Policy Instrument Choice when Marginal Damages are Uncertain: Theory and Evidence from a Laboratory Experiment*

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Abstract

Standard economic theory predicts that, when regulating environmental externalities, quantity instruments such as tradable permits and price instruments such as taxes will produce identical outcomes when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator, even when marginal damages are uncertain from the perspective of the regulator. Even though uncertainty over marginal damages may not matter in theory, it may be important in practice since such uncertainty may lead to behavioral responses on the part of market participants that cause price and quantity instruments to lead to different outcomes. We develop a theory model to compare the equilibria under price and quantity instruments with and without behavioral responses. We then conduct a laboratory experiment to evaluate the equivalence of price and quantity instruments when marginal damages are uncertain but marginal abatement costs are known with certainty. According to our results, in terms of aggregate emissions, the quantity-equivalence of quantity and price instruments cannot be rejected when marginal damages are known with certainty. However, when marginal damages are uncertain, the implementation of an optimal tax leads to more emissions compared to those achieved with a tradable permit system capped at the optimal amount of emissions. The results from the analysis of individual decisions and permit prices provide evidence for behavioral responses from endowment effects and risk attitudes proposed by prospect theory which cause price and quantity instruments to lead to different outcomes.

Keywords: damage uncertainty, experimental economics, externalities, price and quantity instruments, tradable permit systems, behavioral response

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1 Introduction

For several decades, economists have debated whether quantity instruments such as tradable permits or price instruments such as taxes are the more appropriate policy instrument for regulating environmental externalities. Standard economic theory predicts that, when regulating externalities, quantity and price instruments will produce identical outcomes when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator (Adar and Griffin 1976; Stavins 1995; Weitzman 1974). Uncertainties regarding marginal abatement costs generate different policy prescriptions depending on the relative slopes of the marginal damage and marginal abatement cost curves - a relatively flat marginal damage curve would make a price instrument relatively more attractive and vice versa (Adar and Griffin 1976; Weitzman 1974).

While uncertainties regarding marginal abatement costs may matter, the literature largely agrees that uncertainty over marginal damages alone has no impact on the equivalence of price and quantity instruments: according to standard economic theory, even in the presence of uncertainty over marginal damages, both price instruments and quantity instruments perform equally in terms of their ex post efficiency. Stavins (1996) finds that uncertainties in marginal damages only matter if uncertainties in marginal damages and uncertainties in marginal abatement costs are simultaneous and correlated with each other.

In this paper we examine the effects of uncertainty in marginal damages on the outcomes of price and quantity instruments. For many environmental externalities, marginal damages are uncertain; a stark example of an environmental externality with uncertain marginal damages is global climate change (Weitzman 2014). Even though uncertainty over marginal damages may not matter in theory, it may be important in practice since such uncertainty may lead to behavioral responses, or what Shogren and Taylor (2008) call 'behavioral failures'. Such behavioral responses include endowment effects, fairness concerns, and attitudes towards risk deviating from the expected utility framework.[1] If the behavioral responses of market participants differ under price and quantity instruments, then price and quantity instruments may lead to different outcomes.

For instance, under marginal damage uncertainty, decisions from regulatees who are also victims of the externality might be better explained by principles from prospect theory (Kahneman and Tversky 1979) than those from the standard expected utility theory. Under prospect theory, market participants may exhibit loss aversion and/or weigh events by magnitudes that differ from their respective probabilities of occurrence, thus leading to different decisions under uncertainty. For example, a loss averse market participant would overweight negative consequences when marginal damages are uncertain, and therefore overstate the negative impact of the externality.[2]

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[1] For an excellent discussion of behavioral economics, see Thaler (2016), who argues that rather than a paradigm-shifting revolution within economics, behavioral economics is more accurately characterized as a return of economic thinking to the open-minded, intuitively motivated way it began with Adam Smith.

[2] As Tversky and Kahneman (1991, p.1057) argue: "Because of this asymmetry [between pain and pleasure] a decision maker who seeks to maximize the experienced utility of outcomes is well advised to assign greater weight to negative than to positive consequences."

It is possible that market participants exhibiting loss aversion may behave differently under a price instrument than they would under a quantity instrument. For instance, under a permit system, loss averse market participants who are averse to high marginal damages may opt to further reduce the maximum potential damage by buying more permits than are needed to cover their emissions, and then leaving the additional permits unused. In contrast, a price instrument does not give loss averse market participants the opportunity to guard against high marginal damages in the same way. Thus, when market participants exhibit loss aversion, a quantity instrument may lead to a different outcome from a price instrument.

Behavioral responses such as endowment effects (Tversky and Kahneman 1991) and fairness considerations (Fehr and Schmidt 1999) may cause price and quantity instruments to lead to different outcomes even in the absence of uncertainty about either marginal abatement costs or marginal damages. Under a tradable permits policy, market participants exhibiting endowment effects may respond by being more reluctant to sell their permits.

Similarly, under a tradable permits policy, market participants exhibiting fairness concerns can affect inequities in different market participants' contributions to the externality by buying additional permits in order to achieve outcomes that appear more fair to them. In contrast, fairness concerns have less of an effect on market participants under a price instrument, since under a price instrument individuals can only affect inequities in different market participants' contributions to the externality by increasing their own emissions contribution, which they may perceive to have little impact on the behavior of others and which has the adverse effect of increasing the overall externality.

Thus, owing to behavioral responses, and in contrast with standard economic theory, price instruments and quantity instruments may lead to different outcomes even when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator. However, having a large number of participants in the permit market could attenuate any behavioral responses, since each individual may then perceive that they have little impact on the behavior of others, just as they do under a tax system, thus possibly restoring the equality between price and quantity instruments.

In this paper, we develop a theory model to compare the equilibria under price and quantity instruments with and without behavioral responses. Then, through a laboratory experiment, we evaluate the equivalence of the two policy instruments by exposing participants to price and quantity controls under different environments that comply with the traditional preconditions for the instruments' equivalence to hold. In our setting, subjects decide how much to produce of an output that yields individual benefits but also generates an externality that adversely affects all subjects. Behavioral responses aside, standard conclusions about the equivalence of the instruments should follow because certainty about the induced marginal benefits prevail in each of the treatments, and because transaction costs are negligible.

In contrast to our study, previous experiments on emissions trading have not analyzed the underlying market for the output that creates the externality. Instead, they only analyze the permit market by providing a marginal abatement cost function for emissions reduction (or a marginal benefit function for emissions) and a permit endowment to each participant (for an early review on the subject see Issac and Holt (1999)). One exception is the experiment conducted by Plott (1983), which includes buyers and sellers for a generic good that generates an externality, and which in one treatment implements an emission permit market. Plott's study is motivated by his observation that "People are aware, sensitive, and concerned about others so why should they behave in such an atomistic fashion? Intuitions, customs, ethics, and a host of instincts might guide us individually and as groups to behavior other than that suggested by the model" (Plott 1983, p. 106). The experimental design in this study is simpler than Plott's (1983) original study in some respects such as the market structure. We build on Plott's work by adding uncertainty over marginal damages.[3]

In previous theoretical work on the equivalence of quantity and price controls, regulated agents are assumed to be indifferent to the marginal damages generated by the regulated activity (Adar and Griffin 1976; Stavins 1995; Weitzman 1974). For example, the pollution from the regulated firms affects individuals, not the firms themselves. In contrast, our paper considers the situation in which regulated agents suffer the damages from the externality generation. There are many situations in which the regulated agents suffer from the marginal damages from the regulated activity, including common-pool resource problems such as overfished fisheries,[4] groundwater exploitation, road congestion, and air pollution. Our model is particularly well suited to the case of climate change, in which the welfare of individuals could be affected by both the benefits of economic activity and the damages from the greenhouse gas emissions resulting from this economic activity.[5]

Our experimental design also applies to systems in which countries or regions trade carbon permits, such as those studied by Bohm and Carlen (1999), Bohm and Carlen (2002), and Klaasen, Nentjes, and Smith (2005). Importantly, our design accommodates schemes in which individuals participate in so-called personal carbon trading. In a personal carbon trading mechanism, individuals are endowed with tradable carbon allowances.

Previous studies have analyzed such features of a personal carbon trading mechanism as design, acceptability, and behavioral impacts (Bristow et al. (2010), Fawcett and Parag (2010), Starkey (2012a), and Starkey (2012b)). Zanni, Bristow, and Wardman (2013) carry out a survey in which respondents state the changes they would make in face of either an hypothetical tax or a personal carbon trading system. Their results show that stated carbon reductions would be similar under the two policy options. Our study, the first to implement experimental economics methods in

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[3] In Plott (1983), an underlying market for a good generating externalities was constructed in addition to the permit market. The structure of the laboratory market implemented for this study is more similar to the designs used in experiments with a focus in specific aspects of permit markets (e.g., Cason and Gangadharan (2003); Murphy and Stranlund (2007)).

[4] For the regulation of fisheries, taxes have seldom been proposed but different systems of tradable fishing quotas have been implemented (Wilen, Cancino, and Uchida 2012).

