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ENVIRONMENTAL MARKETS: WHAT DO WE LEARN FROM THE LAB?

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Abstract. In recent years, some of the most influential policies have been either tested or evaluated using experimental methods. Experiments have provided significant insights on the implications of different designs on market outcomes and the lessons learned have helped improve academic debate and the interaction between policy makers and researchers. In this paper, we provide an overview of experiments relating to environmental markets. Expenditure on environmental programs has been growing in importance yet it is controversial in current times due to the fiscal cuts around the world. Finding cost-effective ways of reaching environmental goals is thus an objective of most governments. Research using experiments can help isolate how individuals and regulators would respond to incentives and therefore identify the most effective programs.

Keywords. Environmental Policy; Laboratory Experiments

1. Introduction

Experimental economists have been involved in market policy experiments since the beginning of the field. Early evidence regarding the importance of market institutions, particularly the potential of posted-offer markets to result in higher prices and lower efficiency than other institutions, inspired work on the implications of such institutions in real-world markets (Plott, 1986). The area where market experiments have arguably had the largest policy impact is in the design of spectrum auctions. Experiments are an invaluable tool in this complex setting with interdependent demand that renders theory intractable and magnifies the potential importance of behavioral factors. Experiments have informed not just the choice of auction formats but have also thrown light on important details such as eligibility and activity rules. Spectrum auctions are now conducted around the world including the United States, United Kingdom, and Europe.[1] More recently, work has focused on auction design for pollution permits, especially carbon permits.

While experiments continue in the traditional areas of competition policy and auction design, market policy experiments now encompass applications as diverse as smart markets for electricity and more

recently water, institutional design for emissions trading markets such as banking and enforcement, buyback schemes for conservation land, and matching algorithms for labor markets. In our paper, we provide a review of environmental market policy experiments, which we define as experiments that involve markets with a direct environmental policy application.[2] These are experiments, which, in the terminology of Roth (1986), are conducted to "whisper in the ears of princes."[3]

Our survey focusses on experiments concerning environmental markets. Recent years have witnessed an explosion of such experiments, a trajectory likely to continue into future years. Nevertheless, even within the environmental area there is considerable diversity of application, and our survey thus illustrates the potential contribution of experiments in many diverse policy applications. We focus on this area as it is more recent and hence not the subject of many existing surveys, and because of their (potential) influence on actual policy both now and in the future. Furthermore, there exists a series of experiments building up a body of evidence about a particular policy issue. Finally, we believe that many nonexperimental economists will be unfamiliar with these applications, whereas they are more likely to know about historically strong areas such as auction design, smart markets, and competition policy.

From the perspective of policy development, experimental economics is ideally suited to examine emergent environmental markets such as emissions trading, conservation auctions, and markets for water. As environmental concerns have become more prominent in recent years, research in the area has also grown. Cason (2010), Normann and Ricciuti (2009), Cherry *et al*. (2008), Strum and Weimann (2006), Bohm (2003), Cummings *et al*. (2001), and Muller and Mestelman (1998) provide very useful and insightful surveys of how experiments have been influential in addressing environmental problems. Our paper builds on this body of research and highlights how market design has a crucial role in environmental policy making both in tackling more traditional environmental issues such as emissions trading and also in relatively less well-known but emerging areas such as conservation auctions and water markets.

While market policy experiments share the same benefits as standard laboratory experiments, most importantly, control of the environment and the associated ability to make the *ceteris paribus* changes necessary to test various hypotheses, they do typically differ in important ways. Crucially, market policy experiments usually contain a far greater level of institutional or real-world detail and greater complexity than a typical lab experiment does in order to mimic, as far as practicable, the features of the corresponding real-world market. In addition, the inspiration for the research often comes from interested parties rather than just intellectual curiosity and this can lead to short time frames in which to conduct the experiments. Finally, nonstandard subject pools are more common than in standard laboratory experiments.

These differences are intended to enhance the reliability of policy conclusions based on the experimental results, in much the same way as "wind tunnels" are used in engineering to test the practical robustness of theoretically sound bridge and other designs. In the same way, the lab enables testing of the robustness of different mechanisms (e.g. auction formats) to behavioral factors that may not be *a priori* apparent (e.g. potential for collusion). In other applications, the lab can provide "proof of concept" that a complex market can work, as in the early days of smart electricity and gas markets.

The advantages of using laboratory experiments to address policy questions are many. First, the complexity of many policy issues, such as combinatorial auction design and matching algorithms in real-world situations, is virtually impossible to model theoretically. Second, for many policy issues, the data required for empirical testing are simply unavailable, either in a timely fashion, or at all. Field testing of most policies is often not possible, and the lab provides perhaps the only opportunity to explore different policy options and counterfactuals. Third, even if theory and empirical evidence exist, laboratory experiments can test the robustness of those results to behavioral factors, sometimes uncovering unanticipated behavior that may undermine the success of a policy.

The paper proceeds as follows. We divide environmental policy market experiments in two broad categories: those on emission trading markets (Section 2), and other less traditional areas including water markets and conservation auctions (Section 3). We conclude (Section 4) with a discussion of some possible future directions for market policy experiments.

2. Emission Trading Experiments

Plott (1983) was one of the first papers to use experimental methods to examine the performance of emission permit trading in the presence of negative externalities. He compared tradable permits to emission taxes and command and control methods using the double auction trading institution.[4] Plott (1983) found that both incentive methods significantly increased efficiency compared with command and control.[5] Subsequent environmental policy experiments have focused upon the market design and its impact on different aspects such as efficiency, participation, volume of trade, price of permits, transaction costs incurred by participants, heterogeneity of market participants, uncertainty, compliance, and enforcement. In this section, we review some of the burgeoning research in this area and the lessons learnt from this body of work.

2.1 *Trading Institutions*

Many experiments have evaluated features of the trading institutions implemented or planned for specific environmental programs. Trading institutions can have a major impact on price accuracy and volatility in the market and the implications of this choice were clearly seen in the US federal sulfur dioxide trading program designed to reduce acid rain, instituted by the Clean Air Act Amendments of 1990.[6] The US Environmental Protection Agency (EPA) designed a new call auction for trading allowances to emit sulfur dioxide. This was one of the first few programs to allow for a tradable permit market in emissions at the national level and attracted a lot of attention from academics and policy makers around the world.

In order to encourage early, centralized trading with low transaction costs, the EPA initiated a sealed bid, discriminative price auction in which the highest bids for permits were matched to the lowest offers and the successful bidders pay their bid price. The objective was to maximize economic surplus to the seller. Each bid and ask affects transaction prices and thus creates strong incentives for traders to strategically manipulate the market. This auction was criticized for generating biased price signals as the auction rules cause sellers to choose asking prices that under-reveal their true cost of emission control because lower asking prices increase the probability that a seller trades with high-bidding buyers. Combined with the well-known result that buyers have an incentive to under-reveal demand in discriminative auctions in which they have to pay their bid price (Vickrey, 1961), the EPA rules could lead to downwardly biased prices in the market (Cason, 1993, 1995).

