TAXES, TRADING, OR BOTH?: AN EXPERIMENTAL INVESTIGATION OF ABATEMENT INVESTMENT UNDER ALTERNATIVE EMISSIONS REGULATION

A Thesis

Presented to the Faculty of Agriculture and Environment
of The University of Sydney
In fulfilment of the Requirements for the
Degree of Master of Philosophy

By

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January 2014

Statement

This work has not been previously submitted for a degree or diploma in any University. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself. Considerable portions of the thesis draw from the article "Abatement Investment Decisions under Alternative Emissions Regulation: An Experimental Investigation," which I authored with Tihomir Ancev, Rimvydas Baltaduonis, Tim Capon and Andrew Reeson.

Elizabeth Bernold

Zurich, January 2014

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Acknowledgements

Generous contributions from many enabled and enhanced the work presented in this thesis. First and foremost, I thank Dr. Tihomir Ancev, whose support and collaboration through the course of this project made this work possible. Dr. Rimvydas Baltaduonis, Dr. Tim Capon and Dr. Andrew Reeson each provided informal supervision, excellent guidance and support in spite of the challenges presented by other professional obligations, extreme distance and time zone differences. Collaborating with these scholars on such a project has yielded an academic experience that exceeded by expectations.

This project was made possible by Australian Research Council Linkage Grant Australian Research Council's Linkage Grant LP 100200252 "Emissions trading and the design and operation of Australia's energy markets," in partnership with the Australian Financial Markets Association. The research also benefited significantly from discussions with participants of Sydney's Brownbag Lunch Experimental Economics Seminar. Dr. Stephen Cheung, in particular, provided useful insights in the early stages of this project. Taylor Smart contributed excellent assistance in the zTree programming required by the experiment.

My post-graduate experience has been greatly enhanced by peers and colleagues in the Faculty of Agriculture and Environment, especially the Department of Agricultural and Resource Economics. Dr. Tim Capon's willingness to engage with a fresh post-graduate helped me to develop essential skills, confidence and experience as a researcher and economist. Dr. Uttam Sharma and Dr. David Ubilava's interest in contributing time and energy for the benefit of post-graduate researchers was encouraging and energizing. Early in my candidature, Darian Naidoo, Evarn Ooi and David Rogers welcomed me as a peer in spite of their more extensive academic experience. For their constant and engaging inquiry, critique, and especially support, I am grateful.

Acknowledgements could not be complete without attention to my family of supporters. My parents' enthusiasm for adventure first took me to Australia, and their unwillingness to back away from challenge inspires me to lean into complexity, trials and opportunity. My wide 'family' of friends and colleagues in Australia and United States deserves mention here, too: I thank them particularly for their example in striving to always "learn from ever single being, experience and moment." Marc Immer first encouraged my idea to enroll as a post-graduate student at the University, and has been an essential support throughout the time of my candidature. My appreciation goes to Marc for his overwhelming generosity and support from far and now near.

Abstract

Emissions taxes and emissions permit trading schemes are designed to reduce greenhouse gas (GHG) emissions by providing incentives for large emitters to invest in less emissions-intensive production technologies. Whereas taxes place a fixed price on emissions, tradable permit schemes include a secondary permit market, from which allowance prices emerge after the regulation enters into force. Under a newly imposed regulation, the delay in price information contributes to uncertainty about the future cost of compliance that liable emitters will face, thereby challenging liable entities' ability to make optimal abatement investment decisions. Using laboratory experiments, this thesis examines the effects of a policy regime that is similar to the one implemented in Australia in 2012. The regime includes a staged transition over time from a regulation-free environment, to an emissions tax and then to emissions trading. The thesis examines the effects of such a staged transition on investment decisions, the level of emissions, permit prices and trading behavior, comparing it to standard policy regimes of only an emissions tax and only emissions permit trading. The findings suggest that a regime based on a staged transition from a tax to permit trading results in lower compliance costs and higher overall allocative efficiency compared to a regime based solely on emissions trading in a market of heterogeneous producing firms.

Chapter 1. Introduction

1.1 Motivation

Curbing the rise of greenhouse gas emissions has become an important task for leaders across the globe. While standard-based instruments legally compel emitting firms to upgrade their equipment to a certain “standard,” incentive-based instruments are aimed at providing large emitters, such as electricity generators, with financial incentives to invest in lower emissions production technologies, usually by using CO_2 as a proxy for the overall environmental impact of production (Kneese and Schultz (1975); Bohi and Burtraw (1992)). Economists and lawmakers generally agree that incentive-based policy instruments are superior to standards-based instruments at reliably curbing emissions at low cost to society (Downing and White (1986); Tietenberg (2006)).

1.2 Prices or Quantities

The relative merits of the two classes of incentive-based policies: the price-based (emissions taxes) and quantity-based market instruments (emissions trading schemes), can be compared along many practical dimensions, though the comprehensive study and comparison of such instruments in advance of or during early stages of their implementation is costly and logistically difficult. Quantity-based instruments regulate by prescribing the volume of emissions that may be released, and distribute tradable permits in accordance with this quantity cap to emitters. Under a price-based instrument, the regulator seeks to set a price per unit of emission equivalent to the marginal damage cost of the emission. Because any regulator lacks omniscience and therefore perfect information about either the damage costs or the marginal revenue generated by producers per unit of emissions created, a need to revise the price in order to ensure that the quantity of emissions is confined to the identified preferred level is likely (Baumol and Oates (1971)). A particular policy's advantage over another likely depends on its detailed design and implementation in its policy environment. The question of whether it is best to implement a price-based or quantity-based policy in a jurisdiction subsequently generates heated public and scholarly debate (Kelly (2009); Drape (2012); Economist (2013)). A greater understanding of the implications of each of these policy types, and of additional options, is necessary if the debates stand to be resolved satisfactorily.

Emissions trading schemes have been implemented in New Zealand (2008) the European Union (2005), and California (2013); revenue-neutral emissions taxes are in place in Norway (2005), several Canadian provinces (for example, British Columbia (2008)) and Ireland (2010); a contemporaneous hybrid (tax and trading system) rules in Switzerland (2008), and a staged transition from an emissions tax to an emissions trading scheme has been initiated in Quebec (2011) and Australia (2012).

The popularity of emissions trading schemes is allegedly due largely to the business sector's belief that a trading scheme's direct market-based nature would impose lower compliance demands on polluters than a tax (Economist (2013)). However, there is insufficient evidence to conclude that a trading scheme necessarily brings about a superior (less expensive) overall result when compared to a commensurate tax. If the problems of transaction costs and market power are assumed away, and if decision-makers are assumed to be risk neutral and possess full information, theory predicts that emissions can be capped at least cost by firms reducing their emissions under either an emissions tax or emission trading (Tietenberg (1974, p. 480)). These assumptions have been shown to be untenable, though, particularly because of the effects that market uncertainty have on investment decisions (Betz and Gunnthorsdottir (2009, p. 1418); Hahn and Stavins (2011, p. S274)). For example, and importantly in this thesis, uncertainty about future emissions permit prices in an emissions trading scheme can lead firms to invest more or less than the optimal levels in abatement Malueg (1989, p. 56); thereby raising the total social cost of compliance (Aldy and Stavins (2012); Hahn and Stavins (2011)).

Perhaps the most important criteria on which to rate emissions control policies is the extent to which they motivate large polluters to invest in lower-emissions technologies, and the cost of that adoption (Kneese and Schultze (1975, p. 38); Bohi and Burtraw (1992)). Electricity generation and manufacturing, the top-two point-source emitters by sector (Baumert et al. (2005, p. 41)), present themselves as prime targets for policies designed to reduce emissions. Firms' investments in production technologies are of particular concern in these industries because of their potential to greatly reduce emissions from production, significant expense, their long time horizon, and their irreversibility.

Prospect theory suggests that high uncertainty with regards to the future prices for tradable permits (i.e. future return on investment in abatement) can have a significant effect on firms' incentives to invest (e.g., Kahneman and Tversky (1979)). Uncertainty associated with investment incentives and the subsequently distorted investment patterns can result in excessive costs – too much investment by inefficient producers, or too little investment by more efficient producers – thereby raising the overall compliance cost, and reducing the financial efficiency of the regulation (Aldy and Stavins (2012), Hahn and Stavins (2011)). The European Union's emissions trading scheme presents a particularly vibrant example of unanticipated conditions that can befall an emissions trading scheme. There, volatile and mostly low recent prices for emissions permits in Europe have been pointed to as contributors to the weakening of a market-based abatement incentive for emitters to continue to invest in abatement (Krukowska (2012)).

On the other hand, a tax presents itself as a potentially simpler mechanism for inducing emission reduction. The emissions tax could be set at a rate (per unit of emission) that would impel polluters to curb emissions to the target level (Milliman and Prince (1989, p. 251)). Compared to an emissions trading scheme, the steady price signal provided by a tax would lend firms greater certainty about their future compliance costs and therefore the returns they would receive from investment in abatement. The certainty in additional production costs allows decision makers to calculate and then pursue profit-maximizing investment decisions. Under certain conditions, an appropriately set tax could therefore result in a lowest cost compliance investment pattern (Requate and Unold (2003); Requate (2005)).[1]

Early reviews suggest that the revenue-neutral carbon tax implemented in British Columbia in 2007 have led to significantly lower emissions due to reduced fuel consumption in the region, at a relatively low social cost (Economist (2011); Hussain (2012). In spite of the benefit that tax instruments can provide relative to emissions trading, new emissions taxes – particularly those with no appointed end-date – consistently suffer strong political opposition. This contention was recently evidenced in the fierce political and public backlash to the early talks of installing a carbon tax in Australia (Shanahan (2012)), in which use of the word *tax* by the media drew emotional responses from those opposed to costly environmental legislation. Later, in an attempt to garner support prior to the national election, the Rudd government proclaimed in July 2013 that it would transition away from the tax (to the emissions trading scheme) earlier than originally planned (Galbraith (2013)).

In light of the drawbacks associated with emissions trading and taxation, a multi-period combination of the two policies could be a helpful compromise. While installing a perpetual tax on emissions in a previously unregulated jurisdiction is often seen as a politically impractical venture, a temporary tax that would convert to emissions trading 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. A key benefit

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[1] Requate (2005) provides a more comprehensive overview of adoption and implementation incentives resulting from environmental policy instruments.

of this design is that the fixed temporary tax would reduce the uncertainty with regard to short term return on investment, conceivably resulting in an investment pattern that will yield close to minimum social compliance costs and a target-abiding emissions level. Once the tax expires, the permanent emissions trading scheme would provide a long-term, market-based incentive for firms to continue to restrict their emissions to the target level.

1.3 Research Question

The question pursued in this thesis is whether a well-designed tax, temporarily enforced for several periods prior to an emissions trading system's implementation, would yield increased overall efficiency of the regulation by smoothing the transition to an emissions trading system. An alternative effect could be that the additional stage in the regulation's implementation would add additional, costly, confusion amongst liable decision makers. The combined use of price and quantity instruments in a static sense is widely known in the literature (e.g., Roberts and Spence (1976); Pizer (2002); Krysiak and Oberauner (2010)), but the temporal combination of the two instruments has not yet been satisfactorily addressed. As far as the author is aware, this is the first study that explicitly examines this type of temporally hybridized design, in which a quantity-based instrument sequentially follows a price-based instrument.

In the model used in this project, a market regulated by an emissions tax should theoretically incur lower total compliance costs compared with one regulated by an emissions trading scheme. The time horizon considered in the study is the first phase for which the emissions cap is imposed. In this time frame, decision makers are liable to CO_2 regulation for the first time and before the imposed regulation can be revised (for example, based on innovation or investment that occurs). Specifically, it is hypothesized that within this time horizon decision makers who lack perfect information and who are not necessarily perfectly rational will upgrade at more suboptimal magnitudes under an emissions trading regulation than one under a fixed price tax. Following this line of reasoning, a temporal combination of tax and trading would motivate investments that are closer to optimal levels than would a trading-only scheme. In this case, the compliance costs incurred under the transitional scheme should be lower than under a trading-only regime and higher than under a tax-only regime.

1.4 Objectives

An overall objective of this study is to test a novel incentive-based emissions control policy in a controlled and observable setting. In order to accomplish this, a model of emitting, regulated firms is first defined. Next, a laboratory experiment based on the model's framework is to be designed and implemented. To enable comparison of the novel policy to the two commonly discussed policies, three related but separate experimental treatments (one for each policy) should be considered. Abatement investments undertaken, production decisions, compliance costs and the volume of permits traded, and the prices at which they are traded in the secondary permit market are to be used as measures for comparison of the regulations' efficiency.

