>
<td>1/17.5</td>
<td>1/20</td>
<td>1/22.5</td>
<td>1/25</td>
</tr>
<tr>
<td>Cost of Upgrade 1</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>25</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>125</td>
</tr>
<tr>
<td>Cost of Upgrade 2</td>
<td>62.5</td>
<td>75</td>
<td>50</td>
<td>75</td>
<td>75</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Cost of Upgrade 3</td>
<td>112.5</td>
<td>137.5</td>
<td>150</td>
<td>125</td>
<td>125</td>
<td>200</td>
<td>225</td>
<td>250</td>
</tr>
<tr>
<td>Cost of Upgrade 4</td>
<td>162.5</td>
<td>200</td>
<td>250</td>
<td>175</td>
<td>175</td>
<td>250</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Optimal Number of Upgrades</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Optimal Expenditure on Upgrades</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>225</td>
<td>225</td>
<td>150</td>
<td>75</td>
<td>125</td>
</tr>
</tbody>
</table>

* 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

<table>
<thead>
<tr>
<th>Decision stage</th>
<th>Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment stage</td>
<td>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.</td>
</tr>
<tr>
<td>(60 seconds)</td>
<td>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%.</td>
</tr>
<tr>
<td></td>
<td>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.</td>
</tr>
<tr>
<td>Production and Trading Stage</td>
<td>Participants selected a production level between 0 and 10 each period. Participants knew their input costs and revenues associated with each production level.</td>
</tr>
<tr>
<td>(60 seconds)</td>
<td>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.</td>
</tr>
<tr>
<td>Summary Stage</td>
<td>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.</td>
</tr>
<tr>
<td>(15 seconds)</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Description of experimental treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-Liability Phase</th>
<th>Regulated Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax-Only</td>
<td>Pre-Liability</td>
<td>Tax</td>
</tr>
<tr>
<td>Mixed (Staged transition)</td>
<td>Pre-Liability</td>
<td>Tax Trade</td>
</tr>
<tr>
<td></td>
<td>(Periods 6-8)</td>
<td>(Periods 9-13)</td>
</tr>
<tr>
<td>Trade-Only</td>
<td>Pre-Liability</td>
<td>Trade</td>
</tr>
</tbody>
</table>
Table 4: Average aggregate expenditure on investment in abatement by round and treatment (standard deviations in parentheses)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Round</th>
<th></th>
<th></th>
<th></th>
<th>Optimal</th>
<th>Overall Average by Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tax-Only</td>
<td>3042</td>
<td>2329</td>
<td>1819</td>
<td>1521</td>
<td>800</td>
<td>2178</td>
</tr>
<tr>
<td></td>
<td>(469)</td>
<td>(726)</td>
<td>(707)</td>
<td>(422)</td>
<td>(800)</td>
<td>(810)</td>
</tr>
<tr>
<td>Mixed (Staged transition)</td>
<td>2979</td>
<td>2304</td>
<td>1738</td>
<td>1592</td>
<td>800</td>
<td>2153</td>
</tr>
<tr>
<td></td>
<td>(663)</td>
<td>(358)</td>
<td>(355)</td>
<td>(553)</td>
<td>(800)</td>
<td>(727)</td>
</tr>
<tr>
<td>Trade-Only</td>
<td>2933</td>
<td>2373</td>
<td>1821</td>
<td>1667</td>
<td>800</td>
<td>2198</td>
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<tr>
<td></td>
<td>(649)</td>
<td>(787)</td>
<td>(750)</td>
<td>(814)</td>
<td>(800)</td>
<td>(868)</td>
</tr>
</tbody>
</table>
Table 5: Average number of aggregate technology upgrades by round and treatment (standard deviations in parentheses)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Round</th>
<th>Optimal</th>
<th>Overall Average by Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tax-Only</td>
<td>26</td>
<td>19.33</td>
<td>15.33</td>
</tr>
<tr>
<td></td>
<td>(2.9)</td>
<td>(5.4)</td>
<td>(3.4)</td>
</tr>
<tr>
<td>Mixed (Staged transition)</td>
<td>25.67</td>
<td>19</td>
<td>14.83</td>
</tr>
<tr>
<td></td>
<td>(3.4)</td>
<td>(3.0)</td>
<td>(1.0)</td>
</tr>
<tr>
<td>Trade-Only</td>
<td>25.83</td>
<td>21.83</td>
<td>18.83</td>
</tr>
<tr>
<td></td>
<td>(2.8)</td>
<td>(5.0)</td>
<td>(5.2)</td>
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## Table 6. Results from a regression analysis (dependent variable: difference between observed and theoretically optimal number of upgrades in abatement technology)