Cason and Plott (1996) conducted 12 sessions to evaluate the performance of the EPA auction and compared it to an alternative trading institution: the uniform price auction. In the uniform price auction, bids and asks are arrayed as demand and supply schedules, and all trades occur at a uniform market-clearing price. In this auction design, only the bids and asks at the margin affect the uniform transaction price, thus traders have an incentive to truthfully reveal their valuations. Cason and Plott (1996) confirm the theoretical prediction that the EPA auction design creates strong incentives for both buyers and sellers to under-report their true values while the uniform price auction results in unbiased price signals and more efficient market outcomes. Figure 1 compares the efficiency of the two formats.

In 1998, when the market was more mature, Joskow *et al*. (1998) used field data from the private secondary market, where brokers were very active, and found that this market provided some information to participants in the EPA auction about the marginal value of permits. Hence, the emergence of the private market reduced the negative impact of the auction features to some degree.

Franciosi *et al*. (1999) constructed an experimental market with many features of the actual EPA market including both a mandatory auction and a continuous private secondary market. Each trading period consisted of two opportunities to trade: the private market followed by the auction. The private market used a double auction trading institution, while the auction was a sealed bid discriminative auction with a revenue rebate feature. All bids made in the auction were public information and banking of permits was allowed in some sessions. Franciosi *et al*. (1999) found that while trading improved efficiency, prices

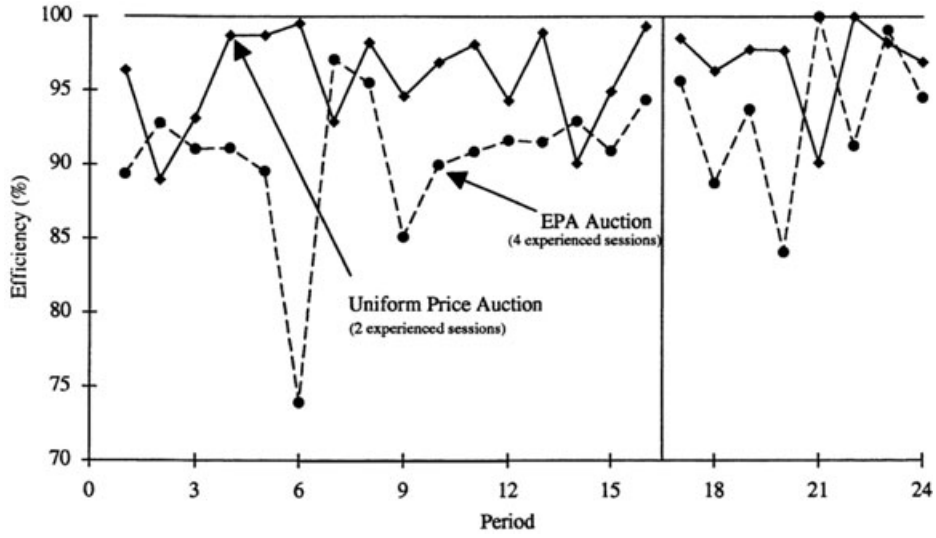

Figure 1. Average Efficiency Levels.

Source: Cason and Plott (1996), figure 5: Random draws environment.

in the private secondary market did not always coincide with those in the auction even at the end of the session. With permit banking, however, permits became durable assets, and this sometimes led to speculative bubbles as evidenced by collapses in permit prices toward the end of a session. Previous experimental research (Smith *et al*., 1988; Palan, 2013; Noussair and Tucker, 2013) has shown that asset markets are susceptible to price crashes and price bubbles. In experimental permit markets, price expectations may be difficult to form as subjects have little experience with the trading process and there is limited trading history to observe. The authors argue that in the field, this difficulty in forming price expectation could be higher due to the uncertainties about technology and about the strength of property rights.

Franciosi *et al*. (1993) compared the performance of revenue-neutral auctions (RNA), where the revenue from permit sales is returned to auction participants based on some assignment of property rights, to standard uniform price auctions, where all bidding revenue accrued directly to the seller.[7] Although the pricing mechanism in RNA is identical to the uniform price auction, the revenue-neutral aspect is a nontrivial feature that could alter the performance of the institution. The authors found that the RNA markets perform as well as the uniform price markets in both trading prices and efficiency levels. However, as is expected, the two institutions differed in terms of the distribution of gains from trade, with bidders who are large net sellers relative to their initial endowments gaining the most from the revenue rebate feature.

Cronshaw and Brown-Kruse (1999) designed an experiment to capture most of the features of the mandatory emissions allowance market under the 1990 US Clean Air Act, including the mandatory transfer of a fraction of permits to the market each period, a discriminative call auction, banking of permits, and the availability of permits at a fixed price.[8] Cronshaw and Brown-Kruse (1999) found that subjects were able to achieve about two-thirds of the gains theoretically available from banking alone and an additional 39–78% of the potential gains when trading was allowed.

Researchers at McMaster University conducted a series of laboratory experiments to testbed proposals by the Canadian government for a nitrous oxide allowance trading program in Southern Ontario. The

proposal intended to create two trading assets: coupons and shares. Each coupon would entitle the holder to discharge 1 ton of nitrous oxide within a year, while shares entitle the holder to a stream of coupons for future years. Coupons would be valid indefinitely and would be distributed to firms in proportion to their holding of shares, where shares may be allocated on the basis of grandfathering, for example. The market institution proposed was unstructured, with private negotiated trades in coupons and shares expected to occur. Muller and Mestelman (1994) conducted experiments where subjects are allowed to trade coupons and shares simultaneously. The experimental design followed Cronshaw and Brown-Kruse (1999) except they utilized the open outcry market institution to resemble the institution proposed for Southern Ontario.[9] They find higher cost savings than in laboratory implementations of the US EPA institutions using the same parameters. Transaction prices, however, show a mediocre performance, as in some sessions prices do not converge to the competitive equilibrium levels. This could be because of the lack of public information about trading prices that results from the open outcry institution, which disseminates a lot less information than in an alternative trading institution like a double auction market.

The Regional Clean Air Incentive Market (RECLAIM) was another tradable permit program implemented at a regional scale, in Los Angeles to reduce the emissions of sulfur and nitrogen oxides. A unique feature in this program was that firms would follow an overlapping compliance schedule.[10] Carlson *et al*. (1993a, b) showed that issuing permits with overlapping compliance cycles would avoid the need for banking of permits, a more palatable option for some environmental groups, which saw banking of permits as a way of postponing pollution.