[5] The debate over the optimal market-based policy for the correction of externalities has been revitalized due to concerns regarding global climate change resulting from anthropogenic greenhouse gas emissions (see Nordhaus (2007), and Stavins (2008) for discussions of policy instrument choice in the context of climate change policy).

this context, adds evidence to the body of knowledge regarding behavioral responses that may occur under quantity controls such as a personal carbon trading system.[6]

Results of our experiment indicate that in terms of aggregate emissions, the quantity-equivalence of quantity and price instruments cannot be rejected when marginal damages are known with certainty. However, when marginal damages are uncertain, the implementation of an optimal tax leads to more emissions compared to those achieved with a tradable permit system capped at the optimal amount of emissions. The results from the analysis of individual decisions and permit prices provide evidence for behavioral responses from endowment effects and risk attitudes proposed by prospect theory which cause price and quantity instruments to lead to different outcomes.

Our results have important implications for the design of policy. If price and quantity instruments are no longer equivalent when marginal damages are uncertain because of behavioral responses, policy-makers should consider the possibility of behavioral responses in the design of policy and in their choice of whether to use a price or quantity instrument.

The remainder of this paper is structured as follows. In Section 2 we present the theory model and derive equilibrium conditions under price and quantity instruments with and without behavioral responses. The experimental design is described in Section 3. The main results from the experiment are presented in Section 4. Section 5 concludes.

2 Theory Model

We develop a theory model to compare the equilibria under under price and quantity instruments with and without behavioral responses. Our model is framed as a situation in which agents, which we can think of as countries or governments, obtain individual benefits from the production of an output that also generates a damage that adversely affects all agents.[7]

2.1 Standard model

We first compare the equilibria under under price and quantity instruments in a standard model without behavioral responses.

In our model, there are N agents i. We can think of the agents as countries or governments. The utility of each agent i is given by the profits from its firms minus the monetized damages suffered by its citizens.

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[6] A standard upstream cap-and-trade system among firms also can be viewed as a price control. Under an upstream cap-and-trade system, the cost of the permits is expected to be passed on through the productive chain to the consumer. Therefore, from the consumer's perspective, a traditional cap-and-trade system in which firms are the regulatees and citizens' participation is limited is not different from a carbon tax. Standard economic theory predicts that a quantity instrument such as a personal carbon trading system would yield the same equilibrium as a price instrument such as an upstream cap-and-trade system. However, behavioral responses may cause the outcomes of a personal carbon trading system to differ from those of an upstream cap-and-trade system.

[7] By substituting consumption for production, our model would also apply to situations in which citizens are regulated, such as personal trading systems. The production context is adopted in this section to keep consistency with the experimental design, in which individual benefits are framed in terms of profits from production.

Profits $\pi_i(q_i)$ are increasing in the amount of externality-generating output q_i produced ($\pi_i'(q_i) > 0$) but at a decreasing rate ($\pi_i''(q_i) < 0$). Specifically, the profit function utilized in the experiment is of the following form:

$$\pi_i(q_i) = A_i q_i - \frac{\alpha_i q_i^2}{2}. \tag{1}$$

The externality-generating output q_i can represent, for example, emissions. We assume that the damage to each agent i from production by all agents is eQ, where the marginal damages e are constant and the same for every agent, and where $Q = q_i + \sum_{j \neq i} q_j$ is aggregate production.

The utility $U_i(\cdot)$ of agent i is therefore given by:

$$U_i(q_i; \sum_{j \neq i} q_j) = A_i q_i - \frac{\alpha_i q_i^2}{2} - eQ. \tag{2}$$

Each agent i decides how much of the externality-generating output q_i to produce. All agents make their decisions simultaneously.

2.1.1 Social Optimum

A social planner who applies equal weight to the utility functions of each of the N agents i would maximize the sum of their utilities. The individual quantities $q_{SO,i}$ produced by each agent i in the social optimum (SO) would therefore be given by:

$$q_{SO,i} = \frac{A_i - Ne}{\alpha_i}. \tag{3}$$

At the social optimum, each agent i's marginal profit is equated to the sum of marginal damages on all N agents of a unit of emissions. At the social optimum, each agent internalizes the effects of its emissions not only on itself, but on all the other agents as well.

2.1.2 No Policy

A baseline scenario (BS) with no externality-correcting policy would yield a competitive equilibrium with the following production $q_{BS,i}$ for each agent i:

$$q_{BS,i} = \frac{A_i - e}{\alpha_i}. \tag{4}$$

In the absence of policy, each agent will equate its marginal profit to the marginal damage of a unit of emissions on itself, ignoring the effects of its emissions on other agents. Compared to the social optimum, in which each agent internalizes the effects of its emissions on all agents, first-order conditions in a competitive equilibrium in the absence of policy yield larger externality-generating output levels q_i for every agent and therefore a larger total quantity of externality-generating output Q than is socially optimal.

2.1.3 Tax

Under a price control scenario (PS), a tax t is charged for each unit of externality-generating output q_i produced. The utility function for each agent i is therefore given by:

$$U_{PS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - eQ - t q_i. \tag{5}$$

The first-order condition yields the following individual quantities $q_{PS,i}$ for each agent i under a price control:

$$q_{PS,i} = \frac{A_i - e - t}{\alpha_i}, \tag{6}$$

which yields the same outcome as the social optimum when the tax is set at the optimal level $t = e(N-1)$.

2.1.4 Tradable Permits

Under the quantity control scenario (QS), there is no charge for the externality-generating output q_i but there is a cap L on the total number of units that can be produced by the N agents as a group. The cap can be set at any level but to achieve the social optimum it must be equal to the resulting sum of units under the social optimum (i.e., under the optimal tax policy). Permits are distributed among agents, and agents must hold a permit for each unit they produce. Permits are tradable, and agents have the option of not using them for production. The initial endowment of permits for each agent is denoted by L_i. The utility function for each agent i is then given by:

$$U_{QS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - eQ + \tau(l_i^s - l_i^b), \tag{7}$$

where τ is the equilibrium price of each of the permits bought (l_i^b) and sold (l_i^s) by agent i.

Let us now separate the damage eQ into the part eq_i generated by agent i itself, and the part $e\sum_{j\neq i} q_j$ generated by other agents:

$$U_{QS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - eq_i - e\sum_{j\neq i} q_j + \tau(l_i^s - l_i^b). \tag{8}$$

Agent $i's$ permit holdings in equilibrium (after trading) is given by:

$$H_i = L_i + l_i^b - l_i^s. \tag{9}$$

Assuming that the cap is set at the optimal level of production, marginal damages e are non-zero, and there is more than one agent ($N > 1$), the cap will be binding ($L < \sum_i q_{BS,i}$) and all the permits will be used in the absence of behavioral responses. Therefore, the damage to agent i generated by others is given by $e(L - H_i)$, the damage generated by using the total number of permits in the market minus the permits owned by agent i. This expression can take the place of $e\sum_{j\neq i} q_j$ in agent i's utility function, yielding:

$$U_{QS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - e q_i - e(L - H_i) + \tau(l_i^s - l_i^b). \tag{10}$$

Each of the N agents maximizes this utility function subject to the individual permit constraint that their permit holdings must cover their production:

$$L_i + l_i^b - l_i^s - q_i \geq 0, \tag{11}$$

which yields the following first-order conditions:

$$A_i - \alpha_i q_i - e - \mu_i = 0 \tag{12}$$

$$-\tau + e + \mu_i = 0 \tag{13}$$

$$\tau - e - \mu_i = 0, \tag{14}$$

where μ_i is the Lagrange multiplier associated with the individual permit constraint (11).

Substituting (13) or (14) into (12) yields the following individual quantities $q_{QS,i}$ for each agent i under a quantity control:

$$q_{QS,i} = \frac{A_i - \tau}{\alpha_i}. \tag{15}$$

The equilibrium permit price τ is endogenously determined in the market for permits. As can be seen from equations (13) and (14), the lower bound for the price of permits is e, which would be the price of permits if the cap were greater than the quantity that would be produced in the absence of any policy and therefore non-binding. Since the cap is binding, it follows that $\sum_i L_i = \sum_i q_{QS,i}$. The last equality allows us to predict the market equilibrium permit price τ.

Summing the N functions in (15), and setting total quantity equal to total number of permits $L = \sum_i L_i$, we derive the following expression for the permit price τ:

$$\tau = \frac{\sum_i \frac{A_i}{\alpha_i} - L}{\sum_i \frac{1}{\alpha_i}}. \tag{16}$$

When there is no uncertainty about marginal damages e and no behavioral responses, the market price for permits converges to $\tau = eN$ when the cap is set at the optimal level. This result is obtained by summing the socially optimal quantities $q_{SO,i}$ given by equation (3) across all agents i, yielding the optimal total production $Q_{SO} = \sum_i \frac{A_i}{\alpha_i} - eN \sum_i \frac{1}{\alpha_i}$. Substituting Q_{SO} for L in equation (16) produces an equilibrium permit price $\tau = eN$ when the cap is set optimally.