Performance under a tax-regulation is compared to that under an emissions trading system with tradable permits for emissions. These two regulatory designs are then to be contrasted to a third design of an initial taxation regime that converts to a regime characterized by trading. The model includes a group of heterogeneous firms that produce and generate sales revenue while incurring costs for the emissions created under production.

1.5 Outline of the Thesis

There are six chapters in this thesis. Chapter 2 refers to some related experimental and theoretical literature. Chapter 3 outlines the theoretical underpinnings on which the experiment is based. Chapter 4 includes a description of the experimental methods and procedure. Chapter 5 conveys the results. Chapter 6 discusses results, some implications carried by the results and suggestions for future research, and concludes.

1.6 Summary of Chapter One

Incentive-based emissions control policies impose additional costs on production that creates emissions, and seek to restrict the quantity of emissions created. These policies aim to maximize reduction of emissions at lowest cost to society. The two traditional incentive-based pollution control instruments, taxes and emissions trading, each carry drawbacks. Taxes are politically unattractive and their optimal rates are difficult to define. Emissions trading schemes present liable emitters with great uncertainty about future prices for emissions, leading emitters to commit to large investments that may be excessively costly (or fail to invest in upgrades that would allow for greater profitability). Utilizing laboratory experiments, this study examines a new type of policy that includes a staged transition from tax to trading regime and asks whether temporally combining the two main policies could better guide liable polluters to optimal abatement investment decisions, ultimately yielding lower compliance cost.

Chapter 2. Review of the Literature

2.1 Overview

From the early twentieth century, economists have been investigating the relative benefits of design characteristics of emissions regulating instruments. Pigou (1920) catalyzed a discussion of welfare-improving taxes, and Coase (1960) introduced the idea of property rights that could be related to pollutants and clean air. Coase's *The Problem of Social Cost* (1960) is widely cited as the seminal work that led to the adoption of limited, tradable permits for pollution. Many studies have examined design features of market-based regulatory instruments such as permit allocation mechanisms (e.g., Cramton and Kerr (2002)), permit banking (e.g., Muller and Mestelman (1998), Bohm (2003)), and implications of cap stringency on investment decisions (Perino and Requate (2012)). Mandell (2008), Krysiak and Oberauner (2010) comment extensively on the usefulness of contemporaneous hybridization of price and quantity controls. Several papers have focused directly on identifying the effect of policy instruments on liable entities' investment decisions (e.g., Requate (2005), Betz and Gunnthorsdottir (2009), Camacho-Cuena, et al. (2012)).

To the best of this author's knowledge, no works have yet explored the implications of a staged transition from no emission controls to an emissions tax to an emissions trading scheme. The bulk of the work in the field of regulating emissions has been theoretical. In the last decade, experimental methods have been applied to specific questions about the design of regulations. The interaction between regulation design, liable entities' risk aversion and uncertainty, and the regulations' ultimate efficiency has received some attention. Missing from the regulatory discussion is a robust investigation of the multi-step mechanism that is proposed in this thesis: namely, a hybridization of the two incentive-based policies. This chapter will provide an overview of the existing scholarly background related to emissions controls, a discussion of recent related experimental studies, and some remarks about the relevant literature on uncertainty.

2.2 Regulatory Regimes

Early twentieth century economists wrangled with conspicuous pollutant externalities and proposed taxation as the optimal instrument by which to regulate emissions. Two instrument classes are presented in the literature. In one class, a benevolent regulator imposes a tax whose unit price is equal to the pollutant's marginal social damages is imposed on each unit of pollution to correct the inefficient market outcome created by the negative externality of pollutants (Pigou (1920)). The challenge confronted in defining this type of tax arises in the assessment of externality cost.

Coase (1960) framed pollution as a property rights problem. By defining clean air and water as tradable property, (or conversely, a right to emit a unit of pollutant as property), the Coase Theorem suggests that agents who trade rights to that property in a market will arrive at an efficient unit price for emissions. This result should hold so long as there are no transaction costs. A government could limit pollution at a cost that would be defined by propertyholders in the market by defining emissions as property and setting a capped limit on the quantity of emissions property to be released (and to be traded).

Weitzman (1974) articulated Pigouvian taxes and a Coase-inspired emissions cap as *prices* and *quantities*, respectively, and commented extensively on their comparative advantages. Weitzman described firms' expected reactions to each regulation via a reaction function. To regulate via prices, a rational regulator would select a tax rate $\tilde{p}$ that will maximize the expected difference between the cost and benefits that will be realized under the regulation given the regulated firms' expected reactions. To regulate via quantities, the regulator would determine an emissions cap $\hat{q}$ and apportions the units of $\hat{q}$ to liable emitting firms. The opportunity to trade these emissions permits in a market should ensure that the firms that stand to gain the most from investment in abatement invest, while those who stand to benefit less invest less or not at all.

According to Weitzman, a need to decide between a tax or a trading regulation is only relevant when regulators are not able to perfectly refine the policy in force at any time (p. 482). If a regulator could adjust a regulation with perfect flexibility, a price or a quantity instrument could be implemented and the other saved as a second-choice. In any imperfect case, the marginal abatement cost and benefit slopes should inform the instrument choice (p. 483). When the marginal costs are steeper, a price regulation is theoretically preferable to quantities; when benefits are steeper, quantity-based regulation is preferred. Because true marginal costs are assumed to be impossible to perfectly evaluate *a priori,* Weitzman suggests that quantity regulation will be preferred to price regulation in most situations.

Ireland (1977) disagrees with Weitzman's preference for a quantity-based regulation. While identifying an effective and cost-minimizing Pigouvian tax is not an easy task, Ireland contends that there is a significant opportunity to define a price that is at least close to the ideal price, and that a tax at this level may still yield preferable results to a quantities strategy (p. 186).

While their thought exercises are helpful starting points for prices versus quantity debates, both solutions fail to fully recognize seriously failings in the series of assumptions enumerated above, and their conclusions are largely untested. Scholars continue to search for the true best regulatory option. Downing and White (1986, p. 29) illustrated that under certain competitive equilibrium conditions, an emissions tax and an emissions trading scheme could theoretically lead to equivalently optimal incentives for firms to invest in abatement. The model defined in their paper assumes that the regulator ratchets the tax level or quantity cap in response to technical innovation, and that the polluting decision maker holds full and perfect information about the regulator's decisions and bases innovation and investment decisions on that innovation. In this case, the competitive equilibrium price for a permit under a cost-minimizing quantities regulation with emissions cap $\hat{q}$ would equal the optimal $\tilde{p}$ that would otherwise be levied by a price-based regulation.

2.3 Experimental Methods

Economic experiments allow researchers to observe behavior under controlled conditions: by manipulating incentives and information conditions (e.g. the regulatory regimes) via *ceteris paribus* variation, causal factors driving behavior can be identified. Experiments are particularly useful in studies of large-scale emissions regulation design because of the challenge confronted when attempting to compare implemented emissions regulation designs to each other empirically. Emissions legislation is implemented with specific design features, in unique jurisdictions, and each regime is subject to forces largely defined by the precise timing of implementation. The challenge that these characteristics lend to analysis is amplified by the small sample of emissions regulations that are in force. Robust definitions of trends that emerge under different types of regulation are difficult to develop (Requate 2005, p. 176).

Vernon Smith (1982) pioneered and defined the role of laboratory experiments as useful test beds for market instruments such as emissions regulations. Populated by human decision makers subject to rules and incentives as they are in the real world, lab experiments provide a feasible, controllable opportunity to carefully study causal relationships between regulations' characteristics and decision makers' behaviour. Laboratory studies, therefore, provide an important and unique opportunity to manipulate various aspects of a regulation and test the theoretical predicted outcomes of various policy designs. While governments may not hold full information about producers' production characteristics and abatement cost schedules, in a lab experiment, the regulator (experiment designer) can derive parameters, and evaluate social welfare-maximizing behavior, even in a multi-party model. By running such an experiment, the experimenter is able to evaluate an instrument's performance by comparing the observed behavior to theoretical predictions.

An extensive literature in complex market-based experiments provides researchers insights into implications of instrument design and about the robustness and relevance of experiments' design features. Plott (1983) first reported a laboratory experiment related to emissions regulations, arguing that simple laboratory experiments can be used to test even complex policy design ideas. From the earliest setups, scholars concerned with the fashion in which emission regulations should be implemented have used increasingly sophisticated experimental methods to study instrument design. An early overview was published by Muller and Mestelman (1998).

Importantly, Gangadharan and Nemes (2005) developed an experimental setup in which emissions were modelled as production costs for producers (as they are under emissions regulations), a significant methodical step forward. Importantly, this study showed that modeling emissions costs as production costs can be a feasible frame for decontextualized experiments seeking to study emissions regulations and allowed for further developments in instrument-related experiment design.

2.3.1 Uncertainty and Overinvestment

Experiments allow for close study of instruments' effects on real decision makers, enabling for neo-classical competitive equilibrium assumption of decision makers' risk neutrality to be relaxed. Uncertainty inherently created by emissions trading schemes yields problems for liable firms, whose aversion to risk is seen to drive costly actions that are seen to reduce their risks (e.g., Sandmo (1971, p. 65)). Excessive compliance costs are incurred by emitters' suboptimal investment decisions (too much, or too little investment in emissions abating technologies). These suboptimal investments carry the second cost of potentially crowding out more productive investment (Gangadharan and Nemes (2005, p. 24)).

Uncertainty yields effects on decision makers that are not perfectly understood, and seem not to be limited to risk-preference. In a laboratory study dedicated to testing the effect of risk attitude toward investment decisions and permit trading in an emissions trading scheme, Ben-David et al. (2000, p. 598) observed that uncertainty about future costs caused decision makers to delay their investment decisions, yielding higher-than-necessary emissions. This finding was in contrast to their theoretical prediction that risk aversion should propel decision makers toward higher investment decisions and lower permit trading volumes. In explanation, the authors suggest that the decision makers' attitude toward investing early or waiting may be determined by their perceived role as a buyer or seller in the permit market. Hahn and Stavins (2011, p. S274) also draw attention to agents' failure to invest according to a cost-minimizing social optimum under regulation, and suggest that this proclivity exists largely because firms are uncertain about future costs of emissions and, depending on their initial allowance of permits and their investment cost structure, invest in abatement to hedge against future high or low permit prices. Baldursson and von der Fehr (2004) demonstrate that risk aversion on the part of decision-making agents may render a tax mechanism to be preferable to a tradable regulation characterized by price uncertainty and volatility.

Pezzey and Jotzo (2012) explore the implications of price uncertainty via a multi-party theoretical model that empirically explored welfare results of taxes versus permit trading under uncertainty, allowing for imperfect information and less-than-perfectly rational actors. Their model highlights the tendencies for firms to invest more suboptimally under an emissions trading scheme than under a tax.

Risk preferences have not been conclusively shown as correlated with decision makers' investment decisions. Betz and Gunnthorsdottir (2009, p. 1423) indicate that tendencies to sub-optimally invest are not restricted to decision-makers with risk-averse attitudes. In their laboratory study, participants' responses to a risk-preference profile measure did not correlate with their investment decisions.[2] Camacho-Cuena, et al. (2012, p. 240) find that a risk assessment measure is not satisfactorily correlated with investment decisions when permits are grandfathered: there was no difference between risk-neutral, risk-preferring or risk-adverse participants' reactions to emissions regulations.

2.3.2 Permit Allocation

Neo-classical economic theory, on which much economic analysis of policy instruments including the above-mentioned equivalence properties of prices and quantities rests, defends that in a competitive market, the final allocation of tradable permits should be efficient, independent of the initial allocation of permits (Arrow and Debreu (1954, p. 279); Montgomery (1972, p. 400)).

[2] Betz and Gunnthorsdottir used a version of Holt and Laury's (2002) risk-preference eliciting lottery that had been modified by Gangadharan and Nemes (2005).

Hahn and Stavins (1992, p. 465; 2011, p. S271-S279) point out that this independence property fails to consider the effect that factors such as non-zero transaction costs, market power, uncertainty and regulatory distortions may have on the benefits from trading and therefore opportunity to reach an efficient equilibrium independent of initial allocation.

In recent years scholars have reached a consensus that the allocation of permits seems to be important and potentially quite problematic. The identified properties under which the independence property breaks down could carry strong effect on trading regulations' overall efficacy and is deserving of special note. While the scholarly community has not reached a unanimous explanation for such an effect, there is agreement that initial allocation plays an important role in a regulation's ultimate efficiency and growing evidence to suggest that initial allocation does matter.