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

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)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Round</th>
<th>Overall Average by Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mixed (Staged transition)</td>
<td>17.71</td>
<td>17.29</td>
</tr>
<tr>
<td></td>
<td>(3.21)</td>
<td>(3.95)</td>
</tr>
<tr>
<td>Trade-Only (All Periods)</td>
<td>21.69</td>
<td>19.97</td>
</tr>
<tr>
<td></td>
<td>(3.30)</td>
<td>(3.16)</td>
</tr>
<tr>
<td>Trade-Only (first 5 trading periods)</td>
<td>21.06</td>
<td>20.75</td>
</tr>
<tr>
<td></td>
<td>(3.60)</td>
<td>(3.70)</td>
</tr>
</tbody>
</table>
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. Difference between actual and theoretically predicted number of investment upgrades for the three types of regulation

Deviation from Optimal Investment
Means with Standard Deviations

Cost of Improving Emission Intensity

Actual - Optimal Upgrade Level

-2 -1 0 1 2 3 4 5

High Medium Low

Tax Only  Staged Transition  Trade Only
Figure 3. Overall efficiency of the three types of regulation.
Appendix 1

History of recent Australian GHG mitigation policy


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. CPM 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.
Appendix 2

Participant Investment Screen

Period: 2 of 13

Balance: $ 37.50

Total Percent Reduction of Initial Required Inputs: 0%

<table>
<thead>
<tr>
<th>Production Level</th>
<th>Production Income ($)</th>
<th>Current Required Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$0.00</td>
<td>0.0</td>
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<tr>
<td>1</td>
<td>$7.50</td>
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<td>8.0</td>
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<tr>
<td>9</td>
<td>$67.50</td>
<td>9.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investment Cost</th>
<th>Reduction of Initial Required Inputs</th>
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<tr>
<td>$12.50</td>
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<tr>
<td>$62.50</td>
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<td></td>
</tr>
<tr>
<td>$112.50</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>$162.50</td>
<td>10%</td>
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</tr>
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</table>
### Participant Production Screen, No Trading

**Period:** 1 of 13  
**Balance:** $0.00  
**Held Inputs:** 0.0  
**Required Inputs:** 5.0  
**Insufficient Inputs:** 5.0  
**Price for an Insufficient Input:** $0.00  
**Expenses Due:** $0.00

<table>
<thead>
<tr>
<th>Production Level</th>
<th>Production Income ($)</th>
<th>Current Required Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$0.00</td>
<td>0.1</td>
</tr>
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<tr>
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<td>4.1</td>
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<td><strong>5</strong></td>
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</tr>
<tr>
<td>10</td>
<td>$75.00</td>
<td>10.0</td>
</tr>
</tbody>
</table>
### Participant Production Screen, with Trading

**Period:** 6 of 13  
**Balance:** $0.00  
**Held Inputs:** 5.0  
**Required Inputs:** 7.0  
**Insufficient Inputs:** 2.0  
**Price for an Insufficient Input:** $32.00  
**Expenses Due:** $64.00