Note that when the cap is set optimally, the permit price at which each agent is willing to buy or sell incorporates the marginal damage on all agents that results from production, as it is derived from the potential use of the permit by others to produce and therefore generate an externality. In contrast, the optimal tax is equal to the marginal damage of one agent's production on all other agents, since the agent already accounts for the marginal damage of its production on itself. This is the reason why the equilibrium permit price $\tau = eN$ when the cap is set optimally is above the optimal tax rate $t = e(N-1)$. Nevertheless, the quantities produced by each agent under the optimal tradable permits policy would remain as they would be under the optimal tax policy.[8]

2.1.5 Implications of standard model

According to the standard model, the optimal level of emissions can be achieved with a tax of $t = e(N-1)$ or a permit price of $\tau = eN$. Within the context depicted by our model, in which regulatees are also victims of the externality, the instruments are quantity-equivalent but not price-equivalent under both certain and uncertain marginal damages when behavioral responses are absent.

Although the participation of affected parties in the permit market could result in participants holding permits without using them, in the absence of behavioral responses this would not occur as long as all market participants are affected equally by the externality and the cap is binding: $L < \sum_i q_{BS,i}$. As can be seen from equations (13) and (14), the lower bound for the price of permits is e, which would be the price of permits if the cap were greater than the quantity that would be produced in the absence of any policy and therefore non-binding. Since the cap is binding, it follows that $\sum_i L_i = \sum_i q_{QS,i}$. Since our model assumes equal marginal damages to all agents and imposes a cap equal to the optimal aggregate production level, in the absence of behavioral responses all permits will be used.

2.2 Endowment effects

We now extend our model to allow for behavioral responses. The first behavioral response we examine are endowment effects. Loss aversion in the form of endowment effects (Tversky and Kahneman 1991) may cause price and quantity instruments to lead to different outcomes even in the absence of uncertainty about either marginal abatement costs or marginal damages.

Under a tradable permits system, loss aversion in the form of endowment effects may lead individuals to be reluctant to sell their permits even if they do not use their permits for their own production. Thus, endowment effects

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[8] The equilibrium permit price would be greater (smaller) than eN when the cap is below (above) the optimal quantity.

can increase the value of each permit compared to the case in which the value of the permit is only linked to the benefits that can be obtained by generating the externality. This can ultimately reduce the externality because the holder of a permit might not find it attractive to use the permit or to sell it at the prevailing market price. Endowment effects may therefore cause the outcome of a tradable permits policy to be different from that under a tax policy.

The existing literature provides mixed results regarding the presence and persistence of endowment effects in large markets. In the case of a tradable permit system between firms, severe loss aversion in the form of endowment effects is not expected to be present since, as Tversky and Kahneman acknowledge, loss aversion in the form of reluctance to sell (i.e., an endowment effect) "...is surely absent in routine commercial transactions, in which goods held for sale have the status of tokens for money" (Tversky and Kahneman 1991, p.1055).[9] On the other hand, endowment effects could be more widespread in a tradable permits system among consumers or countries who would not necessarily perceive permits as "tokens for money". However, findings in Baldurson and Sturluson (2011), Kujal and Smith (2008b), List (2004), and Plott and Zeiler (2005) suggest that endowment effects may only be a temporary phenomenon in markets.

In our context, endowment effects can only arise under a quantity control. Incorporating $\delta_i \geq 0$ as the marginal disutility from selling a permit into equation (10) for an agent's utility under a quantity control yields:

$$U^{EE}_{QS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - e q_i - e(L - H_i) + \tau(l_i^s - l_i^b) - \delta_i l_i^s. \tag{17}$$

Maximizing (17) with respect to q subject to (11) yields the following first-order conditions:

$$A_i - \alpha_i q_i - e - \mu_i = 0 \tag{18}$$

$$-\tau + e + \mu_i = 0 \tag{19}$$

$$\tau - e - \mu_i - \delta_i = 0. \tag{20}$$

Combining (20) with (18) we obtain the following expression for the individual quantities $q^{EE}_{QS,i}$ for each agent i in the presence of endowment effects:

$$q^{EE}_{QS,i} = \frac{A_i - \tau + \delta_i}{\alpha_i}. \tag{21}$$

Equation (21) for the individual quantities $q^{EE}_{QS,i}$ in the presence of endowment effects reduces to equation (15) for the individual quantities $q_{QS,i}$ in the absence of behavioral responses if the marginal disutility δ_i from selling a permit is zero in a sale or if the individual is buying.

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[9] Yet in a passage from their study on endowment effects it is also recognized that "Endowment effects can also be observed for firms and other organizations. Endowment effects are predicted for property rights acquired by historic accident or fortuitous circumstances, such as government licenses, landing rights, or transferable pollution permits"(Kahneman, Knetsch, and Thaler 1990, p.1345).

The equilibrium permit price τ is endogenously determined in the market for permits. Unlike in the standard model, in the presence of endowment effects it is now possible that some permits are left unused. We now explore two cases: (1) all permits are used, and (2) some permits are left unused.

2.2.1 All permits are used

If all permits are used ($\sum_i L_i = \sum_i q_i$), we can solve for the equilibrium permit price τ. Summing up the N individual quantities in (21), setting the resulting total quantity equal to the total number of permits $L = \sum_i L_i$, and solving for τ yields:

$$\tau = \frac{\sum_i \frac{A_i}{\alpha_i} - L + \sum_i \frac{\delta_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{22}$$

As shown earlier, the individual quantities under the social optimum would yield the optimal total production $Q_{SO} = \sum_i \frac{A_i}{\alpha_i} - eN \sum_i \frac{1}{\alpha_i}$. Substituting Q_{SO} for L in (22) produces the following equilibrium permit price:

$$\tau = eN + \frac{\sum_i \frac{\delta_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{23}$$

We can see from this equation that the equilibrium price of permits would be higher compared to the standard case in which $\tau = eN$ as long as at least one individual experiences endowment effects (i.e., $\delta_i > 0$ for at least one i).

When all permits are used, the aggregate quantity in the presence of endowment effects would be the same as that from the optimal tax. However, the final allocation of permits across individuals may differ from that in the standard case.

Substituting (23) back into (21), we obtain the following solution for the individual quantities $q^{EE}_{QS,i}$ for each agent i in the presence of endowment effects:

$$q^{EE}_{QS,i} = \frac{A_i - eN - \frac{\sum_i \frac{\delta_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}} + \delta_i}{\alpha_i}. \tag{24}$$

Comparing this solution to the one from the standard case $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$, the quantity $q^{EE}_{QS,i}$ agent i produces in the presence of endowment effects may be greater than, equal to, or less than the quantity $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$ agent i produces in the absence of endowment effects, depending on the relative values of agent i's parameters and those of others.

Two intuitive results can be drawn from looking at equation (24). First, if every individual has the same δ, the final allocation is not different from the standard case. Second, if no individual has a $\delta_i > 0$, the final allocation is not different from the standard case.

Any other final allocation may be observed given differences in the δ_i's. For any individual j, the difference between the quantity $q^{EE}_{QS,i}$ in the presence of endowment effects and the quantity $q_{QS,i}$ in the standard case would be given by $\frac{1}{\alpha_j}(\delta_j - \frac{\sum_i \frac{\delta_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}})$.

For instance, consider the special case in which only one individual j has a $\delta_j > 0$: in other words, only one individual j exhibits an endowment effect. The difference in quantity q_j in the presence of endowment effects from that in the standard case can be written as $\frac{\delta_j}{\alpha_j}(1 - \frac{\frac{1}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}})$. Since the α_i's are all positive, the second term inside the parentheses is smaller than 1, yielding a higher quantity q_j in the presence of endowment effects compared to the standard case with no endowment effects, for that one individual j with an endowment effect. In this scenario, all other individuals k would have a lower quantity compared to the standard case, with the difference in quantity compared to the standard case given by $\frac{\delta_j}{\alpha_k}(-\frac{\frac{1}{\alpha_j}}{\sum_i \frac{1}{\alpha_i}})$.

2.2.2 Some permits are left unused

If some permits are left unused in equilibrium, this means that for some agents i the individual permit constraint in equation (11) is non-binding, and therefore that the multiplier μ_i on their individual permit constraint is 0. For example, μ_i could be zero for some individual i if their marginal disutility δ_i from selling a permit is sufficiently large. For an individual with $\mu_i = 0$, from equation (20) the equilibrium permit price must be $\tau = e + \delta_i$. In fact, if more than one agent produces less than her final permit holdings, it must be the case that all these agents have the same δ_i. Also note that from equation (18), agents who keep permits unused (and therefore have $\mu_i = 0$) produce the same quantity as that under no policy. Adding up the N functions in (21) combined with the condition $\sum_i L_i > \sum_i q_i$ yields a larger permit price than that resulting when all the permits are used:

$$\tau > eN + \frac{\sum_i \frac{\delta_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{25}$$

Combining this last equation with $\tau = e + \delta_i$, it can be shown that the necessary magnitude of the marginal disutility δ_i from selling a permit in order for total production to be smaller than the total number of permits is the following:

$$\delta_i > e(N-1) + \frac{\sum_i \frac{\delta_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{26}$$

From equation (26) as the number of agents (N), the externality (e), and number of agents experiencing endowment effects increase, the endowment effect of an agent needs to be stronger in order for it to result in some permits being left unused.