In an experimental study designed to examine compliance to emissions regulations, Murphy and Stranlund (2007, p. 203) found what they refer to as a strong initial allocation effect in both inexperienced and experienced subjects in low and medium-penalty treatments (but not high penalty treating). The effect was observed in the transacted prices for permits, the mean and median prices for which were higher in the experimental setup than would have been under a competitive equilibrium. Camacho-Cuena, et al. (2012, p. 244) found that when permits are grandfathered, the final allocation in the experimental setting was closer to the original allocation than it is when permits are auctioned, although investment decisions did not differ based on allocation method (p. 246). When they are allocated permits from the government, decision makers' may overvalue the permits that they receive in the initial allocation, leading firms to hold the permits that they are allocated rather than sell them to producers who indicate a higher marginal value for the permits, in turn limiting the number of transactions. Thaler (1980, p. 43) characterizes a similar phenomenon as an endowment effect. Scholars postulate that this endowment-related effect may be alleviated if firms are made to evaluate their marginal values for permits before they acquire them (as they would in an auction). For this reason, an auction-based mechanism to distribute permits is seen likely to yield a more efficient outcome (Cramton and Kerr 2002, p. 11), and permit auctioning is growing in popularity as the preferred initial allocation method in an emissions trading regulation.

However, in practice permits tend to be freely distributed ('grandfathered') based on a defined rule of thumb at the initial stages of a regulation rather than sold or auctioned to liable entities. Phase 1 of the European Emissions Trading Scheme saw less than 1 percent of permits auctioned, and Phase 2 only 3 percent. Contrary to early calls to auction the majority of permits in Australia (e.g., Garnaut (2011, Ch. 14)), late negotiations yielded free-allocation of almost all permits. In the interest of drawing conclusions that could be useful in current policy applications, the decision to apply a free initial allocation mechanism in this experimental setup was defined by the present popularity of the so-called grandfathering system.

2.4 Conditions of Price and Quantity Equivalency

The literature presents five key conditions under which price and quantity regulations may yield equivalent results:

(1) Zero transaction costs in the emissions marketplace (Stavins 1995; Hahn and Stavins (2011, p. S271));
(2) Zero market power in the market for emissions permits (e.g. Hahn (1984), Gangadharan and Nemes (2006), Malik (2002));
(3) Risk-neutral decision makers responsible for all abatement investment and production decisions (e.g. Weitzman (1974));
(4) The availability of full information (e.g. Requate and Unold (2003, p. 133); Hahn and Stavins (2011, p. S274)); and
(5) Decision makers' full confidence in the emissions regulation's implementation and long-term maintenance (e.g. Jotzo, et al. (2012, p. 398)).

The breakdown of any one of these five conditions would likely break down the equivalence between price and quantity systems. Particularly relevant to the question investigated in this thesis is the inability of decision makers to make optimal investment decisions when they face uncertainty about future emissions costs, as they do under an emissions trading scheme (Betz and Gunnthorsdottir (2009, p. 1419); Hahn and Stavins (2011, p. S274)). Under trading, if even some firms fail to equate their marginal abatement costs with the marginal emissions costs, the ultimate distribution of emissions and emissions permits will be inefficient, rendering aggregate compliance suboptimal (Hahn and Stavins (2011)).

In the setup examined in thesis, Assumptions (1) and (5) are maintained, while assumptions (2), (3) and (4) are allowed to relax. The omniscient regulator (experimenter) defines the targeted $\hat{q}$. Because the regulator holds full information, she evaluates the $\tilde{p}$ that would incentivize profit-maximizing (rational) producers to upgrade their production technologies and adjust their production levels in order to curb emissions to $\hat{q}$ at least cost. Transaction costs are zero (1), and experiment participants' are told that all of the information they are provided with is truthful (5); the expectation is that they will not question whether the regulation will be overturned. Producers can invest in abatement via existing technologies, and their investment decisions inform relative market power in the permit market (2). Perfect risk neutrality, or rationality, of the decision makers is not assumed (3). Producers receive information about the aggregate level of abatement in the market, but do not hold full information about competitors' production and investment characteristics (4).

2.5 Summary of Chapter Two

This chapter reviewed some of the developments in the emissions regulations literature. Previous studies have investigated design features of market-based instruments for emissions regulation such as permit allocation mechanism, permit banking and cap stringency, and defined conditions under which price- and quantity-based regulations can yield equally cost-effective outcomes. Others considered the effect of alternative policy instruments on investment decisions. In their efforts, the studies employed theoretical, empirical and experimental methods. So far, an exploration of a temporal combination of a tax and trading instrument has been left unexplored. The growing prominence of this transitional design as a viable policy option and an interest in studying the regulatory instruments within a controlled setting guided the development of this project.

Chapter 3. Theoretical Foundations

This chapter presents the model framework on which the experiment was designed. The producers' production characteristics including revenue generation, production costs and investment opportunities are described, and the solution for a profit-maximizing producer is articulated. The measure used to compare performance under the regulation is derived.

Notation

Table 3.1 lists and describes the notation used in this thesis.

Table 3.1 Technical Notation

Variable	Description
i	Individual producer, endowed with one of n unique initial technologies
j	Technology level (0, 1, 2, 3, 4) $j > 0$ are technology upgrades, $j = 0$ represents original technology
$U_{i,j}$	Current technology level for producer i
q_i	The current production level selected by producer i
$l(U_{i,j},q_i)$	Emissions produced by agent i at technology level U_j and production level q_i: $(1-0.1j)\ l(U_{i,0}, q_i)$
R_i	Production revenue at chosen production level
$C[l(U_{i,j},q_i)]$	Cost of emitting at the chosen production level with current technology level
$IC_i(U_{i,j})$	Investment costs, for the technology level
$\pi_i\ (U_{i,j},q_i)$	Profit for producer i at production level q_i: revenue less emissions and investment costs
L^*	Target aggregate emissions, identified by regulator
d	Marginal damage cost per unit of emission

3.1 Model framework

The experimental setup is comprised of a number of heterogeneous firms, each endowed with a unique production technology characterized with specific emissions-intensity. Firms can upgrade their production technology to achieve lower emissions-intensity. The firms face government regulation aimed at curbing emissions. All firms are small, and therefore do not influence the tax rate or the price of the output or emissions permits. Regulations aim to curb emissions at minimal cost, and are evaluated by the compliance and damage costs incurred within a specified period. While the study's design was motivated by the electricity sector, which can make marginal investments to lower carbon emissions and is one of the largest emitters of greenhouse gases in Australia and globally, the experiments were conducted without mention of this particular context. The model is therefore relevant to any situation with production and investment decisions subject to alternative incentive-based environmental regulation.

Following Gangadharan and Nemes (2005), producing output in the setup entails generating emissions, which in this case is articulated to the agents as using required *inputs*. An *input* can be seen as a permit (or allowance) to emit during the production process, and is costly under the regulation. Firms can reduce emissions either by cutting back production, by upgrading to a lower emission-intensive technology for production or both.

The heterogeneous design was implemented to endow the laboratory market with key complexity found in a real-world situation. When producers have identical technology (and related production costs, revenues and investment opportunities), permits carry the same value to all producers, who therefore have no profit-driven reason to trade them. After investment, the group of producers that has invested is able to generate more revenue with the same number of permits, consequently raising their perceived value of permits. That creates potentially gainful trade opportunities where the producers with higher value for permits buy additional permits from the producers with lower value for permits in order to expand their production levels for extra profit. The market-clearing price for permits in this type of secondary market is affected only by the number of producers that invest and not by a relative efficiency of the producers that invest (since all maintain equivalent efficiency). The strategic issue of who should invest and when cannot be resolved when firms are homogenous, given that if others invest an individual emitter might be better off waiting to buy permits in the market. Introducing heterogeneity in producers' marginal abatement and production costs allows the market the best chance of providing opportunities for gains from trade.

3.2 Emissions Cap

The regulator chooses the emissions cap L^* directly, or imposes a corresponding emissions tax rate to ensure that L^* is attained. L^* is motivated by the impact of the negative externality, which is introduced as the constant marginal damage cost d; for the purposes of this paper the marginal damage cost is parameterized as d=E$16 per unit of emission. At L^* and the associated tax rate or permit price, some producers can achieve maximum profitability by investing in abatement and producing with the higher efficiency equipment. Other producers might maximize profits by not investing or even by stopping their production all together, and instead they would sell their permits gainfully on the market under a market-based regulation. The aggregate emissions level L is the sum of individual producers' emissions l_i, $L = \sum_{i=1}^{n}(l_i)$.

A regulator with full information, as defined in this setup, knows the minimum aggregate abatement costs and the associated optimal upgrades for each producer under the defined cap level or tax rate. The choice of the magnitude of the negative externality in the engineered setup is not arbitrary. In the social-welfare maximizing result, some producers should optimally upgrade their technology, while the remaining producers should not upgrade at all. Given the endowed technological portfolio, a too-low *d* and an associated high L^* would not impose a sufficient incentive for emitters to change their behaviour. A too-high *d* and associated low L^* could create an environment in which all individual technological upgrades would be cost effective, thereby eliminating the opportunity for gainful permit trading that this experiment is designed to create.

3.3 Producers and Production Characteristics

In the experiment, each producer *i* is endowed with one of *n* unique initial technologies $U_{i,0}$, where $i = (1, \ldots, n)$, and each carries a unique baseline emissions profile $l(U_{i,0}, q_i)$, where q_i represents the chosen output level. The profitability of each technology depends on the level of production and on each producer's abatement cost structure. In a heterogeneous industry, each producer type maintains a unique upgrade cost structure and unique constant marginal revenue per permit. A producer may upgrade her technology up to four times from her initial $U_{i,0}$: $U_{i,j}$, $j = (1, 2, 3, 4)$ that improve emissions-efficiency, each by 10 percent from the initial level $l(U_{i,0}, q_i)$, i.e., $l(U_{i,j}, q_i) = (1\text{-}0.1\times j)\ l(U_{i,0}, q_i)$. Upgrade costs increase with subsequent investments and are higher for emitters endowed with more efficient initial technology.

At the end of each period, producers receive information on the total number of upgrades undertaken by all other participants to date. This design choice was made to reflect that in the real world, firms are likely to know when their peers have undertaken technological upgrades.

3.4 Profit-Maximizing Strategy

A producer's profit is production revenue less investment costs IC_j less the new cost of emitting at the chosen production level:

$$\pi_i(U_{i,j}, q_i) = R_i(q_i) - \sum_0^j IC_i(U_{i,j}) - C[l(U_{i,j}, q_i)] \quad (1)$$

In Equation (1), R is the production revenue and C is the cost of emitting at the chosen production level given the initial technology. A profit-maximizing producer i should upgrade technology until the total investment costs $\sum_{j=0}^{j} IC_i(U_{i,j})$ equal the benefit reaped from investment. This benefit is the difference in the liability costs that would be incurred with initial technology $U_{i,0}$ and liability costs incurred while producing with upgraded technology $U_{i,j}$.

$$\sum_{j=0}^{j} IC_i(U_{i,j}) = C(U_{i,0}) - C(U_{i,j}) \quad (2)$$

The marginal tax rate is equal to the E$16 marginal damage cost described above and is within the range of the permit market's clearing prices that are defined by producers' production efficiencies under the social cost minimizing investment and production pattern. The experiment-designing regulator can evaluate this price range (the market clearing price range under cost-minimizing investment pattern) ex ante.

Under a tax, profit-maximizing producers should invest until investment costs equal the benefits to be gained, simply calculated by incorporating the tax as a future production cost. Under emissions trading, producers should be guided by the emerging permit price in the market and the aggregate number of technology upgrades that have been undertaken, of which they are informed every period.

Some producers should optimally upgrade their technology, while others should not. Producers with the highest potential returns to investment relative to their investment costs (i.e. lower abatement costs relative to marginal production revenue potential) should move first in investing. Their early investment provides a signal to agents with higher abatement costs that there will be opportunities to purchase permits at prices that are likely to be lower than their own abatement costs. Under perfect information, the levels of investment and production for producers that maximizes social welfare theoretically converges to their individually optimal levels under the tax regime. This design results with welfare-maximizing investment levels that are equivalent for each of the eight producers under all of the three schemes.

Participants' learning about the efficiency of decisions over the course of the four rounds, and their behavior, was expected to trend toward the theoretical full-information equilibrium. Specifically, participants' decisions were expected to reflect rapid learning under the high-certainty tax, and slower learning under emissions trading, reflecting low certainty about future returns on upgrade investments in this regime.

3.5 Social Welfare

Social welfare is evaluated via a comprehensive accounting measure. With the assumed perfectly elastic product market, the aggregate measure of realized total surplus *TS* comprises producer surplus, government surplus and consumer surplus.

$$TS = \sum_{i=1}^{n}(R_i) - \sum_{i=1}^{n}\sum_{j=0}^{j} IC_i\left(U_{i,j}\right) - \sum_{i=1}^{n} Tax_i + \sum_{i=1}^{n} Tax_i - dL \tag{3}$$

The first three terms comprise producer surplus (production revenue minus costs), the fourth term government surplus, and the final term represents environmental damage cost. *Tax* is total individual taxes paid. The government surplus is cancelled out by producers' tax costs. The regulation aims to minimize the abatement and damage costs, thereby maximizing total surplus. Environmental damage cost is affected only by the quantity of emissions created in production (L), and due to the positive damage costs *d*, is negative and decreases as emissions increase.