Cason and Gangadharan (1998) compared the performance of an electronic bulletin board system (BBS) designed by the regulatory authorities in RECLAIM to help participants find trading partners and reduce search costs, to a computerized double auction market. The BBS allows firms to indicate trading interests by electronically posting offers to buy or sell permits. Other firms can scroll through these offers and contact the offering firm to negotiate a transaction. In contrast, the computerized double auction has no bilateral negotiation, has a successive improvement rule, and the bids and asks are binding on the proposer. Some of the benefits of bulletin board institutions include providing easier access to a larger number of buyers and sellers and timely and more accurate price information. Information available through the BBS can provide easily accessible indicators of market conditions and reduce market uncertainty. An important advantage of the BBS is that it can handle trade of heterogeneous goods. Overall, the authors find that the bulletin board sessions performed as well as the continuous double auction in terms of price accuracy and volatility.

This paper also studied the impact of the trading restrictions in the RECLAIM program, which were imposed across two zones of the Los Angeles Basin to avoid trades that lead to emissions migration that could harm air quality.[11] Consistent with theoretical predictions, prices were significantly different in two zones when trading was not allowed. When trading across zones was permitted, prices equalized across zones and gains from trade with interzone trading were 4% to 17% higher than gains from trade with no interzone trading.

Ishikida *et al*. (2001) also report experiments that were used to testbed the RECLAIM program. The authors focus on the special features of this market: a small number of participants, no history of market trades, and buyers and sellers transacting in portfolio of trades. They found that under such conditions a two-sided combinatorial market design outperforms a uniform price double auction mechanism. The authors argue that the combinatorial feature of the allocation process allows inframarginal portfolio traders to reveal their true values without risking financial exposure.

Shobe *et al*. (2009) report experiments based on trading rules and policies relating to the first mandatory emissions cap and trade program for greenhouse gases in the United States—the Regional Greenhouse Gas Initiative (RGGI), launched in 2009, which covers10 northeastern states from Maryland to Maine. This program has a declining cap on annual emissions from electricity generators in the region. The treatments compare the performance of four different auction types (uniform, discriminatory, clock, and clock with excess demand) in the presence of a loose cap and a tight cap. A loose cap is defined as one that

has a generous allocation of permits relative to recent emissions history. They find that auction revenues tend to be lower when the cap is loose and that discriminatory auctions yielded higher revenues than the uniform and clock auctions, though this advantage of the discriminatory auction disappears over time. Goeree *et al*. (2010) compare auctions with grandfathering as a means of allocating the initial pollution permits. The RGGI requires the use of auctions for allocating at least 25% of the permits. In contrast, the participants in the European Emissions Trading System are required to use auctions for at most 5% of the allocations. Goeree *et al*. (2010) find that using auctions leads to a higher consumer surplus and lower product prices.

Burtraw *et al*. (2011) compare the price discovery properties of six different auction mechanisms: sealed bid discriminatory, sealed bid uniform pricing, continuous discriminatory, continuous uniform pricing, multiround clock uniform pricing, and multiround clock uniform pricing with end of round information about excess demand. The authors implement an unannounced shift in cost conditions after three rounds resulting in an upward shift in the overall distribution of permit values. They focus on the extent to which each of these auction mechanisms track the increased equilibrium price, as the speed of price discovery under changing market conditions is important in environmental markets. The uniform pricing format outperforms the discriminative pricing mechanisms. In fact, the continuous discriminatory pricing auction yielded the worst price tracking performance. In general, prices were not near the equilibrium levels and after the demand shift, prices did not increase to the predicted level. In addition, tacit collusion occurred in the continuous bidding auctions with bidding observed at the reserve price early in the auction and some bidders not putting in a bid until the final seconds of the round.[12] The sealed bid auctions prevented this problem, as no information was available during the auction. The sealed bid uniform price auction showed the best price tracking properties alongside the multiclock auctions. The multiclock auctions, however, have a tendency to encourage collusion, hence the authors recommend the use of a simple uniform price auction for the RGGI program.

Porter *et al*. (2009) examine three different auction mechanisms (a combinatorial sealed bid auction, a sequential English clock, and combinatorial English clock auction) to maximize revenue and efficiency in Virginia's nitrous oxide auction, which was selling allowances for two fiscal years (2004 and 2005). Each state has a nitrous oxide emissions budget and can allocate its allowances to sources. Most of the emissions are grandfathered, however, new sources have to buy allowances in an auction. In situations when demand is more elastic, they find that the clock auctions perform better. They also describe the choices made for the auction in the field, which was informed by the results obtained in the laboratory. For example, in the field, a Web-based auction was chosen to maximize participation, however, instead of the complex combinatorial auction, they decided to have two separate and simpler sequential auctions of the two vintages due to the short time frame to train bidders.

Rich and Friedman (1998) discuss a pilot permit-trading program implemented in five cities and under consideration for use throughout China. Their experiments show that the trading rules designed by the Chinese EPA (a matching market institution) could lead to low efficiency and under-revelation of bids and asks. The matching market model used by the Chinese regulators maximizes the volume of emissions reduction given the revealed ability (or willingness to pay) of the buyers for the emissions permits. This auction was intended to increase trading volume.[13] The auction rules match the highest bid with the highest ask not exceeding that bid, then the next highest bid with the highest remaining ask less than that bid and iterates until the bids are exhausted. As in the case of the US federal SO_2 program, this auction design creates strong incentives for traders to misrepresent their valuations with buyers substantially understating their willingness to pay and sellers understating their willingness to accept.

In the last decade or so, given the interest in reducing emissions at the global level, several papers have explored the implications of different trading rules on the outcomes in the international carbon market. Research conducted by Bohm (1997), Bohm and Carlen (1999), Carlen (1999), Soberg (2000), Klasssen *et al*. (2005), Mougeot *et al*. (2011), and Cason and Gangadharan (2011) in this area shows that the design details can be important in the global arena as well.

As is clear from the discussion above, regulators must make numerous design choices when implementing new permit markets, and many of these design choices affect the transaction costs incurred by market participants. Regulators must also decide how to endow firms or consumers with permits. Cason and Gangadharan (2003) examine how transaction costs interact with the initial permit endowment to influence the cost-effectiveness of the overall emissions abatement. With zero transaction costs, the initial endowment affects only equity, and not the cost-effectiveness of the final competitive allocation of permits following trading. In the presence of transaction costs, however, cost-effectiveness can be significantly compromised depending on the endowment mechanism used.