2.3 Fairness concerns

A second behavioral response we examine are fairness concerns. Fairness concerns may arise from agents experiencing disutility when their equilibrium permit holdings are less than the average equilibrium holdings of other agents, perhaps because this may mean that others are contributing more on average to the externality than they are.[10]

Under a quantity control, market participants exhibiting fairness concerns can affect the amount of externality generated by others through their decisions in the permit market by incurring costs to achieve outcomes that appear more fair to them. Individuals could do so by holding more permits than their optimal level of externality generation, and possibly leaving some of the additional permits unused, thus precluding others from using the permits at the cost of foregone income from further permit sales. Individuals incurring costs to punish agents taking unfair decisions has been documented in studies such as Fehr and Gachter (2000).

In contrast, fairness concerns have less of an effect on market participants under a price instrument, since under a price instrument an individual is unable to affect the amount of externality generated by others. Under a price instrument, individuals can only affect inequities in different market participants' contributions to the externality by increasing their own emissions contribution, which they may perceive to have little impact on the behavior of others and which has the averse effect of increasing the overall externality.

Similar to previous work on endowment effects, the evidence regarding the impact of fairness concerns in markets is not conclusive. On the one hand, Fehr and Schmidt (1999, p.834) argue that in some instances it is "...the impossibility of preventing inequitable outcomes by individual players that renders inequity aversion unimportant in equilibrium." On the other hand, Franciosi et al. (1995) admits that fairness concerns can result in deviations from competitive equilibrium predictions in bilateral trading situations but not in large multilateral trading markets where gains from exchange are reduced by fair behavior. Kachelmeier, Limberg, and Schadewald (1991) and Kujal and Smith (2008a) consider that in large markets, fairness concerns, like endowment effects, may only affect the competitive equilibrium temporarily.

Following Fehr and Schmidt (1999), we introduce inequity linearly into the utility function. We furthermore assume that advantageous inequity does not have an impact in the utility of agent i. Let γ_i represent the disutility agent i receives from inequity when agent i's equilibrium permit holdings (after trading) H_i are less than the average equilibrium permit holdings of other agents. The utility of agent i is then defined as follows:

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[10] We focus on fairness concerns as arising from inequities in externality generation, rather than from inequities in utility, for several reasons. First, as we are examining situations in which there are externalities that may need to be addressed with either price or quantity controls, it is possible that individuals may be particularly concerned about inequities in externality generation. Second, in our experiment, subjects observe the number of permits held by other subjects, which is correlated with the externality generated by others, but do not observe the utility or marginal benefit type of other subjects. As a consequence, we model fairness concerns as arising from inequities in permit holdings, which are related to inequities in externality generation, rather than from inequities in utility.

$$U_{QS,i}^{FC} = A_i q_i - \frac{\alpha_i q_i^2}{2} - e q_i - e(L - H_i) + \tau(l_i^s - l_i^b) - \gamma_i \left(max \left\{ \frac{L - NH_i}{N-1}, 0 \right\} \right). \tag{27}$$

Maximizing (27) with respect to q subject to (11) yields the following first-order conditions:

$$A_i - \alpha_i q_i - e - \mu_i = 0 \tag{28}$$

$$-\tau + e + \mu_i + \gamma_i \frac{N}{N-1} = 0 \tag{29}$$

$$\tau - e - \mu_i - \gamma_i \frac{N}{N-1} = 0. \tag{30}$$

Substituting either equation (29) or (30) in (28) yields the following individual quantities $q_{QS,i}^{FC}$ for each agent i in the presence of fairness concerns:

$$q_{QS,i}^{FC} = \frac{A_i - \tau + \gamma_i \frac{N}{N-1}}{\alpha_i}. \tag{31}$$

The equilibrium permit price τ is endogenously determined in the market for permits. Unlike in the standard model, in the presence of fairness concerns it is now possible that some permits are left unused. We now explore two cases: (1) all permits are used, and (2) some permits are left unused.

2.3.1 All permits are used

If all permits are used ($\sum_i L_i = \sum_i q_i$), we can solve for the equilibrium permit price τ. Summing up the N individual quantities in (31), setting the resulting total quantity equal to the total number of permits $L = \sum_i L_i$, and solving for τ yields:

$$\tau = \frac{\sum_i \frac{A_i}{\alpha_i} - L + \frac{N}{N-1} \sum_i \frac{\gamma_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{32}$$

Substituting Q_{SO} for L in (32) produces the following equilibrium permit price:

$$\tau = eN + \frac{\frac{N}{N-1} \sum_i \frac{\gamma_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{33}$$

We can see from this equation that the equilibrium price of permits would be higher compared to the standard case in which $\tau = eN$.

When all permits are used and the cap is set optimally, the aggregate quantity in the presence of fairness concerns would be the same as that from the optimal tax. However, the final allocation of permits across individuals may differ from that in the standard case.

Substituting (33) back into (31), we obtain the following solution for the individual quantities $q^{FC}_{QS,i}$ for each agent i in the presence of fairness concerns:

$$q^{FC}_{QS,i} = \frac{A_i - eN - \frac{\frac{N}{N-1}\sum_i \frac{\gamma_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}} + \gamma_i \frac{N}{N-1}}{\alpha_i}. \tag{34}$$

Comparing this solution to the one from the standard case $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$, the quantity $q^{FC}_{QS,i}$ agent i produces in the presence of fairness concerns may be greater than, equal to, or less than the quantity $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$ agent i produces in the absence of fairness concerns, depending on the relative values of agent i's parameters and those of others.

Two intuitive results can be drawn from looking at equation (34). First, if every individual has the same disutility γ_i from inequity, the final allocation is not different from the standard case. Second, if no individual has a $\gamma_i > 0$, the final allocation is not different from the standard case. Any other final allocation may be observed given differences in the γ_i's. The sign of the difference between the quantity $q^{FC}_{QS,i}$ for individual i in the case incorporating fairness concerns and the quantity $q_{QS,i}$ for individual i in the standard case is given by the following expression:

$$\text{sign}(q^{FC}_{QS,i} - q_{QS,i}) = \text{sign}\left(\sum_{j \neq i} \frac{1}{\alpha_j}(\gamma_i - \gamma_j)\right). \tag{35}$$

This is the weighted sum of the differences between γ_i and every other γ_j, the weights given by the inverse of the corresponding α_j. The sign thus depends on the both the weights and the magnitudes of the differences between one's γ_i and everyone else's γ_j but it would be unambiguously positive (negative) if $\gamma_i > \gamma_j$ ($\gamma_i < \gamma_j$) for all j. In other words, if agent i's disutility from inequity is higher (lower) than those of all other agents j, then agent i's quantity in the presence of fairness concerns would be higher (lower) than her quantity in the standard case with no behavioral responses.

Those with a lower permit endowment may have a relatively large disutility γ_i from inequity and thus potentially produce more than predicted in the standard case. The opposite would be true for those subjects with a large permit endowment. However, when all permits are used, the aggregate quantity remains as in the standard case.

2.3.2 Some permits are left unused

If some permits are left unused in equilibrium, this means that for some agents i the individual permit constraint in equation (11) is non-binding, and therefore that the multiplier μ_i on their individual permit constraint is 0. For example, μ_i could be zero for some individual i if their disutility γ_i from inequity is sufficiently large. For an individual with $\mu_i = 0$, from equation (30) the equilibrium permit price must be $\tau = e + \gamma_i \frac{N}{N-1}$. In fact, if more than one agent produces less than her final permit holdings, it must be the case that all these agents have the same γ_i. Also note that from equation (28) agents who keep permits unused (and therefore have $\mu_i = 0$) produce the same quantity as that under no policy. Adding up the N functions in (31) combined with the condition $\sum_i L_i > \sum_i q_i$ yields a larger permit price than that resulting when all the permits are used:

$$\tau > eN + \frac{\frac{N}{N-1}\sum_i \frac{\gamma_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{36}$$

Combining this last equation with $\tau = e + \gamma_i \frac{N}{N-1}$, it can be shown that the necessary magnitude of the disutility γ_i from inequity in order for total production to be smaller than the total number of permits is the following:

$$\gamma_i > e\frac{(N-1)^2}{N} + \frac{\sum_i \frac{\gamma_i}{\alpha_i}}{\sum_i \frac{1}{\alpha_i}}. \tag{37}$$

From equation (37) as the number of agents N, the externality e, and number of agents experiencing fairness concerns increase, the fairness concerns from an agent need to be stronger in order for it to result in some permits being left unused.

2.4 Prospect theory risk attitudes

The third behavioral response we consider are prospect theory risk attitudes. Under marginal damage uncertainty, decisions from regulatees who are also victims of the externality can alternatively be explained by principles from prospect theory (Kahneman and Tversky 1979) instead of those from the standard expected utility theory. Under prospect theory, market participants may exhibit loss aversion and/or weigh events by magnitudes that differ from their respective probabilities of occurrence, thus leading to different decisions under uncertainty. For example, a loss averse market participant would overweight negative consequences when marginal damages are uncertain, and therefore overstate the negative impact of the externality.