Dividing the observed *TS* by the maximum possible TS^* and multiplying by 100% yields an allocative efficiency measure by which performance of regulations can be directly compared to each other:

$$Efficiency = \frac{TS}{TS^*}\times 100 = \frac{\sum_{i=1}^{n}(R_i) - \sum_{i=1}^{n}\sum_{j=0}^{j} IC_i(U_{i,j}) - dL}{\sum_{i=1}^{n}(R_i^*) - \sum_{i=1}^{n}\sum_{j=0}^{j} IC_i(U_{i,j}^*) - dL^*}\times 100 \tag{4}$$

3.6 Summary of Chapter Three

This chapter presented the model on which the experiment described in this thesis is based. The emissions cap and tax rate are defined according to the externality damage cost evaluated by a regulator. Producers evaluate their opportunities to maximize profits with respect to their production characteristics, investment opportunities and the regulation they face. They solve their profit-maximizing investment problem subject to the future price of regulation compliance, which is a known marginal tax rate or an expected price of a permit in the market. The experiment, defined in Chapter 4, is designed to test whether equivalently efficient compliance will be realized under the three schemes.

Chapter 4. Experimental Design and Procedure

Producers' behavior is measured and compared under the three regulatory regimes (treatments) via a laboratory economic experiment programmed in z-Tree (Fischbacher 2007) and conducted in an experimental laboratory at the University of Sydney. All 144 participants 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 run[3]. Each subject participated in only one session.

An experimental session consisted of an instructional stage with an instruction video, a quiz for comprehension, and four 13 period-long rounds (instructional videos and the quiz can be viewed via the links provided in the list of References, Bernold 2012). All rounds in a session were identical in that the same treatment and producer characteristics were induced for the duration of the session. The participants' task was to maximize their earnings by making decisions in their assigned Producer role during the experimental session. Participants' take home earnings were the sum of their earnings in each of the four rounds.

The experiment was designed to create a controlled environment without unnecessary complexities. In an effort to contribute useful findings to the evolving body of experimental literature studying emissions regulatory

[3] A set of trial sessions was run before the experiments presented in this paper. These sessions served as checks for the functionality and comprehensibility of the instructions and software.

schemes, a similar experimental setup to that presented in Camacho-Cuena, et al. (2012) and Gangadharan and Nemes (2005) is utilized. Careful attention was paid to the information provided to participants, since the effect of uncertainty in price signals on investment decisions is central to the research problem. In the experiment, participants were given key information about their production characteristics (production costs, technological upgrade costs and profits) privately. The tax level, permit distribution, the total number of upgrades undertaken, and all trade-related information (such as the best standing bid and ask, and the quantity and price of traded permits) were provided publicly. All information provided to the participants was truthful, and participants knew with certainty exactly when regulations would be imposed, and how long they would last.

In order to minimize the chance of association of the experimental environment with emissions regulation, language used during the session was intentionally decontextualized from typical environmental or regulatory vocabulary. Permits were referred to as *inputs*, the tax was an *input price and* the *input price* was set at an amount different from the carbon tax that was in place in Australia at the time.

4.1 Parameters

Participants in their roles of Producers evaluated their opportunities to maximize profits with respect to their production characteristics, investment opportunities and the regulation they faced. They maximized their profit subject to the future price of regulation compliance, which is a known marginal tax rate, or an expected price of a permit. Participants' earnings were calculated based on their performance in all four rounds. Each participant faced a unique linear production function, unique upgrade costs and finite production capacity (Table 4.1).

Table 4.1: Producer Characteristics[4]

	Producer Type							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Permit's Marginal Productivity with $U_{i,0}$	7.5	10	12.5	15	17.5	20	22.5	25
Upgrade 1 Cost	12.5	12.5	12.5	25	25	50	75	125
Upgrade 2 Cost	62.5	75	50	75	75	100	150	200
Upgrade 3 Cost	112.5	137.5	150	125	125	200	225	250
Upgrade 4 Cost	162.5	200	250	175	175	250	300	300
Efficient* Upgrade Level	0	0	0	3	3	2	1	1
Efficient* Upgrade Costs	0	0	0	225	225	150	75	125

4.2 Period Timeline

Each of the four rounds in a session consisted of 13 periods. Each period included three stages (screenshots in Appendix 2):

1. *Investment Stage* (60 seconds). At the start of every period (except for period one), participants could invest in an upgrade that would reduce their emissions (represented by their production costs) by 10 percent each. Emissions were referred to as inputs, and each production level

[4] Efficient upgrades under the social welfare maximizing investment profile.

required a certain number of inputs. An upgrade reduced the number of inputs required per production level by 10 percent for the remainder of the round. Participants could select up to four incremental upgrades (one upgrade per period). The maximum four upgrades would carry a cumulative 40 percent reduction of emissions. Any upgrade was irreversible and lasted for the remaining periods in the round.

2. *Production and Trading Stage* (60 seconds). Participants selected a production level between 0 and 10 each period. At the beginning of period 1, producers' balances were E$0. Participants knew their costs (emissions) and profits associated with each production level. In the treatments with emissions trading, once the trading scheme was initialized in Period 6, a single unit double auction in emission permits was active during this stage. In periods with trading, the market for permits (inputs) was open for 60 seconds during the production stage.[5] In the market, participants chose the number of bids or asks to submit and transact within the trading period. Each bid or ask was for a single permit. The best current bid and ask were displayed on the screen at all times. To execute a trade, participants acting as 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.

3. *Summary Stage* (15 seconds). Participants were shown a summary of their personal performance for the previous period and the cumulative

[5] Screenshots can be found in Appendix 2.

number of investments undertaken by all agents up to and including that period.

4.3 Treatment Regimes

Treatments were characterized by the regulation implemented during the session. The first five periods of each round comprised a pre-liability phase, in which participants produced with no emissions costs. The emissions regulation (tax only, tax followed by trade, or trade only) was implemented from period 6 onwards in each round.[6] In each of the 13 periods, participants selected a production level in order to generate revenue, had an opportunity to invest in technological upgrades, and received information about the total number of upgrades undertaken by the eight producers. The social welfare maximizing production and investment decisions are the same in all three experimental treatments (Table 4.2).

[6] Five unregulated periods were included prior to the regulation in order to provide participants sufficient time to upgrade their technology levels (with one upgrade possible per period, it would take 4 periods in order to upgrade to the maximum technology level), and the opportunity to generate enough E$ funds to pay for the upgrades. The specific timing of upgrades prior to the regulated phase is irrelevant and to the best of the author's understanding, does not meaningfully affect any analysis or conclusions.

Table 4.2 Treatment Regimes

Treatment	Non-Liability Phase (Periods 1-5)	Liability Phase (Periods 6-13)	
Tax Only	Pre-Liability	Tax	
Trade Only	Pre-Liability	Trade	
Staged Transition	Pre-Liability	Tax (Periods 6-8)	Trade (Periods 9-13)

In the treatments with trading, 5 emissions permits per period were allocated to each participant starting in the first period that trading became active. A single unit double auction was implemented as the trading mechanism due to its low transaction costs and easily understood and utilized design, particularly the ease of placing and accepting bids and asks.[7] In the event that a producer held less than the required number of permits at the end of a period, a higher fine (E$32) per full insufficient permit was levied. This fee adjusted for partial permit insufficiencies. For example, if Producer 1 needed 5.5 permits but only held 5 at the end of the period, the fee levied was $0.5 \times E\$32 = E\$16$. No banking of permits was allowed between periods or rounds.

Participants responded to questionnaires that appeared on their screens in the midst of each session. Participants responded to two survey questions prior to

[7] Smith (1962) provides extensive evidence of the double auction's tendency to elicit best-possible market results in experimental environments. Camacho-Cuena et al. (2012) strongly suggest that the type of auction used after an initial distribution of permits does not have a significant effect on the pattern of technology adoption in an environment similar to the one reported in this thesis.

the first regulation, then immediately following the first regulated phase, and, in half of the sessions, after the completion of the fourth round. The participants used radio buttons to express their agreement (“Highly Disagree” to “Highly Agree” on a scale from 0 to 10) with the prompts: “I like Periods 1-5,” and “I like Periods 6-13.” It was thought that participants would express any frustration arising from poor performance or confusion with the experimental setup in their responses, which would be an important consideration when analyzing relative performance. By asking for participants’ reactions to the regulation before and directly after their first experience operating under the regulation, and also after they had significant experience operating under the regulation, the survey sought to debrief participants about their experiences in the experimental environment.

4.4 Experimental Procedure

On entering the lab, each participant was randomly assigned a role as one of 8 participant types. Each session was randomly assigned to one of the three treatments. Comprehensive instructions about the game’s mechanism were provided in a video that was displayed on large screens visible by all participants, and a written version distributed in hard copy.[8] After viewing the video, participants retained the written instructions and completed a quiz to demonstrate their understanding of their role in the session.

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 for each participant type’s characteristics so that in

[8] The video instructions are available from the authors upon request.

equilibrium each participant had the opportunity to earn the A$30 performance-based payout. Participants earned an average of A$24.35 in addition to the A$10 participation fee (exchange rates are included in Appendix Table 2).

4.5 Summary of Chapter Four

Experiments were run at the University of Sydney's Behavioural Study lab. Eight students participated in each session, of which 18 were run (n = 144). Each session included an instructional video, comprehension quiz, and four replicates of 13 period-long rounds. Each participant was assigned to be one of eight producers in a market. They generated revenue and made decisions about investing in upgrades to reduce their costs. The costs represented emissions. The three experimental treatments were defined by the cost they imposed on producers: (1) a unit tax on inputs, (2) a distribution of inputs with an option to trade, and (3) a tax for three periods, and then a trading regime. Participants were paid in Australian dollars based on their performance in the session.

Chapter 5. Results

This section presents summary statistics and the results of the statistical hypothesis tests used to compare the three experimental treatments based on the alternative regulatory regimes: (1) emissions tax only, (2) emissions permit market only, and (3) staged transition from tax to permit market. The outcomes of decisions in these three experimental treatments were compared in terms of allocative efficiency, market performance, producers' earnings, and preferences elicited from survey responses.

Performance under the three regimes is comparable because participants' efficient decisions (individual investment magnitude and production level decisions under social welfare maximization) are equivalent under all regimes (Appendix Table 2). Investment expenditure, emissions level and production income comprise the allocative efficiency measure used here. Eighteen independent observations (6 from each of the 3 treatments) are reported here. Each producer type (types 1-8) had unique upgrade costs, production efficiencies and an associated efficient upgrade level. Low efficiency producers (types 1-3) are those with highest marginal production costs prior to investment (low marginal productivity per emissions permit). High efficiency producers (types 6-8) hold a high marginal productivity per permit prior to investment. Under the social welfare-maximizing solution, medium and high-efficiency producers should invest in abatement and then produce at high levels. To maximize their profits, low-efficiency producers should neither invest nor produce, but sell their permit allocation (when the market is active). Summary statistics are presented in Table 5.1.

Table 5.1 Summary Statistics

Variable	Mean	Standard Deviation	Min	Max
Producer Efficiency				
Low	0.375	0.485		
Medium	0.25	0.433		
High	0.375	0.485		
Earnings per Round (A$)	6.09	1.579	0	9.99
Permits Used (Emissions)	629.64	47.44	511.1	715.7
Aggregate Number of Investments in Market	19.29	5.6	9	30
Permit Price (Ave. by Period)	17.47	2.8	12.68	25.46
Investment Magnitude Of Inefficiency	1.47	1.25	0	4

n = 576

While the small population of observations challenged the opportunity to draw statistically significant conclusions under some of the units of the measure, others factors clearly demonstrated statistically significant differences between treatments. Four rounds of play were observed in each session. Outcomes under the three treatments were compared via a standard Wilcoxon–Mann–Whitney two-sample rank-sum test. Significance of results was double checked with a robust Fligner-Policello test for differences in the medians of two treatments (Fligner and Policello 1981)[9]. Factors affecting investment efficiency were investigated via panel regression. *P*-values referred to in this section are generated from the Wilcoxon-Mann-Whitney tests, the results of which were in line with the results of the Fligner-Policello tests. *Significance* refers to $p \leq 0.05$ unless otherwise noted.

[9] 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 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. *P-values* presented here emerge only from the Wilcoxon Mann-Whitney test.