A related application is designing trading institutions in the market for fishing quotas. Anderson and Sutinen (2006) use the case of the Rhode Island lobster fishery to examine different trading rules that could reduce price volatility in the market for quotas. They compare double auction and centralized call market trading rules and also introduce an initial lease period, such that permanent transfers of allowances are not allowed in the first few years after the program is introduced. Permanent transfers are allowed only after traders have had some experience with temporary lease transfers. This gradual phasing in of allowance trading is shown to be very effective in accelerating price discovery, improving equilibration, and preventing bubbles and crashes in the market. Tisdell and Ifekhar (2013) compare the performance of simultaneous and combinatorial fishery quotas markets. In simultaneous markets, markets for individual species or fishing sites operate at the same time. In a combinatorial auction, a fisher would trade combinations of quotas for different fish species or fishing sites in the same market. The authors find that combinatorial auctions are more efficient. Moxnes (2012) investigates two systems for fishery regulation: individual transferable quotas and auctioned seasonal quotas and introduces trade of both fishing quotas and fishing vessels. Both systems show similar outcomes in the experiment, however, the auctioned seasonal quotas allows for taxation of resource rent. The government can absorb some of the risk in this system in case the price of fish falls or the costs increase, hence the financial risk to the fishing firms is lower.

2.2 *Uncertainty and Enforcement*

Like all markets, emission markets are exposed to significant economic uncertainty, however, in addition, these markets are also affected by considerable scientific and political uncertainty. This uncertainty could have an impact on investment levels and on compliance strategies chosen by firms and the corresponding enforcement schemes implemented by regulators. Permit banking is one way to minimize unexpected short or long positions at the end of a trading period and can therefore reduce uncertainty and risk in the emission market.

Ben-David *et al*. (2000) explore the effects of uncertainty in tradable permit markets on prices, trading volume, and the firms' ability to realize cost savings. Treatments involve two separate types of uncertainty: uncertainty regarding the timing of permit allocation reductions and uncertainty regarding the magnitude of the reduction. They find that firms respond to uncertainty by adopting a "wait and see" approach with respect to certain decisions that can be feasibly postponed. While this does lead to a reduction in ex ante expected cost savings, it may ex post be optimal in view of the irreversibility of investment in abatement technology. Of course, by waiting for more information, firms could be forgoing abatement during earlier periods that could in turn lead to more expensive compliance efforts later. Due to the uncertainty in the permit market, firms could also be uncertain about their future role as potential buyers or sellers of permits and this reinforces the "wait and see" strategy.

Cason *et al*. (1999) introduce uncertain declines in the allocation of emissions allowances over time in their experiment and find relatively low efficiencies in these markets when there is uncertainty. Kusakawa and Saijo (2003) find that investment uncertainty could also reduce efficiency in emission markets. Ben-David *et al*. (1999) explore the relationship between investment and market performance. They

provide subjects with a choice of three technologies and examine the impact of technological cost heterogeneity on the operation of the permit market. They find that heterogeneity can lead to reduced trade volume and lower efficiency. Gangadharan *et al*. (2013) examine whether emission markets encourage optimal investment in the presence of uncertainty and the extent to which such investment affects market efficiency. In a treatment with both investment and banking, the proportion of permits "overbanked" is reduced relative to the treatment with only banking. This could imply that overbanking may be less of a problem in the field (where investments are presumably possible) than in the laboratory (where they frequently are not).

Cason and Gangadharan (2006) examine the interaction between three key features of tradable permit markets: banking, uncertainty, and enforcement. They allow for the possibility of correlated random shocks to emissions to incorporate uncertainty and study the impact of these shocks on permit prices and on compliance strategies. Their dynamic enforcement strategy uses audit probabilities that depend on past compliance and inspections. They find that the impact of emission shocks on prices is significantly stronger when subjects are not allowed to bank permits, so banking helps to stabilize permit prices (see Figure 2). However, banking leads to lower compliance with regulations because the benefits to under-report emissions are greater when unused permits can be banked for future use or sale. This highlights a tradeoff between banking and compliance, which regulators may need to consider in field implementations.

Murphy and Stranlund (2006, 2007) on the other hand, design an experiment in which emissions are deterministic, banking is not allowed, and audits are random with a known and constant probability. In their first paper, they examine the effects of changing enforcement strategies on the permit market and isolate the indirect effects of enforcement on compliance behavior. In their 2007 paper, their main focus is on how compliance decisions differ under market-based and command and control regulation. They find substantial differences in compliance behavior, with firm-level characteristics an important determinant of enforcement behavior under command and control, whereas the marginal productivity of enforcement does not depend on these firm-level characteristics under an emissions trading program. This suggests that enforcement policies need to be tailored to the mechanism being used to regulate emissions.

Stranlund *et al*. (2011) report results from experiments focusing on enforcement and compliance, when banking of permits is allowed. In contrast to Cason and Gangadharan (2006), however, they examine the separate roles played by reporting (when a firm under-reports its emissions) and permit (when the firm does not hold enough permits to cover its emissions) violations in dynamic emission markets. They find that reporting violations are significant while permit compliance remains high. They argue that policies that set very high permit violation penalties hence serve little purpose and that the main issue that needs addressing is the one relating to self-reporting. Policies that encourage truthful self-reporting would be valuable in the field.[14]

Enforcement can be a bigger concern when trading is between international parties. Who in this case should be held liable for overselling permits beyond the quotas: the buyer or the seller country? Cason (2003) found that when sellers commit to honor their obligations, market performance is improved as compared to situations when such commitments cannot be made or are not observed. Godby and Shogren (2008) compare seller and buyer liability rules and find that emissions trading with a buyer liability rule would lead to less environmental protection and at greater costs, which is consistent with their theoretical predictions. Increasing the monitoring probability did not change this main result. One of the arguments in favor of the buyer liability rule is that it could encourage poorer countries to participate in a global emissions market as they would be the sellers in the market. The buyers, the argument goes, are rich countries who can shoulder the liability burden better. This aspect was, however, not explicitly designed into the experiment.

There is significant potential for using experimental research to explore compliance and enforcement in environmental markets, as evidence regarding compliance lags theoretical work in this area. Field data on compliance can be hard to find and in self-reporting programs, data may not be fully reliable. Hence, experiments can make a substantial contribution in this area.