<table>
<thead>
<tr>
<th>Production Level</th>
<th>Production Income ($)</th>
<th>Current Required Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
<td>1</td>
<td>$7.50</td>
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<td>9.0</td>
</tr>
<tr>
<td>10</td>
<td>$75.00</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**Price at which you are willing to sell ($):**

**Current Sell Offer ($)**

**Current Buy Offer ($)**

**Price at which you are willing to buy ($):**

**History of Transaction Prices:**

---

Select Level 0  
Select Level 1  
Select Level 2  
Select Level 3  
Select Level 4  
Select Level 5  
Select Level 6  
Select Level 7  
Select Level 8  
Select Level 9  
Select Level 10
### Period 1 Summary

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<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
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<td>Held Inputs</td>
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<td>Required Inputs</td>
<td>5.0</td>
</tr>
<tr>
<td>Insufficient Inputs</td>
<td>5.0</td>
</tr>
<tr>
<td>Price for an Insufficient Input</td>
<td>$ 6.00</td>
</tr>
<tr>
<td>Expenses Due</td>
<td>$ 6.00</td>
</tr>
<tr>
<td>Previous Balance</td>
<td>$ 6.00</td>
</tr>
<tr>
<td>Current Balance</td>
<td>$ 37.50</td>
</tr>
<tr>
<td>This Period Profit</td>
<td>$ 37.50</td>
</tr>
<tr>
<td>Total Investments in the Market</td>
<td>0</td>
</tr>
</tbody>
</table>

Period 1: 1 of 13
Appendix 3

Experimental instructions

Table of contents:
Experimental instructions for the tax-only regulation treatment Page 1
Experimental instructions for the inter-temporally mixed regulation treatment Page 4
Experimental instructions for the ETS-only regulation treatment Page 8

Experimental instructions for the tax-only regulation treatment

Instructions

This is an experiment in market decision making. You will be paid for your participation in cash at the end of the experiment. Different participants may earn different amounts. What you earn will depend on your decisions and the decisions of others.

The experiment will take place through computer terminals at which you are seated. We will start with a detailed instruction video. If you have any questions regarding the instructions, raise your hand at the conclusion of the video and your question will be answered so everyone can hear. If any difficulties arise after the experiment has begun, raise your hand and a monitor will come and assist you privately.

At the end of this video you will be asked to complete a quiz that will ensure your understanding of the instructions. From now on, you will only interact with each other via computers.

Today’s experiment is comprised of 4 separate rounds. Each round will last for 13 periods. Each period will consist of an investment stage followed by a production stage with an exception of Period 1. Period 1 will only have a production stage. In each round, you will be a producer in a market that is composed of 8 producers, and your earnings will be based on the profitability of your decisions.

Production Stage

You will choose a Production Level each period. Each Production Level will generate a certain Production Income and will need a certain number of Required Inputs. At the start of each round, all 8 producers will need the same number of Required Inputs for the Production Level. Producers will earn different Production Incomes for each Production Level.

Each period, you may choose to produce at any level between 0 (at which you will produce nothing, earn no income and will require no inputs) and 10. The number of
**Required Inputs** that are needed for each **Production Level** is visible on the right side of the production table. Every **Production Level** requires some number of inputs. If you do not hold sufficient amount of inputs for your chosen **Production Level** at the end of a period, you will be automatically charged the **Input Price** for each **Insufficient Input**. The current **Input Price** per insufficient (i.e. required but not held) input is displayed in the top left corner of the production screen, along with the total **Expenses Due** for the insufficient inputs at the currently selected **Production Level**.

Your production options are on the left side of the screen. You may choose a **Production Level** at which to produce for the current period by clicking a “Select Level” button to the left of each level. Your currently selected **Production Level** is always bolded and highlighted in yellow. Once you have made your final decision and are ready to move on, click the “Continue” button on the top right of the screen. The period will end when the time expires or when the last person has clicked the “Continue” button.