Under the expected utility framework, the outcome would be the same for risk-neutral decision-makers whether or not there is uncertainty in the level of marginal damages $\tilde{e}$ if the mean of $\tilde{e}$ is equal to e:

$$E[\tilde{e}] = pe^h + (1-p)e^l = e, \tag{38}$$

where e^h and e^l respectively represent scenarios with high and low damages that occur with probabilities p and $(1-p)$, respectively.

In contrast, prospect theory assigns weights to the different states of utility, based on underlying preferences for gains and losses under each scenario. According to this theory, low probability events tend to be overweighted (though not necessarily overestimated) by individuals, particularly if the low probability event involves a large loss due to loss aversion. Furthermore, in prospect theory the utility of agents is represented through a value function for gains and losses that exhibits loss aversion.

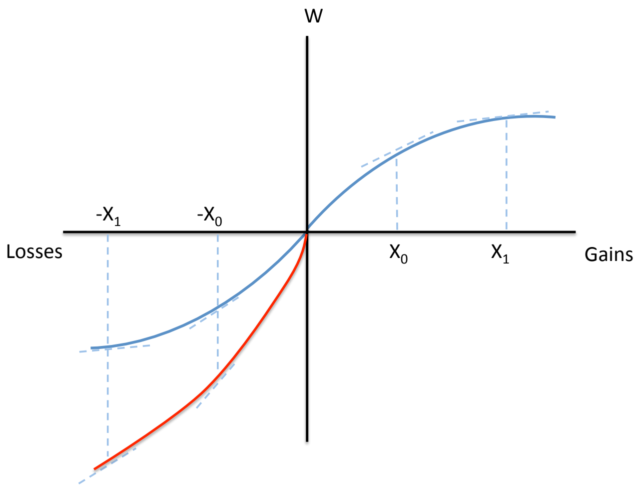
Let us consider the following value function W that separates the losses and the gains and that exhibits loss aversion:

$$W_{QS,i} = U_i(\pi_i(q_i) + \tau l_i^s) + V_i(-e_i q_i - e_i(L - H_i) - \tau l_i^b), \tag{39}$$

where $U_i()$ is the concave utility from gains and $V_i()$ is the convex utility from losses, with $U_i() \geq 0$, $U_i'() > 0$, $U_i''() < 0$; $V_i() \leq 0$, $V_i'() > 0$, $V_i''() > 0$; and $U_i(0) = V_i(0) = 0$. Furthermore, the utility from gaining an amount x is less than the disutility from losing that same amount x: $U_i(x) < -V_i(-x)$ for any $x > 0$.

Figure 1 depicts a a value function W that exhibits loss aversion in that the function is steeper in the negative domain than in the positive domain; losses loom larger than corresponding gains, and this divergence is more pronounced in the value function shown in red over the losses domain. Moreover, the marginal values of both gains and losses decrease with their size. These properties give rise to an asymmetric S-shaped value function, concave above the origin and convex below it (Tversky and Kahneman 1991). When the utility $V()$ from losses is convex, individuals may be more willing to take risks to avoid a loss. We call the convex nature of the utility $V()$ from losses 'risk seeking to avoid losses'.

Figure 1: Value function over gains and losses



The perceived marginal damages e_i which vary across subjects are given by:

$$e_i = w_i(p)e^h + w_i(1-p)e^l, \tag{40}$$

where the weights associated with the high and low damage events are respectively $w_i(p) > p$ and $w_i(1-p) < (1-p)$, and $w_i(p) + w_i(1-p) = 1$, such that the high damage event e^h is given a higher weight than its probability p of occurrence, and vice versa for the low damage event e^l. We call this feature 'overweighting of high damage events'.

The uncertain damage is incorporated as $e_i \geq e$, where $e = pe^h + (1-p)e^l$ is the expected value of the damage, due to heterogeneous overweighting of highly damaging events across individuals.[11]

Maximizing (39) with respect to q subject to $L_i + l_i^b - l_i^s - q_i \geq 0$ yields the following first-order conditions:

$$U_i'\pi' - V_i'e_i - \mu_i = 0 \tag{41}$$

$$-V_i'\tau + V_i'e_i + \mu_i = 0 \tag{42}$$

$$U_i'\tau - V_i'e_i - \mu_i = 0, \tag{43}$$

where μ_i is the Lagrange multiplier associated with the individual permit constraint (11).

Combining equations (41) and (42), we obtain:

$$\pi_i' = \frac{V_i'}{U_i'}\tau. \tag{44}$$

Assuming $\pi_i(q_i) = A_i q_i - \frac{\alpha_i q_i^2}{2}$, we obtain the following expression for individual quantities $q_{QS,i}^{PT}$ for each agent i under prospect theory:

$$q_{QS,i}^{PT} = \frac{A_i - \frac{V_i'}{U_i'}\tau}{\alpha_i}. \tag{45}$$

Equation (45) for the individual quantities $q_{QS,i}^{PT}$ under prospect theory reduces to equation (15) for the individual quantities $q_{QS,i}$ in the absence of behavioral responses if marginal utilities over gains and losses are equal ($V_i' = U_i'$) in a purchase or if the individual is selling.

The equilibrium permit price τ is endogenously determined in the market for permits. Unlike in the standard model, under prospect theory it is now possible that some permits are left unused. We now explore two cases: (1) all permits are used, and (2) some permits are left unused.

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[11] For instance, take the prospect (ηx,p;x,1-p) where $\eta > 1$. The expected value of this prospect is $E = p\eta x + (1-p)x$. Now, assume that instead of probabilities, weights (w_p and w_{1-p}, $w_p + w_{1-p} = 1$) are assigned such that the prospect takes the following form: $V = w_p\eta x + w_{1-p}x$. The difference $V - E = (w_p - p)(\eta x - x)$ is positive because $w_p > p$ and $\eta > 1$.

2.4.1 All permits are used

If all permits are used ($\sum_i L_i = \sum_i q_i$), we can obtain an equation for the equilibrium permit price τ. Summing up the N individual quantities in (45), setting the resulting total quantity equal to the total number of permits $L = \sum_i L_i$, and solving for τ yields:

$$\tau = \frac{\sum_i \frac{A_i}{\alpha_i} - L}{\sum_i \frac{V_i'/U_i'}{\alpha_i}}. \tag{46}$$

As shown earlier, in the absence of risk seeking to avoid losses and weighting of probabilities (i.e., when $V_i''() \leq 0$ and $e_i = e$ for all i), the individual quantities predicted under the optimal tax $t = (N-1)e$ would yield the optimal total production $Q_{SO} = \sum_i \frac{A_i}{\alpha_i} - eN \sum_i \frac{1}{\alpha_i}$. Substituting Q_{SO} for L in (46) produces the following equilibrium permit price once risk seeking to avoid losses and overweighting of high damage events are allowed for:

$$\tau = eN \frac{\sum_i \frac{1}{\alpha_i}}{\sum_i \frac{V_i'/U_i'}{\alpha_i}}. \tag{47}$$

We can see from this equation that the equilibrium price of permits would only be equal to that in the standard case in which $\tau = eN$ if $\sum_i \frac{V_i'/U_i'}{\alpha_i} = \sum_i \frac{1}{\alpha_i}$. This result depends on the ratios of the marginal values of losses and gains, which tends to be greater than one the smaller the loss and the larger the gain. It is important to bear in mind that the expected loss is amplified for those subjects who assign larger weights to highly damaging events with small probabilities. Thus, equilibrium permit prices in situations with possible extreme events are likely to be higher than those in situations with balanced events or those in the absence of behavioral responses.

In this section we assumed that all permits were used; however, the final allocation of permits may be different compared to the standard case.

Substituting equation (47) back into equation (45) we obtain the following expression for individual quantities $q_{QS,i}^{PT}$ for each agent i under prospect theory:

$$q_{QS,i}^{PT} = \frac{A_i - \frac{V_i'}{U_i'} eN \frac{\sum_i \frac{1}{\alpha_i}}{\sum_i \frac{V_i'/U_i'}{\alpha_i}}}{\alpha_i}. \tag{48}$$

Comparing this solution to the one from the standard case $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$, the quantity $q_{QS,i}^{PT}$ agent i produces under prospect theory may be greater than, equal to, or less than the quantity $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$ agent i produces in the absence of prospect theory, depending on the relative values of agent i's parameters and those of others. In general, the sign of the difference in quantity $q_{QS,i}^{PT}$ under prospect theory and the quantity $q_{QS,i}$ in the standard case is given by the following expression:

$$\mathrm{sign}(q^{PT}_{QS,i} - q_{QS,i}) = \mathrm{sign}\left(1 - \frac{V'_i}{U'_i} \frac{\sum_i \frac{1}{\alpha_i}}{\sum_i \frac{V'_i/U'_i}{\alpha_i}}\right). \tag{49}$$

The second element in the last expression can be rewritten as:

$$\frac{\sum_j \frac{V'_i/U'_i}{\alpha_j}}{\sum_i \frac{V'_i/U'_i}{\alpha_i}}. \tag{50}$$

The sign of the difference in expression (49) depends on the magnitudes of the numerator and denominator in expression (50). The difference in the quantity $q^{PT}_{QS,i}$ under prospect theory and the quantity $q_{QS,i}$ in the standard case would be negative, zero, or positive if expression (50) is greater, equal, or smaller than one, respectively, which translates into the following expression being respectively greater, equal, or smaller than zero:

$$\sum_{j \neq i} \frac{1}{\alpha_j}\left(\frac{V'_i}{U'_i} - \frac{V'_j}{U'_j}\right). \tag{51}$$

From the last expression it can be inferred that if every individual shares the same constant marginal value on gains and losses, the final allocation under prospect theory is not different from the standard case. When the ratio of an individual $i's$ marginal values over losses and gains exceeds (is below) that of every other individual, the quantity of this individual would be smaller (greater) compared to the standard case. Larger risk seeking to avoid losses and risk aversion over gains tends to push this ratio up. The slopes also depend on the magnitudes of the losses and the gains. The larger the loss and the larger the gain, the smaller would be the slope of the corresponding function (i.e. V' and U') and vice versa.