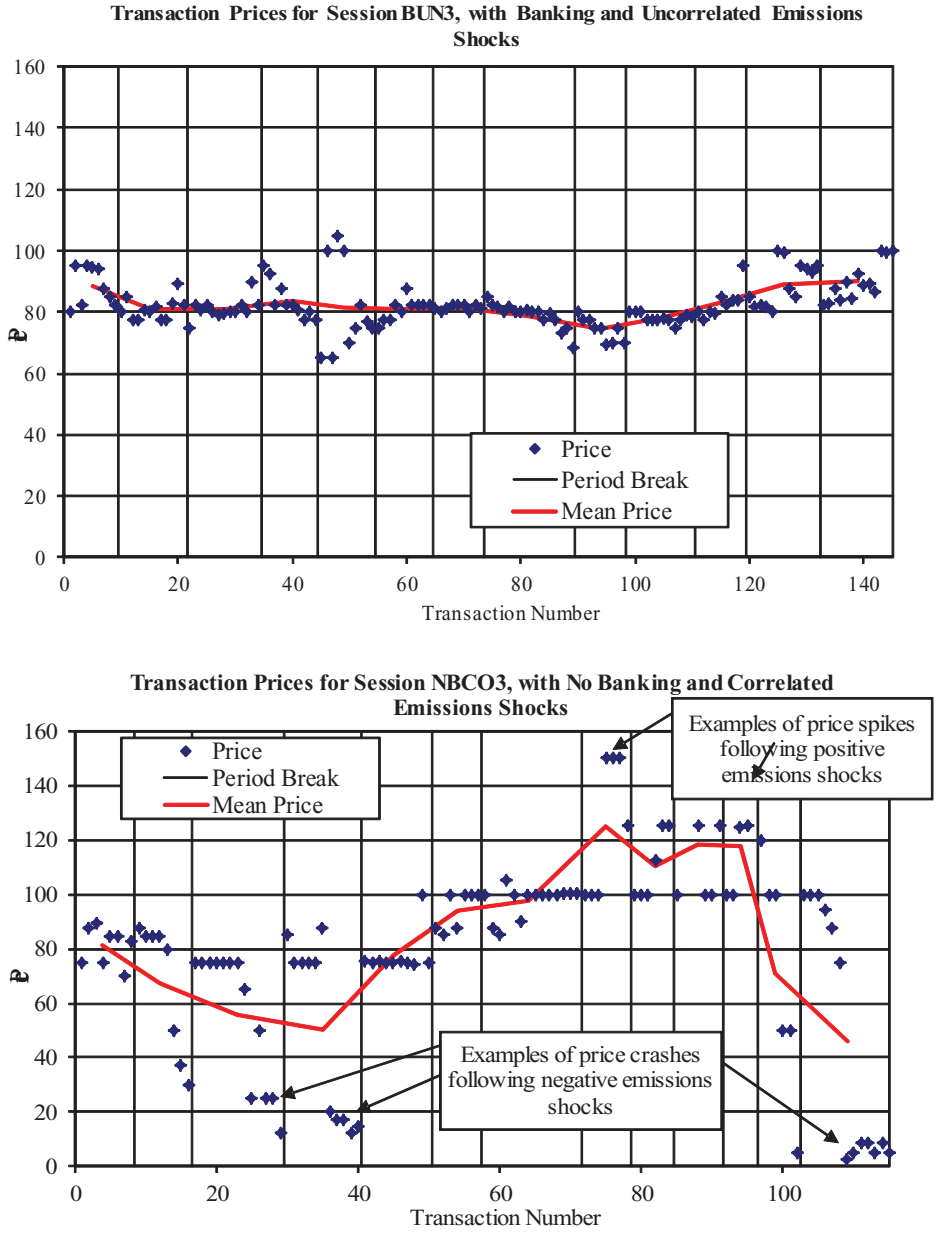

Figure 2. Impact of Banking on Permit Prices in the Presence of Uncertainty.

Source: Cason and Gangadharan (2006), figures 2 and 3.

2.3 *Market Power*

Most of the theoretical literature on environmental markets assumes competitive markets. Nevertheless, the ability to exercise market power under alternative trading institutions has been studied extensively, with the double auction mechanism considered the most robust to market power (e.g. Smith, 1981).[15] Ledyard and Szakaly-Moore (1994) adapted Smith's parameters to an environmental market framework and found that strong monopolists were able to achieve about 25% of the potential monopoly price increase even in the last period of the experiment. Brown-Kruse (1995) also detected market power in laboratory markets related to emissions trading. In their experiment, single buyers (or single sellers) of emission permits on one side of the market faced 10 sellers (or 10 buyers) of one permit each, however, an important difference to previous experiments was that the dominant firm had information about the cost schedules of the remaining participants. In the last period of their sessions, monopolists achieved an average of 40% of the potential price gain and monopsonists 166% of the potential price reduction. Godby (1999) replicated many of these results. An asymmetric information hypothesis (where the dominant firm knows the production and abatement costs of fringe firms but not vice versa) would then be useful in explaining why these experiments favor the market power model. Naturally occurring economies often include large firms that could have informational advantages to smaller firms. Hence, real-world applications of double auction markets may not be very resistant to monopoly pricing.

Muller *et al*. (2002) conduct experiments in which they aggregate the five buyers into a single monopsonist or the five sellers into a single monopolist. They also find that the double auction's apparent robustness to market power pricing outcomes is not as general a result as the previous experimental literature by Smith (1981) would suggest, with market power outcomes frequently observed. However, widespread price discrimination implies that trading efficiency is not hampered as market price in the double auction converges to (near) competitive equilibrium price over time, whereas income distribution effects emerge as the most important consequence of imperfect competition as equilibrium quantity is less than competitive equilibrium.

Soberg (2000) examines the impact of market power in emissions trading markets, when the trading institution is one-sided (such as the offer auction and the bid auction). He also finds that the main impact of market power is on income distribution issue not efficiency, with price being near the competitive equilibrium price but the quantity traded is less than competitive equilibrium. Permit trading, whether under a single-sided or double auction, yields an approximately cost-effective allocation of emissions despite monopolization of the permit market.

Cason *et al*. (2003b) examine whether a dominant firm can exercise market power in the context of a laboratory testbed relating to a nitrogen reduction program. They use the double auction trading institution and parameters that approximate the abatement costs of sources in a proposed tradable emissions market for the reduction of nitrogen in the Port Phillip Watershed in Victoria, Australia. In Port Phillip Bay, there is one large emitter of nitrogen that accounts for 94% of emissions and many small emitters. Their results suggest that even though prices vary considerably, a monopoly supplier of permits was not able to dominate a potential tradable emissions permit market in this region.

3. Other Environmental Policy Experiments

More recently, environmental policy experiments have emerged in diverse fields outside the traditional domain of emission trading markets. In this section, we discuss applications to water markets (spurred by development of smart electricity markets), land buybacks for environmental purposes (applications of auction work), and various eco-labeling schemes.

3.1 *Water Markets*

In recent years, sophisticated water markets have developed around the world. While researchers and policy makers agree that such markets enhance the efficiency of water use, by encouraging water conservation and by moving water from low- to high-value uses, debate continues about ways to improve the trading process. Water markets will continue to grow in importance due to increased scarcity and rainfall variability.

Murphy *et al*. (2000) demonstrate the viability of smart markets for water, which allow for the pricing and allocation of resources in technologically interdependent environments, using California as a case study. Individual water users provide information on willingness to pay or willingness to accept, and this along with budget and capacity constraints are inputs for the optimization algorithm that computes the prices and allocations that maximize the gains from trade. The authors design a sealed bid uniform price double auction mechanism with location-specific bids for the simultaneous allocation of water and transportation capacity rights among the three groups of buyers, sellers, and transporters. The market results in highly efficient allocations even with uncertain water supply, relatively thin markets, and volatility in the quantities traded. Given the problems associated with the development of water markets in California (third-party impacts, manipulation by a few dominant parties), smart markets provide a viable alternative that can incorporate the same allocation criteria that the regulator uses, yet be adaptable to changing information and market conditions.