Your **Balance** will be updated with your **Production Income** at the end of each period’s production stage. At the conclusion of each production stage, you will see a summary of your performance for the period. The Summary Screen displays your **Held Inputs**, **Required Inputs**, **Insufficient Inputs**, **Input Price**, **Expenses Due**, and **Balance** as of the end of the Period.

### Investment Stage

Starting in Period 2, you may invest to reduce the number of **Required Inputs** needed for production. An opportunity to invest will be presented to you prior to each period’s production stage. Each investment stage will last for 60 seconds. Any investment you make will take effect in the current period, and will lower your **Required Inputs** for all of the remaining periods in the round.

By investing once, the **Required Inputs** for each **Production Level** will be reduced by 10 percent. Investments are additive, meaning that if you make multiple investments, your originally **Required Inputs** will be reduced by the sum of the respective percent reduction levels. For example, choosing two 10 percent investments would reduce the number of **Required Inputs** by 20 percent, so if the initial number of **Required Inputs** is 10, this requirement would be 8 inputs after two investments. You can see your current production schedule on the left side of the screen during the investment stage.

You will have the opportunity to invest before each production stage starting in Period 2, and may invest at most once per period. Each investment has a cost. The **Investment Cost** is deducted from your **Balance** when you click the “Invest” button. Investment options and costs will not change during today's experiment.
Input Prices
For the first 5 periods of each Round, the *Input Price* for each *Insufficient Input* will be E$0. Starting in Period 6 of each round, you will be charged an *Input Price* of E$16 for each *Insufficient Input*. The total * Expenses Due* in connection with the *Insufficient Inputs* will be denoted in the upper left area of your screen. For example, if you need 8 *Required Inputs*, your *Expenses Due* will be E$16 times 8, or E$144.

Summary
You are a producer in a market composed of 8 producers. You may select a *Production Level* between 0 and 10 each period. You will earn *Production Income* and submit *Required Inputs* in association with your chosen *Production Level*. From Period 6 onwards, you will be charged E$16 for each *Insufficient Input*. You may choose to make investments that will reduce your *Required Inputs* (at most one investment per period).

At all times during the Investment and Production stages, you may access a calculator by clicking the icon in the bottom right corner of your screen.

At the conclusion of each production stage, you will see a summary of your performance for the period. The Summary Screen displays your *Held Inputs*, *Required Inputs*, *Insufficient Inputs*, *Input Price*, *Expenses Due* and *Balance* as of the end of the period. The Summary Screen also displays the total number of investments that the 8 Producers in the market have completed as of the current period.

At the end of each round your remaining *Balance* will be converted into cash. The rate of experimental dollars to Australian dollars at which you will be paid is displayed on your screen. Your earnings from all four rounds will be added and paid to you in cash at the end of the experiment.

Thank you for your attention. If you have any questions, please raise your hand.
Experimental instructions for the inter-temporally mixed regulation treatment

Instructions

This is an experiment in market decision making. You will be paid for your participation in cash at the end of the experiment. Different participants may earn different amounts. What you earn will depend on your decisions and the decisions of others.

The experiment will take place through computer terminals at which you are seated. We will start with a detailed instruction video. If you have any questions regarding the instructions, please raise your hand at the conclusion of the video and your question will be answered so everyone can hear. If any difficulties arise after the experiment has begun, raise your hand and a monitor will come and assist you privately.

At the end of this video you will be asked to complete a quiz that will ensure your understanding of the instructions. From now on, you will only interact with each other via computers.

Today’s experiment is comprised of 4 separate rounds. Each round will last for 13 periods. Each period will consist of an investment stage followed by a production stage with an exception of Period 1. Period 1 will only have a production stage. In each round, you will be a producer in a market that is composed of 8 producers, and your earnings will be based on the profitability of your decisions.

Production Stage

You will choose a Production Level each period. Each Production Level will generate a certain Production Income and will need a certain number of Required Inputs. At the start of each Round, all 8 producers will need the same number of Required Inputs for each Production Level. Each producer will earn different Production Income for each Production Level.