5.1 Investment

Participants' implicit task was to attain the level of investment in technology upgrades that would return them maximum financial benefit during the course of the round. To achieve maximum social welfare, several producers should stop production altogether and profit by selling their allocated permits, while others should generate their maximum profits by procuring permits needed after investing into some technological upgrades of their own. The by now well-established propensity for participants to overact (here, over-upgrade) in the lab (documented by Gangadharan and Nemes (2005); Camacho-Cuena, et al. (2012)) is observed in this data set. To account for this bias, the efficiency of upgrades was evaluated via a measure of difference in actual and efficient upgrades.

5.1.1 Aggregate Investment

When observed by round, aggregate upgrades were consistently but insignificantly higher under the trading only scheme than the staged transition or tax-only schemes. The upgrade choices demonstrate learning with experience. Aggregate upgrades and costs reduce toward the efficient level under all treatments over the four rounds of the experiment (Table 5.2, Table 5.3) but costs are considerably higher than the efficient expenditures even in the tax-only treatment, which was closest to efficient. Observed learning, indicated by the efficiency of upgrade decisions, occurred faster in the tax only and transition regimes than in the emissions trading scheme. There was a significant difference in aggregate market upgrade expenditures between the first two rounds in the tax (p = 0.055) and in the staged transition regime (p = 0.078), but no significant reduction in expenditure under the trading only scheme (p = 0.15). By round 4, the variability in investment expenditures is notably lower under the tax only than the other regimes, and notably lower under the transition regime than the trading only regime.

Table 5.2 Mean Investment Expenditure (E$)
By Round and Treatment (Standard Deviations in parentheses)

	Round					
Treatment	**1**	**2**	**3**	**4**	**Efficient**	**Overall by Treatment**
Tax Only	3042 (433)	2329 (670)	1819 (653)	1521 (389)	800	2178 (795)
Staged Transition	2980 (611)	2304 (330)	1738 (327)	1592 (510)	800	2153 (714)
Trade Only	2934 (552)	2373 (726)	1821 (692)	1667 (751)	800	2199 (852)

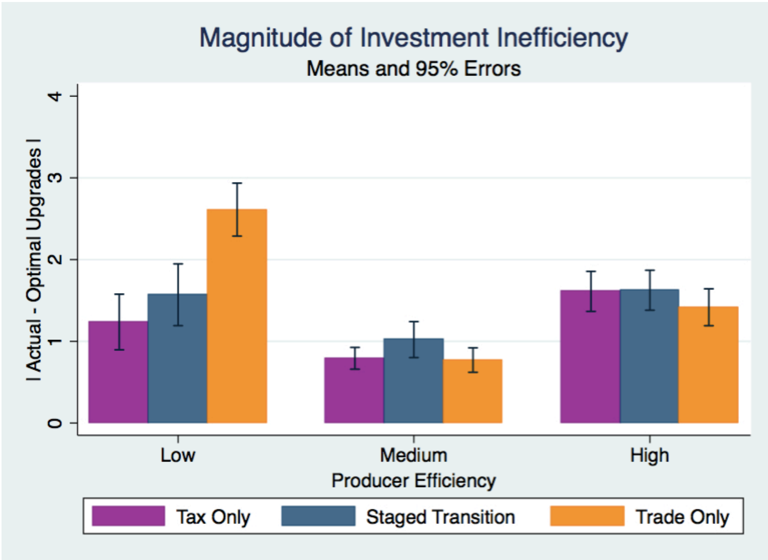
Table 5.3 Average Number of Upgrades
By Round and Treatment (Standard Deviations in parentheses)

	Round					
Treatment	**1**	**2**	**3**	**4**	**Efficient**	**Overall Average by Treatment**
Tax-Only	26 (2.9)	19.33 (5.4)	15.33 (3.4)	13.83 (1.5)	10	18.63 (5.9)
Staged Transition	25.67 (3.4)	19 (3.0)	14.83 (1.0)	14 (1.0)	10	18.38 (5.3)
Trading-Only	25.83 (2.8)	21.83 (5)	18.83 (5.2)	17 (5.7)	10	20.88 (5.6)

5.1.2 Investment by Specific Producer Type

Investment levels by the low-efficiency producers (who should not have invested at all in order to maximize their profits) were much higher under trading than the tax (p = 0.002, Figure 5.1). Moderately efficient producers' (producers 4 and 5) decisions did not vary across treatments. The highest efficiency producers invested closest to the optimum under the trading-only scheme, and significantly more efficiently under the trading-only than tax scheme ($p = 0.048$).

Figure 5.1 Magnitude of Investment Inefficiency



5.1.3 Regression Analysis

In addition to non-parametric tests, random effects analysis allowed further evaluation of the effects treatment imposed on producers' investment decision. In this analysis, deviation of a participant's investment decision from the investment decision under the social-welfare maximizing profile is used as the dependent variable explained by features of the producer's condition. Multivariate models allow the mean effect of each factor to be evaluated while holding the other defined factors constant, and enable formal testing of the significance of the relationship between regulation type (and the other explanatory variables) and the efficiency of investment decision. The random effects model allows individual participants to be tracked across a session's four rounds, ensuring a further degree of control on the other explanatory variables' effects on the investment efficiency. Findings should help to clarify the effect that the regulation has on the investment decision. The regressions utilize standard errors clustered by session. The random effects results presented here are in line with the significance results from ordinary least squares tests executed with the same specifications. The regression results are also in line with the findings of the non-parametric tests, and, in that the regression model tracks individual players while controlling for multiple explanatory variables at once, contributes strength to the robustness of the findings presented in the preceding sections (Table 5.4).

In an effort to present a thorough overview of the results' analysis, two regression models are presented here. Model 1's explanatory variables are a subset of the explanatory variables included in Model 2, which includes the interaction of producer efficiency type to interact with regulation type. Model 2 includes the more comprehensive explanation of upgrade efficiency and yields a higher R^2 value, and therefore is preferred to the more simplistic Model 1. While it is suspected that Model 1 may carry omitted variable bias (due to the lack of inclusion of the interaction terms), it cannot be concluded with full certainty that the explanation is wrong. The omission of the producer efficiency type interacted with the treatment type as an explanatory variable in Model 1 seems to bias the analysis, resulting in sign inconsistency on the coefficients on the trade-only treatment dummy across the models.

Table 5.4 Investment Efficiency
Regression Results
Dependent Variable: Efficiency of Individuals' Investment Decisions

	(1)	(2)
Regulation		
Tax Only	-0.285***	-0.299
	(0.093)	(0.249)
Trade Only	0.009	-.609**
	(0.110)	(0.292)
Producer Efficiency		
Low	0.5**	0.037
	(0.243)	(0.321)
High	0.599***	0.5***
	(0.15)	(0.179)
Producer Efficiency* x *Regulation		
Low Efficiency		-0.148
Tax Only		(0.384)
		1.54***
Trade Only		(0.422)
High Efficiency		
Tax Only		0.185
		(0.374)
		0.111
Trade Only		(0.306)
Aggregate Number of Investments	0.87***	0.86***
	(0.010)	(0.010)
Previous Round's Average Permit	-0.002*	-0.003
Price	(0.27)	(0.019)
Constant	0.496*	-0.274
	(0.27)	(0.282)
R^2	0.1556	0.252
n	432	432

Investment efficiency is identified as an outcome determined by a number of explanatory factors, and is defined for the purposes of evaluation as *inefficiency*. The values are standardized by absolute value: under and over-investment are each denoted as positive values. Tax-only and trade-only treatments are measured in comparison to the staged transition treatment, which is utilized as the baseline for purposes of comparison.

As demonstrated by the significance results from the panel analysis, the tax and transition regimes help the lower-efficiency producers in their investment decisions more than the trading only regulation. In the simpler random effects specification (Model 1), the tax-only treatment is significantly correlated with lower investment efficiency than the transition treatment; the transition treatment was not different from the trade-only. Both low-efficiency and high-efficiency producers invest at significantly less-efficient investment magnitudes than do medium-efficiency producers in all treatments. Model 2 suggests that the efficiency of low-efficiency producers' investment decisions is not significantly different under the tax compared to the transition treatment, but the least efficient producers invest significantly less efficiently under the trade only treatment. The treatment effects remain significant even when other possible explanatory factors (the total number of upgrades in the market, the previous round's permit price) are controlled for.

5.2 Emissions

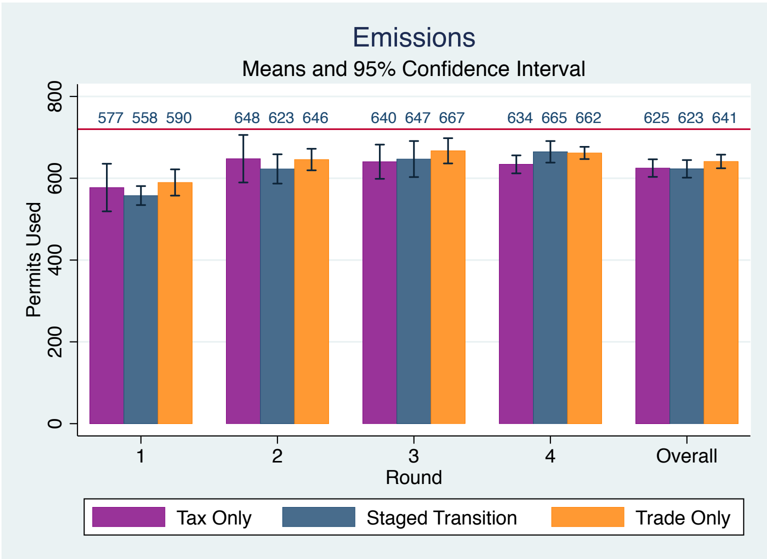
Emissions are the number of permits (inputs) used for production. Permits were used during both the pre-liability and regulated phases. During the pre-liability phase, an unlimited amount of permits was available to producers at no cost, while the target emissions level was 320 during the regulated phase.

5.2.1 Full Round Emissions

Emissions under the tax only and the transition schemes were not statistically different when compared over all rounds, but were generally highest in the trade-only treatment. In round one, emissions were highest under trading-only and lowest in the transition treatment; the difference was marginally insignificant at the 95 percent significance level (p = 0.055). Emissions in the final round were highest under trading only regulation and lowest under the tax only; emissions were significantly higher in the trading only (p = 0.016) and transition (p = 0.037) than the tax only (Figure 5.2).

Figure 5.2 Emissions

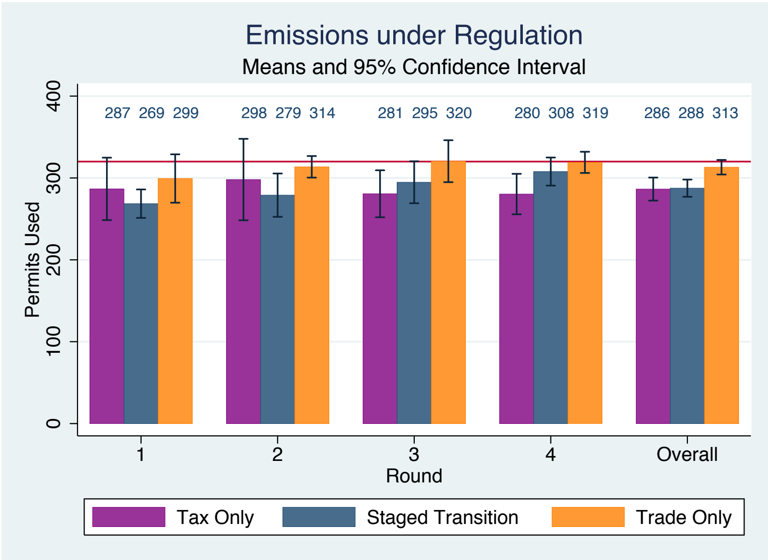
The red line denotes the maximum emissions in pre-liability phase plus the capped emissions level L^* in liability periods



5.2.2 Emissions under Regulation

The timing of participants' investment decisions in the pre-regulation phase, whose effect was not intended for close study under this experimental model, imposes a noisy effect on the emissions generated in the pre-regulation phase. To ensure the validity of the analysis of emissions levels, emissions were also evaluated in the regulated phase only, eliminating consideration of the pre-regulation phase emissions. In round one, liability phase emissions were highest under trading only and the lowest in the transition (p = 0.05). In the regulated phase of the fourth round, emissions were higher in the transitional scheme (p = 0.054), and the trading-only scheme (p = 0.007) than in the tax. Accounting for all rounds, emissions under the tax and the transition scheme were not statistically different, but emissions were markedly lower in the staged transition than in the trading-only regulation (p = 0.055) (Figure 5.3).