A follow-up paper, Murphy *et al*. (2009), incorporates instream flow values into the water allocation mechanism by allowing active participation by an environmental trader. The quality of the instream flows can affect nonconsumptive uses of water such as the survival of native fish species. The smart market mechanism leads to mutually beneficial trades that also satisfy environmental constraints. The authors find that while active participation by an environmental trader can lead to efficient and stable outcomes, it also leads to strategic behavior as the trader has incentives to misrepresent their true willingness to trade. In addition, while efficiency is higher due to resource allocation between upstream and downstream users, some benefit more than others leading to concerns over regional impacts.

Duke and Gangadharan (2008) also consider a market where environmental concerns generate restrictions on water trades. They evaluate the performance of the Sunraysia Salinity Levy, a differential salt impact levy introduced by the Victorian Government in Australia in 2002 to manage salt concentrations in rivers resulting from water trades (SRWA, 2002).[16] Only buyers pay the levy, but the magnitude depends on the location of the buyer and the seller along the river. The levy is imposed only on buyers who buy water from lower impact zones, thereby creating a disincentive for water trades that increase salinity concentrations but no incentive for water trades that decrease salinity concentrations.[17] Duke and Gangadharan (2008) compare the salinity levy to an alternative salinity tax with no geographical restrictions and to a baseline water market with no salinity regulation. Their results show that both the salinity levy and salinity tax lead to significant environmental improvement as compared to the water market with no regulation. The salinity tax leads to lower water prices and more water trades in the early periods compared to the levy. The tax also reduces the cost of salinity control for the regulator and has a superior environmental outcome as compared to the levy. This testbed experiment confirms that economic incentives do improve the environmental outcome, however, using an instrument that creates barriers to trade across zones may not be the most cost-effective method. Hence, trading restrictions need to be considered with care.

In a related paper, Duke *et al*. (2008) study the use of simultaneous double auctions for both water permits and salinity rights in the Murray River and examine whether these simultaneous markets can efficiently allocate salinity, abatement, and water rights between irrigators. The subjects in the experiment respond to the incentives and choose to spend money on technological improvements, which could lead to private abatement in the salinity market. This showed regulators that when given a choice, individuals

adopt new methods to reduce their impact, and that with appropriate incentives in the salt and water market, less water is used.

Tisdell *et al*. (2004) explored the impact of the trading market institution (open call or closed call auction) on the level of environmental damage caused by water extraction. They also examined the impact of providing information about the environmental consequences of extraction (at the individual and aggregate level), allowing traders to communicate with each other, and the option to verbally sanction others. They found that the open call market (where bids were common knowledge) provided the worst return per unit of environmental damages. Aggregate information treatments were more effective than providing individual information, and providing opportunities for communication also reduced water extraction.

In further work, Tisdell (2007) examined different policy options to reduce total suspended solids in water catchments in Queensland, Australia. He compared closed call tenders and cap-and-trade (both of which are market-based), to a command and control mechanism, finding that the cap-and-trade system led to high rates of convergence of prices to equilibrium predictions. Similar to the early results in emissions trading, he found that market mechanisms helped in minimizing the cost of obtaining the environmental outcome.

Lefebvre *et al*. (2012) examine how water rights with different security levels can help farmers to manage better and more flexibly, the risks associated with stronger and more frequent water restrictions. The holders of "high security rights" are served first in case of scarcity, and the remaining volume of water determines the allocation to owners of "low security rights." The western part of the United States has a differentiated water right system. Two Australian states, Victoria and New South Wales, initiated a differentiated water right system, respectively, in 1994 and 2000. In other states, water allocations are simply proportional to water rights, without differentiation. Uncertainty relating to water allocation can often motivate farmers to hold more rights than necessary. With differentiated rights, they could instead buy more secure rights. The authors examine two main treatments: the number of security levels for water rights (one or two) and the presence of transactions costs in the water rights and allocation markets. They find that security-differentiated water rights can improve the performance of water markets but the outcome is dependent on market transactions costs. The differentiated system offers opportunities for risk allocation, irrespective of the transactions cost scenario: less risk-tolerant farmers can trade off lower average profits for lower variability of profits, by constituting the right portfolio of high-security and low-security shares. Hence, as risk becomes a major concern for farmers, differentiated markets become a valuable water policy option. The differentiated system can also increase farmers' profits, provided transactions costs in the rights market are lower than in the allocation market.

Garrido (2007) tests two specific market regulations included in the water reforms in Spain. He examines whether prohibiting senior water rights holders from selling to junior users leads to inefficiencies in the market. He also explores if allowing intertemporal use of water storage facilities could reduce stocks and water price instability. Currently, any water left in the reservoir is common property, and this "use it or lose it" rule leads users to exhaust their entitlement before the end of the season. Garrido has four treatments: two comparing restricted versus unrestricted trading, and two in which the storage facilities can be used for private water savings across periods or not. He finds that unrestricted trading is beneficial and that permitting users to use the storage facility leads to higher water levels in the reservoir and lower price instability. Hence, property rights over saved water can have important implications on the use of water during the water shortage periods.

3.2 *Conservation Auctions and Agricultural Policy*

Another application of auctions is designing buybacks of land for different conservation purposes. For example, Cason *et al*. (2003a) conduct testbed auctions for the Victorian Bush Tender program in Australia,

which aimed to reduce the aggregate nitrogen load in the Port Phillip watershed. The experiments aimed to identify information conditions that allow the regulator to award land management contracts to maximize pollution abatement for a fixed auction budget. Of particular concern was the incentive for landholders' to truthfully reveal their opportunity cost of land management changes that mitigate the environmental impacts of nitrogen pollution. The auctions had multiple rounds of sealed bids, used a discriminative pricing rule, and the regulator's budget constraint was fixed but unknown to landholder sellers (as in practice). The primary treatment variable was whether the environmental benefit (quality) of the sellers' proposed land use changes is revealed to landholders prior to submitting their offers. Revealing the benefits may increase the perceived fairness and transparency of the auction, educate landholders about the most beneficial land use changes, or promote philanthropic behavior among landholders. On the other hand, revealing information may lead to strategic bidding behavior. They find that revealing the benefits led to lower abatement and higher landholder/seller profits. Lower seller profits are better from the government's perspective, as sellers are not "overpaid" to deliver improvements in environmental quality.

In follow-up work, Cason and Gangadharan (2005) compare the impact of discriminative versus uniform price auctions on landowners' profits and the environmental benefits acquired for a given, fixed auction budget. They find that while the uniform price auction creates a greater incentive to reveal costs than the discriminative format, due to the heterogeneity of landowners' cost some landowners are "overpaid" in the uniform price auction because they receive payments that exceed their opportunity cost. Hence, the discriminative price auction has superior overall market performance. Cason and Gangadharan (2004) discuss some implication of different design features for conservation auctions.