You may choose to produce at any level between 0 (at which you will produce nothing, earn no income and will require no inputs) and 10. The number of Required Inputs that are needed for each Production Level is visible on the right side of the production table. Every Production Level requires some number of inputs. If you do not hold a sufficient number of inputs for your chosen Production Level at the end of a period, you will be automatically charged the Input Price for each Insufficient Input. The current Input Price per insufficient (i.e. required but not held) input is displayed in the top left corner of the production screen, along with the total Expenses Due for the insufficient inputs at the currently selected Production Level.
Your production options are on the left side of the screen. You may choose a Production Level at which to produce for the current period by clicking a “Select Level” button to the left of each level. Your currently selected Production Level is always bolded and highlighted in yellow. Once you have made your final decision and are ready to move on, click the “Continue” button on the top right of the screen. The period will end when the time expires or when the last person has clicked the “Continue” button.

Your Balance will be updated with your Production Income at the end of the production stage. At the conclusion of each production stage, you will see a summary of your performance for the period.

Investment Stage
Starting in Period 2, you may invest to reduce the number of Required Inputs needed for production. An opportunity to invest will be presented to you prior to each period’s production stage. Each investment stage will last for 60 seconds. Any investment you make will take effect in the current period, and will lower your Required Inputs for all of the remaining periods in the round.

By investing once, the Required Inputs for each Production Level will be reduced by 10 percent. Investments are additive, meaning that if you make multiple investments, your originally Required Inputs will be reduced by the sum of the respective percent reduction levels. For example, choosing two 10 percent investments would reduce the number of Required Inputs by 20 percent, so if the initial number of Required Inputs is 10, this requirement would be 8 inputs after two investments. You can see your current production schedule on the left side of the screen during the Investment Stage.

You will have the opportunity to invest before each production stage starting in Period 2, and may invest at most once per period. Each investment has a cost. The Investment Cost is deducted from your Balance when you click the “Invest” button. Your investment options and costs will not change during today’s experiment.

Input Prices
For the first 5 periods of each Round, the Input Price for each Insufficient Input will be E$0. In Periods 6, 7 and 8 of each round, you will be charged an Input Price of E$16 for each Insufficient Input. The total Expenses Due in connection with the Insufficient Inputs will be denoted in the upper left area of your screen. For example, if you need 8 Required Inputs, your Expenses Due will be E$16 times 8, or E$144.

Starting in Period 9 and for the remainder of each of the rounds, you will each receive 5 inputs each period. You may buy and sell inputs to satisfy your requirements and to maximize your earnings. If you do not hold sufficient inputs to satisfy the Required Inputs at the end of a period, you will be required to pay a new
Input Price of E$32 for each insufficient input. For example, if you have 7 Held Inputs at the end of a period and need 9 Required Inputs, your Expenses Due will be E$32 times 2, or E$64. Inputs unused at the end of a period will not be available in future periods. You will receive more detailed instructions about trading later.

Summary
You are a producer in a market composed of 8 producers. You will each choose to produce at a Production Level between 0 and 10 each period. You will earn Production Income and submit Required Inputs in association with your chosen Production Level. You may choose to make investments that will reduce your Required Inputs (at most one investment per period). In Periods 6, 7 and 8, you will be charged an Input Price of E$16 for each Insufficient Input. Starting in Period 9 and for the remainder of each round, you will receive 5 inputs each period. You may then buy and sell inputs to satisfy your input requirements, and will be charged E$32 for each Insufficient Input.

At all times during the Investment and Production Stages, you may access a calculator by clicking the icon in the bottom right corner of your screen.

At the conclusion of each production stage, you will see a summary of your performance for the period. The Summary Screen displays your Held Inputs, Required Inputs, Insufficient Inputs, Input Price, Expenses Due, and Balance as of the end of the Period. The Summary Screen also displays the total number of investments that the 8 Producers in the market have completed as of the current Period.