It should be noted that subjects that overweight the probability of bad events more would have smaller V'. Thus, overweighting would tend to increase the individual quantity (i.e., by reducing V') while risk seeking to avoid losses would tend to decrease the individual quantity (i.e., by increasing V').

2.4.2 Some permits are left unused

If some permits are left unused in equilibrium, this means that for some agents i the individual permit constraint in equation (11) is non-binding, and therefore that the multiplier μ_i on their individual permit constraint is 0. For example, μ_i could be zero for some individual i if his perceived marginal damages e_i is sufficiently large. For an individual with $\mu_i = 0$, from equation (43) the equilibrium permit price must be $\tau = e_i \frac{V'_i}{U'_i}$. In fact, if more than one agent produces less than her final permit holdings, it must be the case that all these agents have the same $e_i \frac{V'_i}{U'_i}$. Also note that from equation (41), agents who keep permits unused (and therefore have $\mu_i = 0$) do not necessarily produce the same quantity as that under no policy. Adding up the N functions in (45) combined with the condition $\sum_i L_i > \sum_i q_i$ yields a larger permit price than that resulting when all the permits are used:

$$\tau > eN\frac{\sum_i \frac{1}{\alpha_i}}{\sum_i \frac{V_i'/U_i'}{\alpha_i}}. \tag{52}$$

Combining this last equation with $\tau = e_i \frac{V_i'}{U_i'}$, it can be shown that the necessary magnitude of $e_i \frac{V_i'}{U_i'}$ for total production to be smaller than the total number of permits is the following:

$$e_i \frac{V_i'}{U_i'} = eN\frac{\sum_i \frac{1}{\alpha_i}}{\sum_i \frac{V_i'/U_i'}{\alpha_i}}. \tag{53}$$

From equation (53) as the number of agents (N) and the externality (e) increase, prospect theory risk attitudes of an agent need to be stronger in order for them to result in destruction of permits.

2.4.3 Price control

Under the price control regime, the value function in the presence of prospect theory risk attitudes is given by:

$$W_{PS,i} = U_i(\pi_i(q_i)) + V_i(-e_i Q - t q_i). \tag{54}$$

First-order conditions yield the following individual quantities $q_{PS,i}^{PT}$ for each agent i under prospect theory and a price control:

$$q_{PS,i}^{PT} = \frac{A_i - (e_i + t)\frac{V_i'}{U_i'}}{\alpha_i}. \tag{55}$$

Whether this quantity differ from the quantity $q_{PS,i} = \frac{A_i - e - t}{\alpha_i}$ in the standard case depends on the magnitude by which perceived marginal damages e_i exceeds the expected marginal damage e, and on the relative slopes of the value function over the gains and losses.

On its own, overweighting of high damage events would increase perceived marginal damages e_i, and thus reduce the quantity produced under a price control. On its own, risk seeking to avoid losses tends to reduce production under a price control by increasing the slope of the value function in losses (V') at every point on the domain.

However, the combined effect of both overweighting bad events and risk seeking to avoid losses is less straightforward. As overweighting gets more severe, the slope of the value function in losses (V') will be smaller due to the convexity of the value function in the loss domain, thus pushing production upwards. As a consequence, the combined effect of both effects from prospect theory combined on the quantity produced under a price control is ambiguous.

2.5 Predicted effect of behavioral responses

Table 1 summarizes the predicted effect of behavioral responses on aggregate quantities (or emissions) and permit prices, relative to the standard case in the absence of behavioral responses, according to our theory model. In the case of tradable permits, the effects reported apply to both the case in which all permits are used and the case in which some permits are left unused.

Table 1: Possible behavioral responses under different hypotheses and their predicted impact on permit prices P and emissions Q

Hypothesis	Tax	Tradable Permits
1. Endowment effects	No predicted deviation	↑P
2. Fairness concerns	No predicted deviation	↑P
3. Prospect theory: Overweighting of high damage events	↓Q	No predicted deviation
4. Prospect theory: Risk seeking to avoid losses	↓Q	↓P
5. Prospect theory: Both effects combined	Ambiguous	Ambiguous

Under both endowment effects and fairness concerns, our theory predicts that the outcomes under a price instrument would not deviate from that under the standard theory, but that under a quantity instrument permit prices would be higher than they would be in the absence of behavioral responses. The predicted increases in permit prices for the first two hypotheses follow from equations (23) and (25) for endowment effects, and (33) and (36) for fairness concerns.

As reported in Table 1, the net effects of prospect theory on permit prices P and emissions Q are ambiguous. Prospect theory's S-shaped value function on gains and losses and overweighting of high damage events would respectively imply that: (a) bad states with assigned weights larger than their probability of occurrence would have no effect on permit prices P under a tradable permits policy, but reduce emissions Q under a tax regime; and (b) the convexity of the value function over losses that implies risk seeking to avoid losses would reduce permit prices P under a tradable permits policy, and reduce emissions Q under a tax regime.

However, when both overweighting of high damage events and risk seeking over losses are combined, the combined effect could be an increase in both permit prices P under a quantity instrument, and emissions Q under a tax instrument due to the potentially larger loss which entails a lower marginal disutility given the convexity of the value function over losses. The results for aggregate quantities under the tax instrument in the presence of overweighting of high damage events and risk seeking to avoid losses follow from the discussion in Section 2.4.3, while the result for permit prices is based on equations (47) and (52).

In addition, under quantity instruments, when behavioral responses are present, potential damages can be further reduced by individual actions such as buying more permits than are needed to cover their emissions, and then leaving the additional permits unused. However, as explained in our theory model above, for the latter case to occur it is necessary that at least one individual experiences very large endowment effects, fairness concerns, or prospect theory risk attitudes. Moreover, individuals need to regard themselves as capable of affecting the relevant outcomes.

3 Experimental Design

3.1 General design and procedures

The central hypothesis to be tested in this experiment is that the equivalence between quantity and price controls is not affected by uncertainty over marginal damages. Our experimental procedure is summarized in Table 2. To test our hypothesis, we exposed groups of individuals to different policies and marginal damage (MD) environments, and then compared the prices and quantities between groups. The policies imposed were a baseline scenario with no regulatory intervention (BS), a tax policy scenario (PS), and a tradable permits policy scenario (QS). In addition, some of the participants played games in which the marginal damage was uncertain.

Table 2: Summary of experimental design and procedures

Subjects	Ninety-six undergraduate students from the University of California. Average payment per subject was USD 15 USD, which included a USD 5 fee for showing up to the experiment. The rest of their earnings depended on their cumulative performance in the two games. Experimental subjects were only allowed to participate in one session.
Groups	Twelve independent 8-person groups.
Sessions	Seven 1-hour sessions, consisting of five 2-group sessions and two single-group sessions, conducted in a computer room at the University of California at Davis.
Marginal damage type	C: $e = 3$. Ub: $e_l = 0$ or $e_h = 6$ with 1/2 probability each. Ue: $e_l = 2$ or $e_h = 12$ with probabilities 9/10 and 1/10, respectively. The expected values of e under the two uncertainty treatments were equal to that from the certainty treatment.
Marginal benefit types	Marginal benefit schedules derived from linear functions $\pi_i = A_i - \alpha_i q_i$ where $i =$LO, ML, MH, and HI with respective parameters $A_i = (35, 30, 55, 50)$, and $\alpha_i = (10, 5, 10, 5)$. The functions were truncated at zero profits and production q_i was restricted to be a positive integer (see Table 3).
Treatments	Each treatment consisted of a policy treatment (BS, PS, or QS) combined with a marginal damage environment (C, Ub, or Ue). All groups started the experiment with BS followed by either PS or QS (six groups in each). Each group played only under one of the three marginal damage environments (four groups in each).
Stages	Policy treatments played in one of two orders: BS-PS or BS-QS. Both BS and PS consisted of a single 20-second production-decision stage followed by screening of results for 10 seconds. In the QS treatment, the production stage was preceded by a permit market (90 seconds) and the screening of results after the production-decision stage lasted 20 seconds. Every policy treatment consisted of 9 rounds including an initial trial round. Participants did not know in advance the total number of rounds in each game.