Cummings *et al*. (2004) test design features for the Georgia irrigation auction used to pay farmers to suspend irrigation in drought years. They compared uniform and discriminative pricing formats, as well as different tie-breaking rules (inclusive or random) to inhibit collusion, and information conditions regarding provisionally accepted offers (either the permit ID number or the highest accepted price). The goal was to maximize the number of acres taken out of irrigation within a fixed budget constraint. Field experiments with farmers were also conducted. The random tie-breaking rule, and announcing only the permit ID numbers of provisionally accepted offers, resulted in a lower average cost for the regulator. These two features, along with the discriminative price format, which performed similarly to the uniform price format in the experiments but was preferred for political reasons, were adopted in the actual field auction conducted in 2001.

Parkhurst *et al*. (2002) use experiments to demonstrate how an agglomeration bonus for voluntarily conserving adjoining land could assist efforts to create contiguous conservation corridors on private land. Including an agglomeration bonus significantly decreased the fragmentation of the conserved land compared with simple incentives without a bonus where in fact, conserved land remained completely fragmented. Furthermore, allowing for preplay communication resulted in about 80% of pairs coordinating on the first-best outcome. This first paper uses a normal form coordination game, but in later work, Parkhurst and Shogren (2007, 2008) check the robustness of their results in a more realistic, but complicated, spatial coordination setting. The agglomeration bonus remains an effective policy tool in this more complex setting once participants gain experience.

A small literature exists that considers various aspects of agricultural policy, with most of the focus on the design of support payments. Bastian *et al*. (2008), Nagler *et al*. (2009), and Phillips *et al*. (2010) all find support for the theoretical prediction that decoupled support payments are nondistortionary as compared with production-based subsidies. As with other market policy experiments, Bastian *et al*. (2008) incorporate some relevant real-world features in their design such as a posted bid auction, spot delivery, and matching the guaranteed price to historical target price level. Motivated by policy changes introduced in 2002, McIntosh *et al*. (2007) investigate supply responses to countercyclical payments given to farmers (in addition to direct payments) in a world of price uncertainty. They find that such payments lead to inefficient production decisions and (possibly) higher government payments, but greater income certainty for risk-averse farmers. Bahrs *et al*. (2008) investigate different trading mechanisms for subsidy

entitlements (decoupled payments) in situations of excess demand or excess supply (of entitlements) and uncertainty about the true value of the entitlement. Wu and Roe (2005) experimentally evaluate proposals to prohibit the use of tournament-like performance contracts for agricultural producers. They find that agent welfare is higher under fixed performance contracts than tournament-based contracts except when the variance of the common production shock is large. Furthermore, on average, agents exerted higher effort with fixed contracts.[18]

3.3 *Other Market Experiments that Inform Environmental Policy*

Eco-labels and eco-standards have become very popular in recent years, and now appear on dishwashing liquids, detergents, appliances, and houses, to give a few examples. Consumers, while willing to pay for better environmental quality of products in some cases, are also suspicious of the labels that private firms put on their products. Hence, there is pressure on governments to regulate these labels, for example by mandating third-party certification of environmental quality. Cason and Gangadharan (2002) study a posted price market for experience goods, in which consumers find it difficult to identify the environmental quality (low or high) of the good prior to purchase. They compare a lemons market (with no information) to three treatments, which allow for reputation building, unverified claims (i.e. "cheap talk"), and voluntary but costly quality certification. They find that while seller reputation and unverified claims can sometimes increase the provision of high-quality goods, the only reliable way to improve product quality is to use certification.

Burfurd *et al*. (2012) examine the impact of policies to achieve optimal levels of investment in energy efficiency in rental markets. Field evidence shows that rental properties often have lower levels of energy efficiency than owner-occupied buildings, a gap, which policy makers are currently considering policies to reduce. They examine the following policy treatments: mandatory and voluntary energy-efficiency ratings (similar to energy-efficiency stars for appliances), a regulatory minimum upgrade treatment (similar to energy-efficiency standards for appliances), and a cost-share arrangement designed to increase the property owner's incentive to invest in energy efficiency. Mandatory information and voluntary information policies deliver comparable empirical performance (and are superior to the other policies) in terms of efficiency, upgrade levels, and upgrade prices. Figure 3 presents the raw data on upgrades and prices.

4. Conclusion and the Way Forward

Every year governments around the world spend significant public resources on policy making. The success or failure of a policy, be it in the area of competition, the environment, or matching markets, can, however, depend critically on the design of the policy and how individuals respond to it. Much of the research relating to market policy has focused on intricate aspects of the design. These have provided significant insights for researchers and policy makers on what trading institutions to use, what kind of trading rules to incorporate, what features to allow, and what to be cautious about.

Behavioral aspects of these policies have received less attention, and this is particularly evident in the environmental area (Shogren and Taylor, 2008; Shogren *et al*., 2010). For example, do different kinds of individuals respond differently to the same policy, and if so, what are the implications for policy design? There may also be spillovers from the market arena to other areas in which individuals interact, which could influence the final outcomes of the policy. A recent example of research that explores the performance of markets in the presence of behavioral factors is Cason and Gangadharan (2013) who consider whether competitive interactions affect agents' propensity to cooperate, using a double auction market and a public goods game. They find that although participants often cooperate when given an opportunity, the frequency of cooperation is lower when they also compete in the market. Communication improves cooperation in all environments, particularly when the market is present. Hence, spillovers