At the end of each round your remaining Balance will be converted into cash. The rate of experimental dollars to Australian dollars at which you will be paid is displayed on your screen. Your earnings from all four rounds will be added and paid to you in cash at the end of the experiment.

Thank you for your attention. If you have any questions, please raise your hand.
**Input Trading**

From now on, you will each receive 5 free inputs each period. You may buy and sell inputs from each other to satisfy your input requirements while you are in the production stage of each period.

The market box on the right side of the screen is divided into several areas.

To offer to sell an input, click on the space under “Price you are willing to sell ($)” and enter the price that you are prepared to sell one input for. When you are satisfied with your Sell Price, click the “Submit” button.

To offer to buy an input, click on the space under “Price you are willing to buy ($)” and enter the price that you are prepared to buy one input for. When you are satisfied with your Buy Offer, click the “Submit” button.

You will see the current lowest Sell Offer and current highest Buy Offer in the center area. When you see a Sell Offer at a price you would like to buy an input, select the Offer and click “Buy Input.” When you see a Buy Offer at a price you would like to sell an input, select the Offer and click “Sell Input.” Your sales and purchases will instantly update your Balance and Held Inputs.

Below, you can see the history of the recent prices of traded inputs.

If you do not hold sufficient inputs to satisfy the number of Required Inputs at the end of a period, you will be required to pay the Input Price of E$32 for each Insufficient Input. Held Inputs not required at the end of a period will not be available in future periods and will not generate any additional income if held.
Experimental instructions for the trade-only regulation treatment

Instructions

This is an experiment in market decision making. You will be paid for your participation in cash at the end of the experiment. Different participants may earn different amounts. What you earn will depend on your decisions and the decisions of others.

The experiment will take place through computer terminals at which you are seated. We will start with a detailed instruction video. If you have any questions regarding the instructions, raise your hand at the conclusion of the video and your question will be answered so everyone can hear. If any difficulties arise after the experiment has begun, raise your hand and a monitor will come and assist you privately.

At the end of this video you will be asked to complete a quiz that will ensure your understanding of the instructions. From now on, you will only interact with each other via computers.

Today’s experiment is comprised of 4 separate rounds. Each round will last for 13 periods. Each period will consist of an investment stage followed by a production stage with an exception of Period 1. Period 1 will only have a production stage. In each round, you will be a producer in a market that is composed of 8 producers, and your earnings will be based on the profitability of your decisions.

Production Stage

You will choose a Production Level each period. Each Production Level will generate a certain Production Income and will need a certain number of Required Inputs. At the start of each round, all 8 producers will need the same number of Required Inputs for the Production Level. Producers will earn different Production Incomes for each Production Level.

Each period, you may choose to produce at any level between 0 (at which you will produce nothing, earn no income and will require no inputs) and 10. The number of Required Inputs that are needed for each Production Level is visible on the right side of the production table. Every Production Level requires some number of inputs. If you do not hold sufficient amount of inputs for your chosen Production Level at the end of a period, you will be automatically charged the Input Price for each Insufficient Input. The current Input Price per insufficient (i.e. required but not held) input is displayed in the top left corner of the production screen, along with the total Expenses Due for the insufficient inputs at the currently selected Production Level.

Your production options are on the left side of the screen. You may choose a Production Level at which to produce for the current period by clicking a “Select
Level” button to the left of each level. Your currently selected Production Level is always bolded and highlighted in yellow. Once you have made your final decision and are ready to move on, click the “Continue” button on the top right of the screen. The period will end when the time expires or when the last person has clicked the “Continue” button.

Your Balance will be updated with your Production Income at the end of each period’s production stage. At the conclusion of each production stage, you will see a summary of your performance for the period. The Summary Screen displays your Held Inputs, Required Inputs, Insufficient Inputs, Input Price, Expenses Due, and Balance as of the end of the Period.