The experiment was programmed and conducted with the experimental software z-Tree (Fischbacher 2007). Experimental subjects received detailed and identical instructions that were read aloud by the experimenter at the beginning of each session and prior to each policy intervention (detailed instructions and screenshots from the participants' interface are available from the authors upon request). Experimental subjects anonymously interacted with other subjects within only one group during the whole experimental session through computer terminals.

Participants were endowed with experimental cash (M_i) every round that, where applicable, could be used to pay for units produced (q) under a price control PS, to buy permits (l) under a quantity control QS, or to keep for themselves. They also received a marginal benefit schedule listing the profits they would receive from the production of units of a fictitious good. Participants were given one of four types of marginal benefit schedules classified as low (LO), medium-low (ML), medium-high (MH), and high (H) marginal benefit types, respectively, with two individuals per group in each category.[12] The marginal benefit schedules were given by $\pi_i = A_i - \alpha_i q_i$ for $i =$LO, ML, MH, and HI, with respective parameters $A_i = (35, 30, 55, 50)$, and $\alpha_i = (10, 5, 10, 5)$. The functions were truncated at zero profits and production q_i was restricted to be a positive integer. Subjects knew only their own marginal benefit schedules, which remained constant during the 9 rounds of each of the policy treatments.

Production by each member of the group created negative impacts on all members of the group. In order to simplify the decision-making, the damage (e) was specified as a constant for each unit produced in the group (the actual value of that constant being revealed either before or after the production decision was made depending on the marginal damage environment).

Table 3 shows, for each marginal benefit type, the marginal benefit schedule, the permit and experimental cash endowment, and the quantity predicted by the theory model for each policy scenario. Initial endowment, marginal benefits, deductions, and prices, were all defined in terms of tokens, the experimental currency. Tokens had a corresponding value in dollars announced prior to the beginning of the experiment which was used to convert experimental earnings to their dollar value.

As described in Table 2, groups played under different environments regarding the damage function, which we refer to as different marginal damage (MD) environments or treatments. The damage ($e = 3$) was known with certainty in four of the groups (certainty treatments, C). In eight other groups the damages were uncertain, with a state (e_l) being less averse than the other (e_h), but with the expected value of e under the uncertainty treatments equal to that from the certainty treatment. In four of these eight groups the two states would occur with equal probabilities (balanced uncertainty treatment, Ub), while in the other four the two states were assigned extreme probabilities (unbalanced uncertainty treatment, Ue).

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[12] Inducing valuations for fictitious goods in this manner is common practice in economic experiments and has been formally justified in Smith (1976).

All twelve groups were first exposed to the baseline scenario (BS), after which half of them played the price control scenario (PS) and the other half played the quantity control scenario (QS). Each policy treatment consisted of eight rounds (plus an initial trial round) in which individuals chose the number of units of the good they wanted to produce.

Under the quantity control QS, the group quota was distributed as personal tradable permits among individuals. Permits allowed participants to produce units of the good (q) which delivered cash gains as described in Table 3. Although the distribution of permits was not equitable, the symmetric partition of the group into high and low marginal benefit minimized the possibility of agents exerting market power in non-monopolized double-auction markets.

In the permit-trading stage of each round of the QS treatments, individuals were allowed to sell and buy permits under a continuous double auction mechanism prior to entering the production decision stage. In this experiment, current valid bids (asks) were shown ranked from highest to lowest (lowest to highest) at every point in time, and trade occurred when a buyer (seller) accepted the current ask (bid).[13] Once an agreement was reached, the new highest bid and lowest ask were shown at the top of their respective lists. In the production decision stage, individuals could only produce a quantity of the good that was less than or equal to the number of permits they hold, which precluded the development of strategies involving non-compliance (Murphy and Stranlund 2007).

Table 3: Marginal benefit (MB) schedules, endowments, and predicted quantities

	LO	ML	MH	HI
Marginal benefit from producing:				
1 unit	25	25	45	45
2 units	15	20	35	40
3 units	5	15	25	35
4 units	0	10	15	30
5 units	0	5	5	25
6 units	0	0	0	20
7 units	0	0	0	15
8 units	0	0	0	10
9 units	0	0	0	5
10 units	0	0	0	0
Theoretical prediction for q_{BS}	3	5	5	9
Theoretical prediction for $q_{PS} = q_{QS}$	1	1	3	5
Token endowment (BS and PS)	160	140	90	10
Token endowment (QS)	120	160	150	180
Permit endowment (QS)	4	3	2	1

The aggregate demand for units is derived from adding the inverse marginal benefit schedules of the eight subjects in each market.[14] Setting the aggregate demand for units equal to the aggregate marginal damage of 24 (3 tokens

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[13] This version of the continuous double auction institution that incorporates the so-called *rank queue* facilitates convergence towards equilibrium (Smith and Williams 1983). See Friedman (1991) for an updated overview and history of this trading mechanism used for example in the New York Stock Exchange. The layout of the permit market stage of this experiment builds upon that used by Zetland (2008, Ch.7) in the context of water rights in southern California.

[14] Each of the experimental markets were composed of 8 subjects acting as firms. Muller and Mestelman (1998) note that between 8 and 12 individuals are typically recruited for each experimental permit market, a convention followed by the studies included in Issac and Holt (1999).

times 8 subjects), the social optimum is reached at 20 units produced in the group (44 units being the competitive equilibrium in the absence of correcting policies). This optimal quantity could be achieved by imposing a limit on the total production by the group equal to 20, or by charging a tax between 18 and 21. As seen in the theory model, the optimal tax is lower than the aggregate marginal damage (24) since subjects already account for the marginal damage their own production inflicts on themselves. The tax was set at $21 which is equal to the sum of individual damages on the rest of the group per unit produced. From Table 3 one can verify that such tax level would yield the respective theoretical prediction q_{PS} for each subject when using the respective marginal benefit schedule and $e = 3$. The policy scenarios are further described as follows:

- *No policy (BS):* This is the baseline scenario with no policy to reduce the externality. There is no cost for producing units of the good and the individual before-damage earnings in each round are the sum of the unit profits. Tokens are then deducted from each subject's account based on the total number of units produced in the group (Q, which is the sum of what the 8 participants in the subject's group decided to produce). The final earnings in each 30-second round is given by equation (2) plus the initial endowment (M_i). After each of the nine rounds, participants could observe for ten seconds what Q was and how their earnings were calculated. As it was mentioned before, subjects were allowed only to produce units in whole numbers. The optimal individual quantity $q_{BS,i}$ predicted by theory is given by equation (4).

- *Price control scenario (PS):* A fee ($t = 21$) for each unit produced of the fictitious good was announced and each individual's earnings are reduced by tq_i and augmented by M_i compared to equation (2). The rest of characteristics from BS remained equal. The optimal individual quantity $q_{PS,i}$ predicted by theory is given by equation (6).

- *Quantity control scenario (QS):* As in BS, there is no price to be paid per unit produced of the fictitious good. However, a limit on the total amount of units that can be produced ($Q = 20$) was introduced. This quantity is based on the aggregate marginal benefit function and corresponds to the amount that would be produced if t was the fee charged for producing units. Permits that give the right to produce units were distributed to every member of each group; the allocation of permits is given in Table 3. Subjects were allowed to make bids to buy a permit from others and make offers to sell a permit to others, and/or accept offers/bids from others. This is translated into the constraint in equation (11) which allows in principle for the possibility that individuals do not use all the permits they hold.

  The permit market was opened for 90 seconds prior to the production decision stage each round.[15] After the permit market closed each round, individuals had 20 seconds to decide how many units of the good they wanted

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[15] Plott and Gray (1990) suggest that a continuous double auction mechanism requires eight seconds per equilibrium transaction. From Table 3, each LO subject is predicted to sell three units, and each ML subject is predicted to sell two, for a predicted total of ten equilibrium transactions, or 80 seconds.

to produce just as in BS and PS. The optimal individual quantity $q_{QS,i}$ predicted by theory is given by equation (15) , and the per round earnings are given by equation (10) plus M_i.

As summarized in Table 1, we predict that behavioral responses from fairness concerns and endowment effects would have no effect on aggregate emissions Q under a price instrument (tax) but would increase permit prices P under a quantity instrument (tradable permits), both when marginal damages are certain and when marginal damages are uncertain. Furthermore, the effect of both aspects of prospect theory combined on permit prices P and aggregate emissions Q are ambiguous.[16]

Allowing for heterogeneity in the individual marginal benefit and endowments in our experiment enables us to further distinguish among the different behavioral responses. Table 4 summarizes the results from our theoretical model for the effects of behavioral responses on individual quantities in our experiment, relative to the individual quantities in standard case in the absence of behavioral responses.