Figure 5.3 Emissions under Regulation
L^* denoted by red line



5.3 Production Income

While low-efficiency producers produced at their highest levels under the trading only scheme, medium and high-efficiency producers produced most, and therefore generated their highest production revenue, under the tax. In round 4, low-efficiency producer types produced significantly more under the trading only scheme than under the tax only (p = 0.002), and more under the staged transitional scheme than the tax (p = 0.044). The low-efficiency producers' highest revenue lower than the high efficiency producers': by utilizing permits to produce, low-efficiency producers high production levels reduced overall welfare. Low-efficiency producers' production revenues were significantly higher under the staged transition than tax only (p = 0.008) and higher under the trade only scheme than staged transition (p = 0.007) when measured over all rounds. Despite the significant differences measured in producer efficiency groups, the difference between market-aggregated production incomes was not statistically significant between treatments.

5.4 Allocative Efficiency

The efficiency measure discussed in Subchapter 3.6 accounts for the proportion of total surplus observed in the experiment compared to the total theoretical surplus.[10] A higher efficiency score indicates a lower total compliance cost (abatement plus damage cost) incurred. Overall cost is consistently lower under the staged transition scheme than under the trading-only scheme and higher than under the tax-only scheme.

5.4.1 Full round allocative efficiency

Overall cost is consistently lower under the staged transition scheme than under the trading-only scheme and higher than under the tax-only scheme (Figure 5.4, Table 5.5). The tax-only treatment was more efficient than trading-only in the first round (p = 0.078) and more efficient than the staged transition overall (p = 0.037). In the final round, the tax was consistently more efficient than the trading only scheme, although the difference was marginally insignificant (p = 0.109). When accounting for all rounds, the tax only regime was significantly more efficient than the transition scheme (p = 0.037). The difference between the staged transition regime and trading only was not significant under this measure, when taking all rounds into account.

[10] Social welfare *TS* is comprised of producer surplus (production revenue minus costs), the government surplus, and consumer surplus: $TS = \sum_{i=1}^{n}(R_i) - \sum_{i=1}^{n}\sum_{j=0}^{j} IC_i\left(U_{i,j}\right) - \sum_{i=1}^{n} Tax_i + \sum_{i=1}^{n} Tax_i - dL$. Dividing the observed *TS* by the maximum possible TS^* and multiplying by 100 yields allocative efficiency.

Figure 5.4 Allocative Efficiency

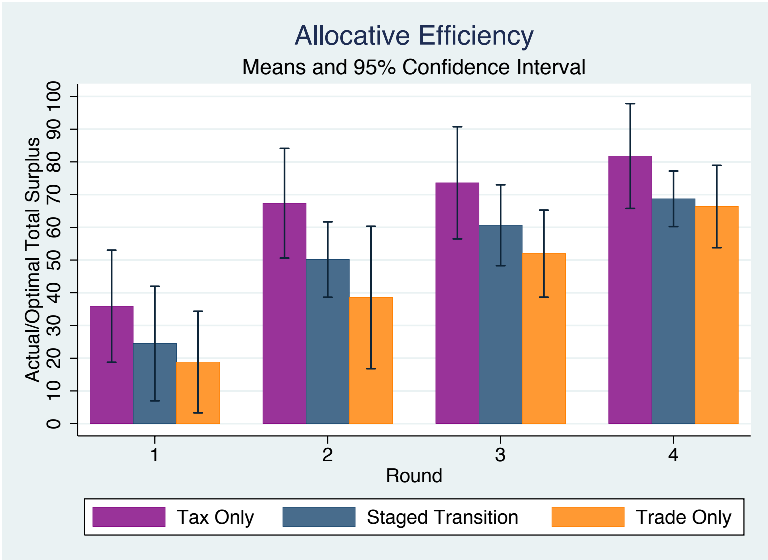


Table 5.5 Allocative Efficiency
Means, Standard Deviation in Parentheses

	Round				Overall by Treatment
	1	**2**	**3**	**4**	
Tax Only	36% (16%)	67% (16%)	74% (16%)	82% (15%)	65% (23%)
Staged Transition	24% (17%)	50% (11%)	61% (12%)	69% (8%)	51% (21%)
Trade Only	19% (15%)	39% (21%)	52% (13%)	66% (12%)	44% (23%)

5.4.2 Allocative Efficiency Under Regulation

Production incomes and emissions created prior to the regulation can be removed from analysis by restricting efficiency accounting to the regulated phase only, eliminating a possibly misleading effect caused by the timing of participants' investment decisions during the pre-liability period, allowing for clearer assessment of the effect of regulation. Measuring allocative efficiency under the regulation-only clearly points to the superior performance of the transition scheme when compared to the trading only regime. Investment outlays under the transition and trading only regimes in the initial round were so large that they outweighed revenue, yielding negative allocative efficiency. While a learning effect toward higher allocative efficiency with consecutive rounds was observed in all three treatments, the staged transition was significantly more efficient than the trading-only regime (p = 0.004), albeit less efficient than the tax-only (p = 0.002). Regulated phase efficiency was observably higher and varied less under the staged transition than trading-only in the final round, but the difference between these two regimes in the final round was insignificant (Figure 5.5, Table 5.6).

Figure 5.5 Regulated Allocative Efficiency

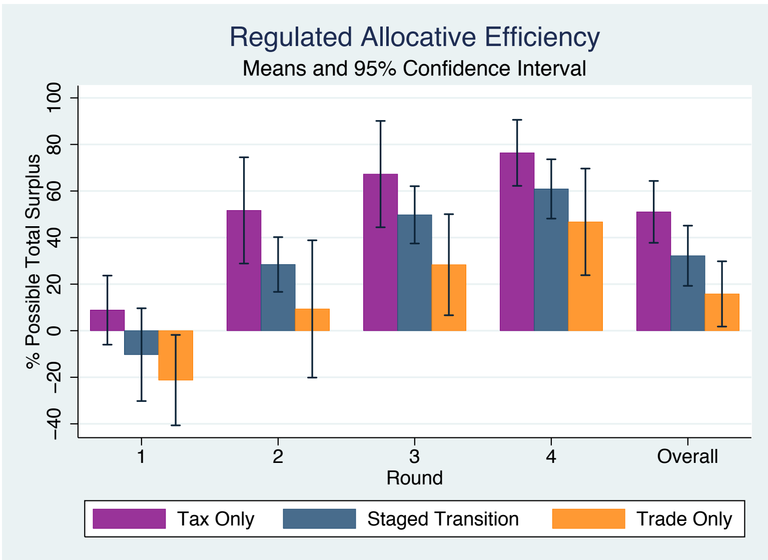


Table 5.6 Regulated Allocative Efficiency
Means and Standard Deviations[11]

	Round				Overall by Treatment
	1	2	3	4	
Tax Only	9% (14%)	52% (22%)	67% (22%)	76% (14%)	51% (31%)
Staged Transition	-10% (19%)	28% (11%)	50% (12%)	61% (12%)	32% (31%)
Trade Only	-21% (19%)	9% (28%)	28% (21%)	47% (22%)	16% (35%)

5.5 Permit Trading

Under the social welfare-maximizing solution, medium and high-efficiency producers should invest in abatement and then produce at high levels, purchasing the permits they require in excess of their allotment in the market. To maximize their profits, low-efficiency producers should neither invest nor produce, but sell their permit allocation (when the market is active).

5.5.1 Quantity Transacted

Significantly fewer permits were traded per period under the trade-only scheme than the transition regime. With the exception of round 1, significantly more permits changed hands per period under the transition scheme than the trading only scheme ($p < 0.001$ each round, when only the first 5 periods with trade and also when all periods with trade are accounted for) (Table 5.7).

[11] Negative allocative efficiency reflects investment costs that heavily outweigh the surplus.

Table 5.7 Volume of Permits traded per Period
Averaged by Round and Treatment

	Round				Overall	Theoretically Expected Optimum
	1	2	3	4		
Staged Transition	4.57 (2.98)	9.83 (2.14)	12.07 (2.52)	12.17 (2.67)	9.66 (4.02)	15
Trade Only	4.20 (2.70)	6.83 (2.27)	7.47 (2.11)	9.73 (2.50)	7.06 (3.09)	15
Overall by Round	4.38 (2.82)	8.33 (2.66)	9.77 (3.27)	10.95 (2.84)	8.36 (3.81)	15

High efficiency producers' relatively lower production levels under the trading only regime are attributable to the supply of permits available to them in the market. Under the social welfare-maximizing solution, 15 permits would be traded per period, but in the observed environment, markedly fewer changed hands. Fewer permits were traded under the trading-only regime, suggesting that under great uncertainty, the less-efficient producers preferred to upgrade their production technology, and then hold and produce with their allocated permits rather than sell them in the market (even at prices higher than the marginal revenue they could generate per permit via production!). An inability to acquire sufficient permits confined the more-efficient producers' ability to produce at high levels.

5.5.2 Prices

Table 5.8 provides a summary of permits' transacted prices. Mean and median transaction prices observed in the market were higher than the competitive equilibrium prediction under both regimes with trading, although prices seem to have been significantly affected by the regulation type. When compared via individual round or overall, transacted prices were significantly higher (further from the competitive equilibrium prediction) in the trading-only treatment than the transition treatment (overall $p < 0.001$).[12] Prices, and the range in transacted prices, declined from early rounds to the later rounds in both treatments but there was no significant difference in the speed of decline. The range of transacted prices was much wider in the trading-only treatment than the transition treatment when comparisons were made within the first two rounds ($p = 0.037$) or in the last two rounds ($p = 0.001$).

Table 5.8 Permit Prices

	Round				Overall by Treatment
	1	**2**	**3**	**4**	
Staged Transition	18.43 (5.99)	17.13 (6.15)	16.79 (4.44)	16.43 (4.11)	16.95 (5.06)
Trading Only (All Periods)	22.22 (7.08)	19.45 (11.26)	19.09 (8.21)	17.45 (4.67)	19.16 (8.08)
Trading Only (first 5 trading periods)	21.49 (6.88)	20.10 (13.80)	19.63 (9.68)	17.74 (4.49)	19.37 (9.29)

Speculative trading, in the sense of producers buying permits in excess of their own needs with the purpose of reselling them to other producers, was not observed in either treatment.

5.6 Preferences and Earnings

In response to the preference survey, participants indicated that they liked the tax-only liability least, transition more, and the trading-only scheme most. The

[12] The result of higher prices under higher investment levels is due to inefficient investment strategies and producers' subsequent values for permits. Sanin and Zanaj (2011), for example, model a market in which investment in abatement will lead to higher permit prices.

staged transition was liked significantly more than the tax scheme ($p = 0.025$). No significant difference between liking of the staged transition and trading-only scheme was reported.

Due to the free allocation of permits in the regulations with trading, producers' Experimental dollar earnings were higher in the trading-only regime than the transitional ($p < 0.01$) and the tax ($p < 0.01$). These differences in the E$ earnings were significant in all rounds and for all producer types, except for round 1, in which Producer 1 earned a statistically equivalent amount under the transition and trading regimes. Taxes collected were higher under the tax-only than transitional ($p < 0.01$) and trading-only schemes ($p < 0.01$). These differences in the E$ earnings were significant in all rounds and for all producer types, except for round 1, in which Participant 1 earned a statistically equivalent amount under the transition and trading only regimes.

The Experimental dollar: Australian dollar exchange rates used in the experiment were calibrated so that potential take-home earnings were the same for all participants in all treatments. While participants' E$ earnings were higher in the trading-only than the transition regime ($p < 0.01$) and the tax ($p < 0.01$), cash payouts (A$) were higher in the tax-only treatment than trading-only ($p < 0.001$) and transition ($p = 0.003$) (Table 5.9).

Table 5.9 Average Individual Earnings (A$), by Round and Treatment

Treatment	Round 1	2	3	4	Average Round Earnings, by Treatment
Tax Only	4.59 (2.0)	6.52 (1.29)	6.88 (0.93)	6.92 (0.99)	6.23 (1.66)
Staged Transition	4.81 (1.59)	6.07 (1.61)	6.46 (1.12)	6.70 (1.19)	6.01 (1.56)
Trade Only	5.11 (1.48)	6.02 (1.54)	6.35 (1.45)	6.61 (1.13)	6.02 (1.51)

5.7 Framework robustness

A concern when implementing the complex experimental design was ensuring that the results would be meaningful and applicable. In designing this study, key attention was paid to developing mechanisms that participants would easily understand. The main goal was to ensure that the observed behavior would result from the key mechanisms being manipulated and tested, and would not, alternatively, be arbitrarily affected by unintentional factors.

Several measures were undertaken in order to minimize and test for participants' understanding. The feedback and results from these ventures are encouraging. Participants performed well on a comprehension quiz they took after receiving instructions (before the start of the first round of play). Participants observably focused on their investment decisions during the course of the sessions (using the on-screen calculator and taking notes in advance of selecting upgrades).