**Investment Stage**
Starting in Period 2, you may invest to reduce the number of Required Inputs needed for production. An opportunity to invest will be presented to you prior to each period’s production stage. Each investment stage will last for 60 seconds. Any investment you make will take effect in the current period, and will lower your Required Inputs for all of the remaining periods in the round.

By investing once, the Required Inputs for each Production Level will be reduced by 10 percent. Investments are additive, meaning that if you make multiple investments, your originally Required Inputs will be reduced by the sum of the respective percent reduction levels. For example, choosing two 10 percent investments would reduce the number of Required Inputs by 20 percent, so if the initial number of Required Inputs is 10, this requirement would be 8 inputs after two investments. You can see your current production schedule on the left side of the screen during the investment stage.

You will have the opportunity to invest before each production stage starting in Period 2, and may invest at most once per period. Each investment has a cost. The Investment Cost is deducted from your Balance when you click the “Invest” button. Investment options and costs will not change during today’s experiment.

**Input Prices**
For the first 5 periods of each Round, the Input Price for each Insufficient Input is E$0. Starting in Period 6 and for the remainder of the rounds, you will each receive 5 free Inputs each period. You may buy and sell Inputs to satisfy your requirements and to maximize your earnings. If you do not hold sufficient Inputs to satisfy the Required Inputs at the end of a period, you will be required to pay a new Input Price of E$32 for each Insufficient Input. For example, if you have 5 Held Inputs at the end of a period and need 8 Required Inputs, your Expenses Due will be E$32 times 3, or E$96. Inputs unused at the end of a period will not be available in future periods. You will receive more detailed instructions about trading later.
**Summary**

You are a producer in a market composed of 8 producers. You will each choose to produce at a *Production Level* between 0 and 10 each period. You will earn *Production Income* and submit *Required Inputs* in association with your chosen *Production Level*. From Period 6 onwards, you will receive 5 free inputs each period. You may then buy and sell inputs to satisfy your input requirements, and will be charged E$32 for each *Insufficient Input*. You may choose to make investments that will reduce your *Required Inputs* (at most one investment per period).

At all times during the Investment and Production Stages, you may access a calculator by clicking the icon in the bottom right corner of your screen.

At the conclusion of each production stage, you will see a summary of your performance for the period. The Summary Screen displays your *Held Inputs, Required Inputs, Insufficient Inputs, Input Price, Expenses Due*, and *Balance* as of the end of the Period. The Summary Screen also displays the total number of investments that the 8 Producers in the market have completed as of the current Period.

At the end of each round your remaining *Balance* will be converted into cash. The rate of experimental dollars to Australian dollars at which you will be paid is displayed on your screen. Your earnings from all four rounds will be added and paid to you in cash at the end of the experiment.

Thank you for your attention. If you have any questions, please raise your hand.
Input trading

From now on, you will each receive 5 free inputs each period. You may buy and sell inputs from each other to satisfy your input requirements while you are in the production stage of each period.

The market box on the right side of the screen is divided into several areas.

To offer to sell an input, click on the space under “Price you are willing to sell ($)” and enter the price that you are prepared to sell one input for. When you are satisfied with your Sell Price, click the “Submit” button.

To offer to buy an input, click on the space under “Price you are willing to buy ($)” and enter the price that you are prepared to buy one input for. When you are satisfied with your Buy Offer, click the “Submit” button.

You will see the current lowest Sell Offer and current lowest Buy Offer in the center area. When you see an Sell Offer at a price you would like to buy an input, select the Offer and click “Buy Input.” When you see a Buy Offer at a price you would like to sell an input, select the Offer and click “Sell Input.” Your sales and purchases will instantly update your Balance and Held Inputs.

Below, you can see the history of the recent prices of traded inputs.

If you do not hold sufficient inputs to satisfy the number of Required Inputs at the end of a period, you will be required to pay the Price of E$32 for each Insufficient Input. Inputs unused at the end of a period will not be available in future periods and will not generate any additional income if held.