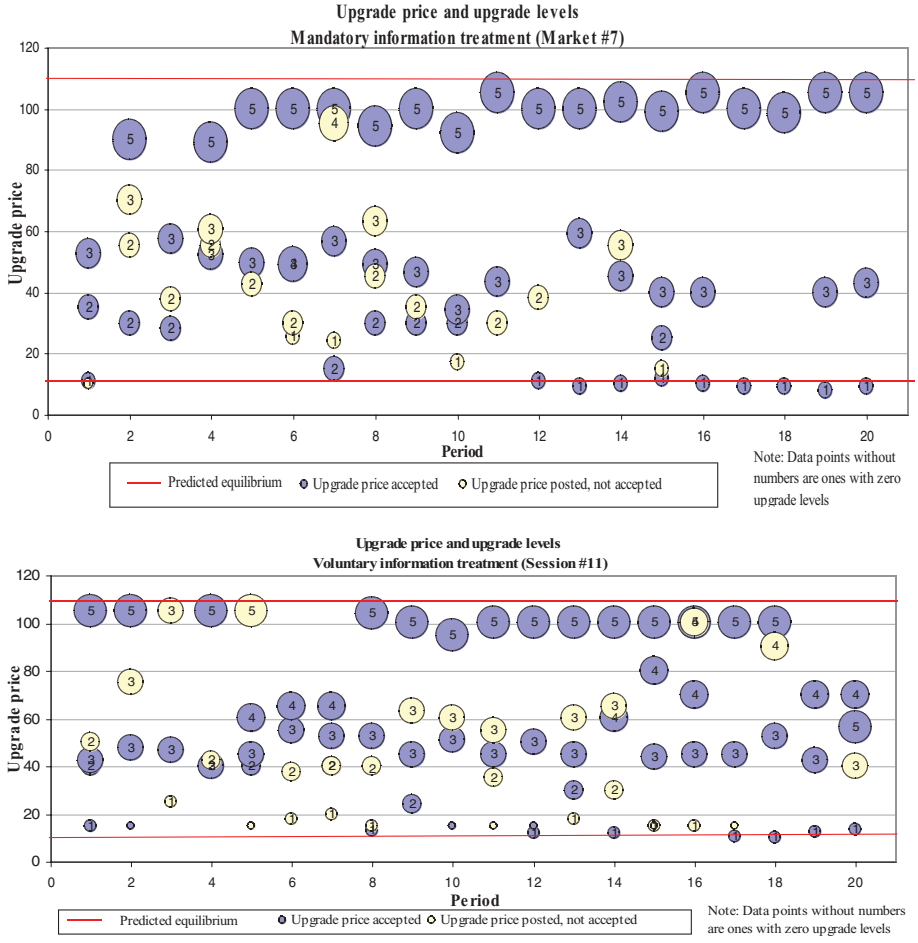

Figure 3. Information and Labeling.

Notes: In the mandatory information treatment, properties with a high upgrade level (circles with 5 written inside them) are rented at approximately E$110 and the ones with a low upgrade level (circles with 1 written inside them) are rented around E$10. With full information, market transactions are therefore consistent with the separating equilibrium and the theoretically optimal prices. The properties with a medium upgrade level (3 written inside the circle) are rented for upgrade prices in the middle of this range, consistent with a pooling equilibrium. In the voluntary information treatment, though performance is similar, there are relatively more instances of the pooling equilibrium being played throughout the 20 periods.
Source: Burfurd *et al*. (2012), figures 4B and C.

though they exist, are not very high, suggesting that it could be possible to encourage cooperative efforts without reducing competition and efficiency.

While many experiments have explored the effectiveness of emissions trading, few experiments since Plott (1983) have investigated the impact of different tax regimes. This could be partly because pollution taxes are considered politically infeasible in many countries. Kallbekken *et al*. (2011) examine markets where there is a negative externality and find evidence of tax-averse voting behavior. This opposition to

taxes is not because of lack of understanding of the effects or the efficiency properties of the tax. Framing the policy as a tax instead of a fee lowers support for it, whereas specifying how the revenue from the tax would be used increases support. Specifically, support for the policy is higher when revenues are used to reduce inequality.

Other recent research also demonstrates that providing a specific context in the experimental market (as compared with neutral framing) can improve decision making in the experiments (Cummings *et al*., 2004; Tisdell *et al*., 2004; Ward *et al*., 2008) or have a detrimental impact as in Cason and Raymond (2011) where using an environmental context lowered compliance with the policy.

Behavioral motivations can therefore affect the implementation and outcomes from efficient policies. Market policy experiments provide an ideal method for examining the magnitude of such effects and exploring whether cleverly designed markets can mitigate such issues. As environmental concerns continue to grow, so will the importance and relevance of environmental market experiments.

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Notes

1. Reviews of the extensive spectrum auction design literature can be found in Plott (1997), Roth (2002), and Normann and Ricciuti (2009).
2. We therefore exclude environmental policy experiments that do not involve markets (e.g. common pool resources, nonpoint pollution mechanisms, compliance experiments) as well as market experiments without an obvious and relatively direct policy implication (e.g. valuation studies).
3. The literature on general market policy experiments is vast. Surveys of specific areas include Staropoli and Jullien (2006) regarding the design of wholesale electricity markets, Roth (2002, 2008) who summarizes market design applications, and Normann and Ricciuti (2009) who focus on competition policy, auctions, smart markets for gas, electricity, and water, and some environmental policy.
4. The double auction is shown to be the most efficient and competitive of laboratory trading institutions (Smith, 1962) and for this reason is often used as a benchmark from which to determine efficiency of alternative trading institutions.
5. Efficiency in experiments is defined as the actual gains from trade as a proportion of the maximum possible gains from trade.
6. Price accuracy refers to mean price deviations from the predicted competitive equilibrium by period for each experimental session. Price volatility refers to variability of price about the mean price as measured by a coefficient of variation.
7. The distinguishing feature of the RNA is the system for distributing the receipts from the auction. Each bidder receives a payment equal to the market value of their grandfathered holding of permits. RNA rules were considered for the EPA auctions in the initial discussion stages, with a variant involving a discriminative pricing rule ultimately adopted.
8. In order to facilitate trade between permitted facilities and to allow new firms to enter the market the EPA withholds 2.24% of total allowances to sell at auction.
9. The open outcry market is similar to the pit trading on commodity exchanges, and permits multiple trades among agents and contracts to be negotiated privately.
10. Cycle 1 firms have an annual compliance year of January 1 through December 31, while Cycle 2 firms have an annual compliance year of July 1 through June 30. Transactions can be conducted with firms in either cycle.

11. Tradable permit schemes with no geographic restrictions can result in concentrated emission hot spots when the pollutant does not mix uniformly in the air or water shed.
12. With continuous bidding, subjects could view the status of their bids and see if they were provisionally winning or not and increase their bids before the end of the round.
13. Permit trading in China would involve an offset ratio greater than 1, implying that the seller eliminates more than 1 ton of emissions for each 1 ton permit acquired by a buyer, so increasing trading volume would help the regulator meet its goal of reducing total emissions.
14. See Friesen and Gangadharan (2012) for a comparison of voluntary and compulsory self-reporting policies.
15. This was because in the double auction, nonmarket power firms can withhold demand, hence indirectly forcing the firm with market power to lower prices. Smith (1981) described this apparently unorganized, collective behavior among buyers as a form of tacit collusion. The result was near-competitive market prices, although traded quantities were reduced. Smith and Williams (1989) also replicated these results.
16. Excess water can enter the groundwater system via vertical drainage; depending on soil type, gradient, and distance from the river, salt contained in the soils and groundwater is moved toward the river.
17. Irrigators located in the "High Impact Zone" can only buy water from sellers also located in this zone. Irrigators located in the "Low Impact Zones" can purchase water from sellers in any impact zone but must pay a salt levy per unit of water traded if they buy water from a lower impact zone (SRWA, 2002).
18. There is also a literature on eliciting willingness to pay for various agricultural commodities such as hormone-free beef and non-GM products, but as the link with market policy is less direct, we do not discuss these here.

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