Under both the transition and trading only treatments, participants responded very positively to the preference survey in the first round, which was implemented to probe for their frustration with the regulation. The results are summarized in Table 5.10. Participants responded to two survey questions prior to the first regulated phase, then immediately following the first regulated phase, and, in half of the sessions, after the completion of the fourth round. The participants used radio buttons to express their agreement ("Highly Disagree" to "Highly Agree" on a scale from 0 to 10) with the prompts: "I like Periods 1-5," (*a* in the below Table) and "I like Periods 6-13" (*b* in the below Table).

Table 5.10 Survey Responses

	Prior to first Regulation		After Round 1		After Round 4	
Treatment	***a***	***b***	***a***	***b***	***a***	***b***
Tax Only	8.0 (2.3)	3.6 (2.6)	8.3 (1.9)	3.7 (3.4)	8.91 (1.8)	2.63 (3.6)
Staged Transition	7.6 (2.62)	4.3 (2.3)	7.0 (2.9)	6.5 (2.8)	6.45 (3.7)	7.25 (2.9)
Trade Only	7.4 (3.0)	5.6 (2.4)	6.5 (2.8)	6.7 (2.5)	5.92 (3.2)	6.4 (3.5)

The participants' positive responses lend support for the assumption that behaviour was indeed affected by the nature of the regulation (and not, conversely, somehow due solely to chance). In fact, participants express higher preference for the regulation (*b*) under the trade only and staged transition treatments than under the tax only in all three of the surveys. At the first survey, the transition and trade only regulations were liked significantly more than the tax ($p = 0.025$ and $p < 0.001$, respectively). The differences in "like" of the regulatory regimes remained significant in subsequent surveys.

There was no significant difference in preference for the transition and trade only regimes in any of the surveys.

5.8 Summary of Chapter Five

Results of 18 experimental sessions were presented in this chapter. In addition to general results for the full market, relevant trends specific to three categories of producers' efficiencies (low efficiency, medium efficiency, high efficiency) were noted. In the experiments, low-efficiency producers behaved according to their profit-maximizing solution by producing little or not at all under the tax and transition schemes, but invested and produced at high levels under the trading-only regime. Medium and high-efficiency producers generated their highest levels of production under the tax, less under the transition and least under the trading only regime. Overall performance of the regulations was evaluated mainly by allocative efficiency, a measure of social welfare comprised of investment costs, emissions damages and production income. The tax only regime was most efficient, the transition less efficient, and the trade only regime the least efficient. The permit market was observed via the prices and quantities of permits traded: more permits were traded in the staged transition than the trading-only regime, while the prices were statistically higher under the trading only regime than transitional. Finally, participants' earnings were reported and reported preferences discussed.

Chapter 6. Discussion and Conclusion

A new CO_2 emissions regulation consisting of a staged transition from a tax to a permit market has been implemented in Australia. To allow controlled comparison of the effectiveness of such a regime to the more traditional tax-only and trade-only emissions regulations, an experiment based on a model of the three regulatory regimes was designed and executed. The results demonstrate that a transition regime may yield less costly compliance in its first phase when compared to an emission-trading scheme implemented in isolation, and seem to suggest that a transitional regime could yield preferable outcomes to a trading only scheme.

6.1 Overview of results

As measured in this study, both an environment regulated by a tax, and one governed by a regime with a staged transition incurred lower total compliance costs than did an experimental environment operating under the trading-only regime. The transition regime yielded more costly compliance than the tax only but less costly than trade only regulation. The bulk of the higher costs in the trading-only and transition treatments were due to the inefficient abatement investments made by inefficient producers. Inefficient producers were most likely to unproductively invest heavily in abatement, hold their permits and produce under the trading treatment than they were under the tax and transition schemes. The related eventual low supply of permits eliminated an opportunity for more efficient producers to generate as much income as would have otherwise been possible, and in turn, reduced total welfare.

6.2 Discussion

Forming the basis for this study was a concern that new cap and trade regimes lead liable producers to upgrade their technologies in ways unforeseen by regulators and analysts, thereby affecting permits' future prices in directions (high or low) that are unanticipated. Associated uncertainty about permit prices disrupts producers' investment optimization.

A market regulated by a tax $\tilde{p}$ was hypothesized to fare better (incur lower costs) than would one regulated by a new trading setup with cap L^*. A market with a staged transition between tax and trading was thought to perform somewhere in between. Specifically, producers were predicted to successfully optimize to reach cost minimizing investment decisions under a tax-only system, but fail to do so in a trade-only regime.

Under a trading system in this experimental setup, it seems that it is more difficult for the less efficient producers to identify themselves as such, so they invest more in costly abatement than in the other treatments, reducing social welfare. Price uncertainty in the newly created market and what seems to be an endowment-related effect of initial permit allocation both contribute to inefficiency in abatement decisions and a slower learning process demonstrated under the regulations that include trading. Implementing a temporary tax in the transition reduces some of the costly effects observed in the trade-only regime. Even with the extensive opportunity for learning and information gathering that the setup provided in the multiple rounds, and even though the average prices that emerged in the market were not substantially higher than the tax level, the decision makers incurred excessive compliance costs in the early and latter rounds of the sessions with trading compared to the tax sessions.

The results suggest that a well-designed transition from an emissions tax to a tradable permit scheme can yield benefits when compared to an application of an emissions trading scheme. The beneficial effect seems to be due to the temporary tax's resolution of uncertainty about compliance costs in the early stages of the regulation's implementation. Results presented in this thesis are contingent on specific parameters (tax level, producers' production characteristics, cap severity) that were modeled in this study, and should be tested more robustly before implemented.

Practitioners considering a staged transition regime may find additional concerns with the multi-step regulation. The primary concern that comes to mind is the tax $\tilde{p}$'s correlation with the unit price p that would eventually arise in a permit market in a transition regime. If $\tilde{p}$ is not equal to p, or if $\tilde{p}$ is not equal to the expected p, producers' incentives to invest will be affected by a weighted combination of the prices. The combination would be weighted based on the expected duration of the tax and the expected duration of the trading scheme. This concern has not been investigated in this experimental setup, but seems worthy of closer study.

Liable entities' confidence that the regulation will actually be implemented and enforced in the manner it is reported to is a closely related concern. Low confidence that a proposed regulation will be enforced presents additional uncertainty and noise to the expected unit price for emissions. Considering the political discord that is often present during the implementation of environmental policy, entities may predict that the reported enforcement will be revised, or at an extreme, short-lived. Naturally, an opportunity to manipulate the political environment in order to eliminate costly regulations may be eagerly seized by industry representatives. Jotzo and Jordan (2012) found a high level of policy uncertainty amongst representatives of Australian firms reported a lack of confidence that the carbon price would be enforced in Australia in the medium term, even after the first step of the carbon regulation was implemented. Policy uncertainty may be exacerbated by a transition design, which is concerning.

Costliness of simple confusion regarding the additional step inherent in a transitional regime is another concern. The additional step on its own may cause confusion in liable entities, yielding higher emissions, less-than efficient investment strategies, or both. The regulator must evaluate whether these concerns may be outweighed by the potential benefits of an introductory tax.

Forming the basis for this study was a concern that new cap and trade regimes lead liable producers to dramatically upgrade their technologies in ways unforeseen by regulators and analysts, thereby affecting permits' future prices in directions that often cannot be anticipated. Associated uncertainty about permit prices disrupts producers' investment optimization calculations. Excessive investment in abatement upgrades during Phase 1 of the United States' SO_2 market has been pointed to as a cause of unexpectedly low early allowance prices (Schmalensee, et al. (1998)). An initial allocation effect has been pointed to as a possible cause for lower-than-expected trading volumes in the EU Emissions Trading System (Murphy and Stranlund (2007)). The volatile carbon certificate prices in the early stages of the European Emissions Trading Scheme exacerbated uncertainty and reduced confidence in future returns on investment in abatement (Jung (2012)).

In spite of the danger of higher than necessary compliance costs, emissions trading schemes, especially those that include permit grandfathering, are favored by businesses over taxes. The experiment's survey responses suggest this preference among this study's participants, even though participants earned less under trading treatments than tax treatments (of course, an alternate and untestable explanation for the preference communicated via the survey was participants' preference for activity in the trade treatment compared to the stagnancy in the tax treatment).

The potential benefits enjoyed by a long-running, well-regulated permit market may ensure that quantity rather than price is the efficient regulatory instrument in the long term. But, as clearly observed in this lab setup, the uncertainties of a new trading environment can lead to inefficient compliance strategies and higher-than necessary compliance costs. An introductory tax may reduce the costs.

In spite of the extensive opportunity for decision makers had to learn through four rounds, and though producers received reliable information regarding the regulation and the aggregate abatement investments, the trading-only regulation performed worse than did the transitional system in this setup. This suggests that the temporary resolution of cost uncertainty provided by the tax in the transition regime is important.

6.3 Final remarks

These results appear to be helpful in guiding thinking and discussion about implications of regulatory structures, and it is hoped that the findings contribute to the first stages of what is hoped to be a wider study of this type of innovative regime. Further attention should be paid to the implications of a transition regime, with regards to the opportunity of gains from trade in an emissions market that allows for the entry of new firms, innovation in available technology, and the degree to which the temporary tax rate acts as a price anchor in the permit market. A comparison of the three regime designs discussed in this study, with auctioned permit allocation rather than free permit allocation, would provide a more complete overview of the outcomes of the regulations' implementation. A seemingly important direction of study would be to analyze the effect of a clearly inefficient tax on costs and efficiency. Another intriguing extension of this work would be to explore the characteristics of a regulation that would include a transition from trading to a tax regime, with the stage 2 tax level to be selected based on the prevailing price that permits were traded for in the stage 1 trading period.

This study has aimed to provide useful insight to legislators, businesses and lobbyists while shedding light on the benefits a transitional regulation could yield a wide swath of stakeholders. Curbing emissions effectively on a global scale requires creative solutions: application of tested, innovative regulative strategies such as a staged-transition may prove to be widely useful, not only in Australia.

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APPENDICES

Appendix 1: Tables

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

Producer	Tax Only	Staged Transition	Trade Only
1	E$50	E$103	E$135
2	67	120	152
3	83	137	169
4	111	164	195
5	154	207	239
6	190	243	275
7	226	280	312
8	263	316	348

Appendix Table 2: Social Welfare Maximizing Investment Levels

Producer	1	2	3	4	5	6	7	8	Aggregate
Level	0	0	0	3	3	2	1	1	10
Cost (E$)	0	0	0	225	225	150	75	125	800

Appendix 2: Selected zTree screenshots

Participant Investment Screen

Period: 2 of 13

Time Remaining: 58

Continue

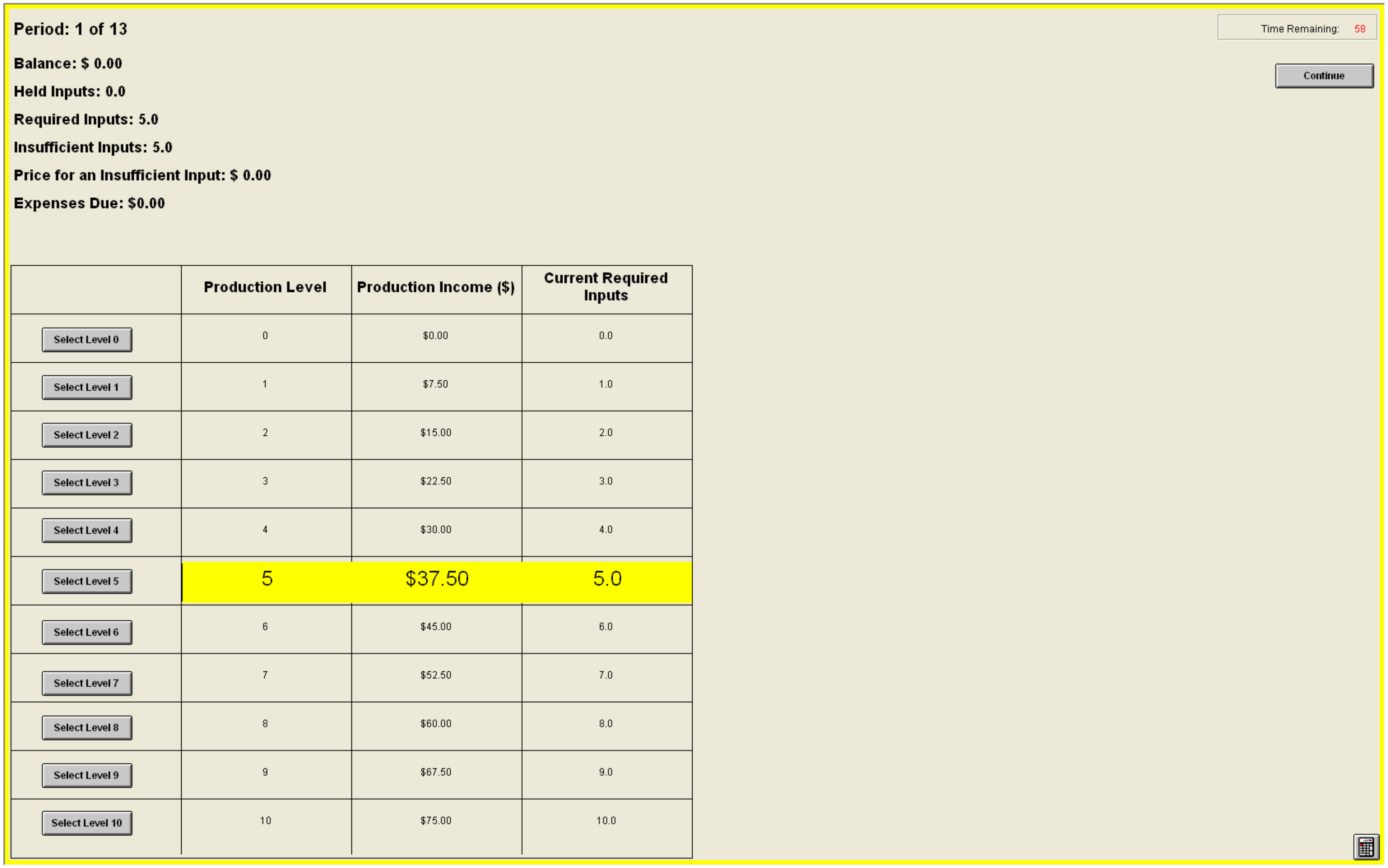
Balance: $ 37.50

Total Percent Reduction of Initial Required Inputs: 0%

Production Level	Production Income ($)	Current Required Inputs
0	$0.00	0.0
1	$7.50	1.0
2	$15.00	2.0
3	$22.50	3.0
4	$30.00	4.0
5	$37.50	5.0
6	$45.00	6.0
7	$52.50	7.0
8	$60.00	8.0
9	$67.50	9.0

Investment Cost	Reduction of Initial Required Inputs	Status
$12.50	10%	Invest 1
$62.50	10%	
$112.50	10%	
$162.50	10%	

Participant Production Screen, No Trading



Period: 1 of 13

Time Remaining: 58

Continue

Balance: $ 0.00

Held Inputs: 0.0

Required Inputs: 5.0

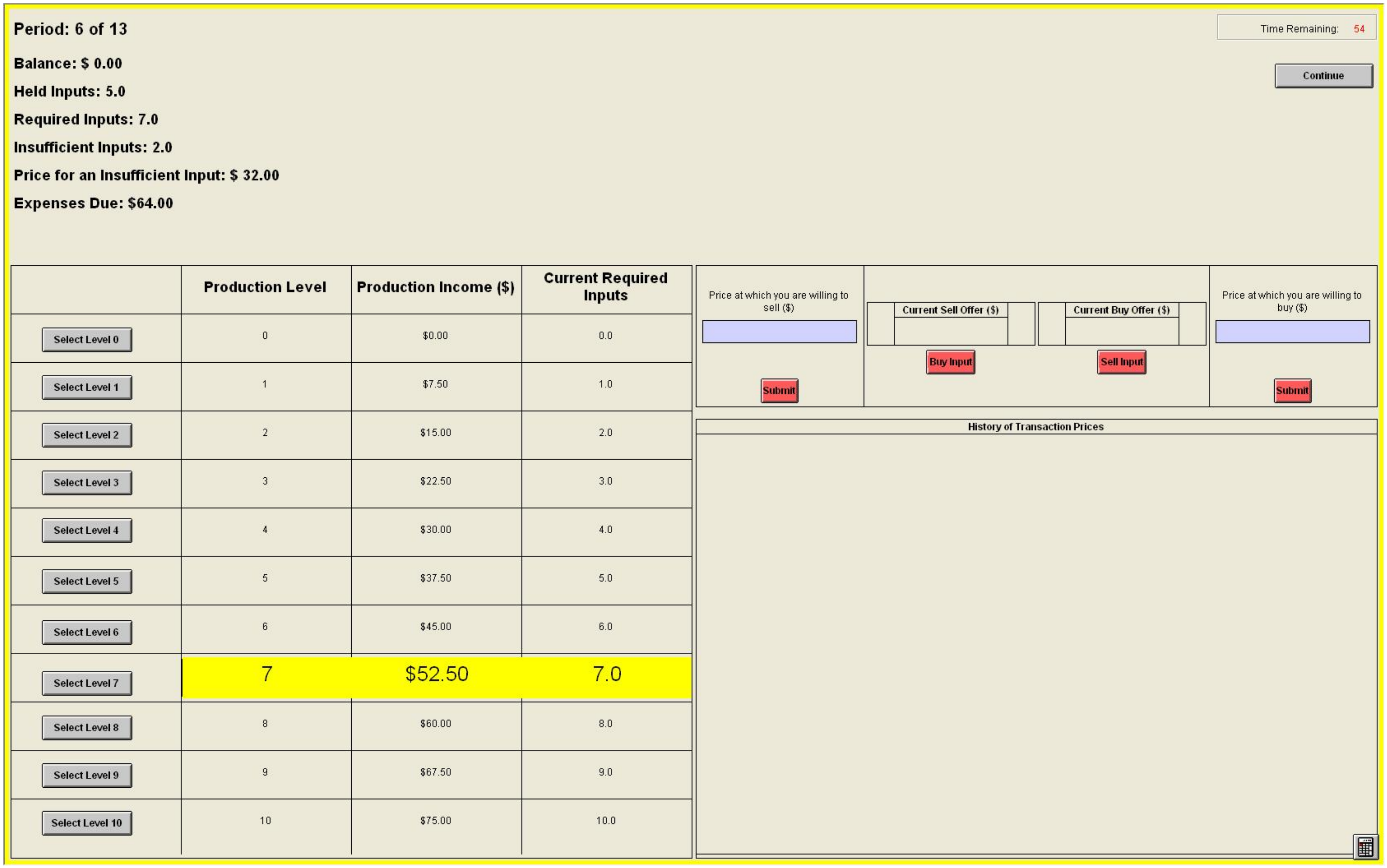
Insufficient Inputs: 5.0

Price for an Insufficient Input: $ 0.00

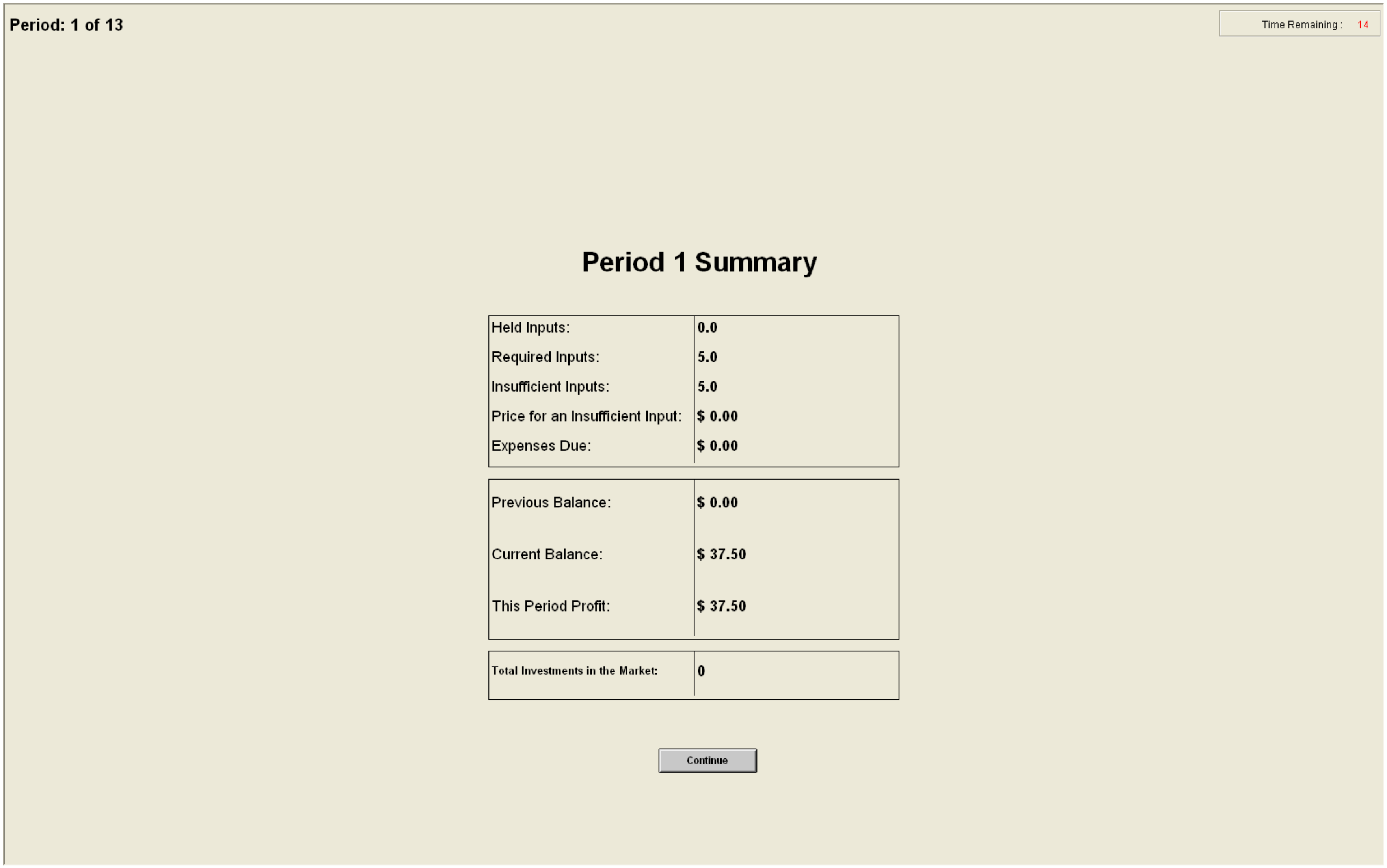
Expenses Due: $0.00

	Production Level	Production Income ($)	Current Required Inputs
Select Level 0	0	$0.00	0.0
Select Level 1	1	$7.50	1.0
Select Level 2	2	$15.00	2.0
Select Level 3	3	$22.50	3.0
Select Level 4	4	$30.00	4.0
Select Level 5	5	$37.50	5.0
Select Level 6	6	$45.00	6.0
Select Level 7	7	$52.50	7.0
Select Level 8	8	$60.00	8.0
Select Level 9	9	$67.50	9.0
Select Level 10	10	$75.00	10.0

Participant Production Screen, with Trading



End of Period Summary Screen



Appendix 3: Participant Instructions and Quiz

These instructions were distributed to participants via hard copy, and via a video[13], at the beginning of each experiment session. In the sessions with trading, the "Input Trading" portion of the instructions was distributed and viewed immediately before the first trading period.

[13] Instructions videos can be downloaded via Dropbox or viewed on YouTube. Links are provided in the reference list (Bernold 2012(a – e)).

Tax 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.

Staged Transitional 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.

Trading 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[14]

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.

[14] These instructions were distributed in the hybrid and the pure emissions trading treatments.

Instructions Quiz

This quiz was provided via a GoogleDoc, which required participants to provide correct answers to each question in order to proceed. The full version of the quiz is viewable via the link provided in the list of References (Bernold 2012).

This quiz is designed to ensure your understanding of the experiment instructions. Please read and answer each question carefully.

Question 1) Once in the production stage, how can you reduce the number of inputs that will be due at the end of the period?

a. Sell inputs
b. Buy inputs
c. Reduce your selected Production Level
d. Invest

Question 2) If you change your Production Level, when will that change take effect? Please choose the best response.

a. Immediately
b. Last Period
c. Next Period

Question 3) How many Inputs will be required for a Production Level that was initially 10 inputs, following two 10% investments?

a. 10
b. 9
c. 8.1
d. 8

Question 4) How many producers are in the market?

a. 1
b. 5
c. 8
d. 10

Question 5) In Period 1, what is the price per Input that you use?

a. $0
b. $16
c. $32
d. This will depend on others

Question 6) In Period 7, what is the Price per Input that you use?[15]

a. $16
b. $5
c. $32
d. $0

Question 7) For how many periods will each Round last?

a. 2
b. 3
c. 13
d. 10

Question 8) What information do you receive about the other Producers' decisions?

a. Their production levels.
b. Their investments.
c. Their Expenses Due.

Thank you for completing the quiz.

Please click the Submit button, and wait for further instructions.

[15] In the pure trading treatment, Question 6 read "In Period 7, what is the Price per Input that you use in excess of your Held Inputs?" The answer was "$32".