From our experimental design, endowment effects and fairness concerns have opposite impacts on individual quantities under a quantity control: while endowment effects would increase production by LO and ML subjects and decrease production by MH and HI subjects, fairness concerns would decrease production by LO and ML subjects and increase production by MH and HI subjects. As seen in equation (24) of our theory model, individuals with a relatively larger endowment effect will produce relatively more than individuals with a smaller or no endowment effect. Likewise, as seen in equation (34) of our theory model, individuals with relatively higher fairness concerns will produce relatively more than individuals with lower or no fairness concerns. In our design, LO and ML subjects have a larger permit endowment than MH and HI subjects, and thus are more likely to exhibit endowment effects but less likely to exhibit fairness concerns.

Table 4: Possible behavioral responses under different hypotheses and their predicted impact on individual emissions q_i

	Tax		Tradable Permits	
Hypothesis	LO&ML	MH&HI	LO&ML	MH&HI
1. Endowment effects	NA	NA	↑	↓
2. Fairness concerns	NA	NA	↓	↑
3. Prospect theory: Overweighting of high damage events	smaller ↓	↓	NA	NA
4. Prospect theory: Risk seeking to avoid losses	↓	larger ↓	↑	↓
5. Prospect theory: Both effects combined	More likely to ↑	Ambiguous	Ambiguous	Ambiguous

The predicted impacts on individual quantities under a tax policy from the model incorporating prospect theory follows from equation (55) of the theory model.

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[16] Yet another behavioral response not considered in this study is the theory of bounded rationality which implies that subjects do not perform all the calculations necessary to achieve rational outcomes and instead apply heuristic rules in their decisions. Lin and Muehlegger (2013) examine one such ’heuristic strategy’ and its resulting equilibrium. In a tradable permit system, bounded rationality could result in non-optimal exchanges and, under uncertainty, in miscalculations of expected values (Kahneman 2003). In our study, we minimize game misconceptions such as those analyzed in Plott and Zeiler (2005) through a careful revision of the instructions.

On its own, overweighting of high damage events under a tax regime may have less of a negative effect on the production of individuals with low marginal benefits, who have lower gains and therefore larger marginal utility in gains.

On its own, risk seeking to avoid losses under a tax regime may have more of a negative effect on the production of individuals with higher marginal benefits since the marginal utility of gains decreases as the gain increases, increasing the ratio of marginal values over losses and gains.

Although the combined effect of both overweighting of high damage events and risk seeking to avoid losses under a tax regime is ambiguous, it is more likely to have a positive effect on the production of individuals with low marginal benefits due to their larger marginal utility in gains.

In the case of tradable permits, from equation (48) overweighting of high damage events alone does not have an impact on individual quantities. However risk seeking to avoid losses tends to increase production from subjects with low marginal benefits at the expense of reduced production from subjects with high marginal benefits. The combination of both effects results in ambiguous predictions for the individual quantities.

4 Results

4.1 Units produced

Table 5 shows the means and standard deviations of the total units produced by each group per round for each of the different treatment combinations. As expected, the total number of units produced is larger in the absence of any regulation, approaching the competitive equilibrium of 44 units. Interestingly, for both the price control (PS) scenario and the quantity control (QS) scenario, the total number of units produced seem to be larger under the balanced uncertain marginal damage environment (Ub) than under either the certain marginal damage environment (C) or the unbalanced uncertain marginal damage environment (Ue). The numbers in the table also suggest that the difference between the quantity under price control (PS) and quantity control (QS) interventions is smaller when the marginal damage is known with certainty, particularly in later rounds.

Figure 2 presents graphs of the mean and standard deviation of the total number of units as a function of treatment round for each of the different treatment combinations. The solid blue lines indicate the mean and the dotted blue lines indicate one standard deviation above and below the mean. The red lines indicate the theoretical prediction for total number of units for each policy treatment.

Table 6 presents the results from panel regressions of the total number of units produced by marginal damage environment on a dummy for the quantity policy treatment (*QS*), a dummy for the last 4 rounds (*last*), and an interaction between the dummy for the quantity policy treatment and the dummy for the last 4 rounds. The regressions use group observations from all rounds (trial round excluded) of the policy treatments, yielding four groups with eight periods each. We use a population-averaged linear panel model with a first-order autocorrelation error structure.

Using the regression results from Table 6, we conduct hypothesis tests comparing the total number of units produced by policy treatment with their respective theoretical prediction and also with each other. The results are reported in Table 7. The first two rows of Table 7 present the difference between the observed total number of units produced and the theoretical prediction (20 units). The last row in Table 7 shows the difference between the observed outcomes under the two policies (the treatment effect).

The following four results can be gleaned from Table 5, Table 7, and Figure 2.

Result 1: In the no policy scenario (BS), the total number of units produced is smaller than predicted under each of the three marginal damage environments.
Support: Table 5 and Figure 2 show that the total number units produced falls short of the theoretical prediction (44) in all rounds of the experiment.

Result 2: In the price control scenario (PS), the total number of units produced is larger than predicted under the balanced uncertain marginal damage environment (Ub) and equal to the theoretical prediction under the certain marginal damage environment (C) and the unbalanced uncertain marginal damage environment (Ue).
Support: Table 5 and Figure 2 suggest this result, which is confirmed by the deviations $Q_{PS} - 20$ reported in the first row in Table 7 which are positive and statistically significant for Ub in both early and later rounds, but are not significant for either C or Ue.

The result that the number of units produced is equal to the theoretical prediction in the price control scenario (PS) under the certain marginal damage environment (C) is consistent with the predicted behavioral responses in Table 1, which predicts no deviation in number of units produced under a tax system with certain marginal damages. Thus, as predicted, there are no behavioral responses resulting from an endowment effect, fairness concerns, or prospect theory in the price control scenario under the certain marginal damage environment.

As summarized in Table 1, when damages are uncertain, neither the endowment effect nor fairness concerns would affect the number of units produced under a price control scenario. However, the combined effect of both aspects of prospect theory on emissions Q when damages are uncertain are ambiguous.

The result that the number of units produced is larger than the theoretical prediction in the price control scenario (PS) under the balanced uncertain marginal damage environment (Ub) suggests that the combined effect on production of overweighting of high damage events and risk seeking to avoid losses may be positive. Under the unbalanced uncertain marginal damage environment (Ue), the result indicates that the number of units produced is equal to the theoretical prediction in the price control scenario (PS), thus suggesting that the combined effect of both aspects of prospect theory is zero or that neither overweighting of high damage events nor risk seeking to avoid losses are present.

Result 3: In the quantity control scenario (QS), the total number of units produced is equal to the theoretical predictions under each of the three marginal damage environments.
Support: Table 5 and Figure 2 suggest this result which is confirmed by the non-statistically significant deviations $Q_{QS} - 20$ reported in the second row in Table 7.

As in a price control scenario, a potential consequence of behaviors predicted by prospect theory under a quantity control is a positive effect on production. However, due to the limit on production imposed by the cap, group overproduction cannot occur. As reported in result 8, deviations from the theoretical prediction are instead reflected in permit prices that absorb the impact of a shift of the demand function for permits.

Result 4: The total number of units produced is larger under the price control scenario (PS) compared to the quantity control scenario (QS) in early rounds under the balanced uncertain marginal damage environment (Ub) and in later rounds under the unbalanced uncertain marginal damage environment (Ue). In all other cases, the difference is not statistically significant.
Support: Table 5 and Figure 2 suggest this result, which is confirmed by the differences $Q_{PS} - Q_{QS}$ reported in the last row in Table 7 which are positive and statistically significant for early rounds of Ub and later rounds of Ue, but are not significant for any other case.

Thus, in contrast to the standard economic theory, we find that price and quantity controls lead to different outcomes when marginal damages are uncertain, which provides evidence for the presence of behavioral responses.

Table 5: Mean and standard deviation of total units produced by treatment combination

	BS		PS		QS	
	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8
MD Environment						
Certainty (C)	28.44	35.19	21.13	19.75	18.38	19.38
	(6.98)	(6.86)	(6.77)	(4.53)	(1.19)	(0.74)
Uncertainty-b (Ub)	33.75	39.25	27.00	23.25	18.88	20.00
	(6.28)	(7.59)	(6.57)	(2.12)	(1.55)	(0.00)
Uncertainty-e (Ue)	31.69	34.38	20.88	22.88	18.13	17.88
	(8.18)	(7.06)	(6.01)	(5.08)	(1.81)	(1.96)

Note: Standard deviations in parentheses.

We also conduct an empirical analysis that makes use of the variation across individual observations under the two policy interventions. In particular, we run regressions of the units produced by each individual subject in each round

Table 6: AR1 population-averaged panel regressions of total number of units produced

	Dependent variable: Total number of units produced		
	Certainty	Uncertainty-b	Uncertainty-e
QS	-3.012	-8.363 ***	-2.996
	(1.666)	(1.923)	(2.534)
Last	-1.775	-3.956 *	1.888
	(1.696)	(1.848)	(2.273)
QS*Last	2.855	5.085	-2.588
	(2.398)	(2.614)	(3.215)
Constant	21.342 ***	27.225 ***	21.419 ***
	(1.178)	(1.36)	(1.792)
Observations	32	32	32
Groups	8	8	8

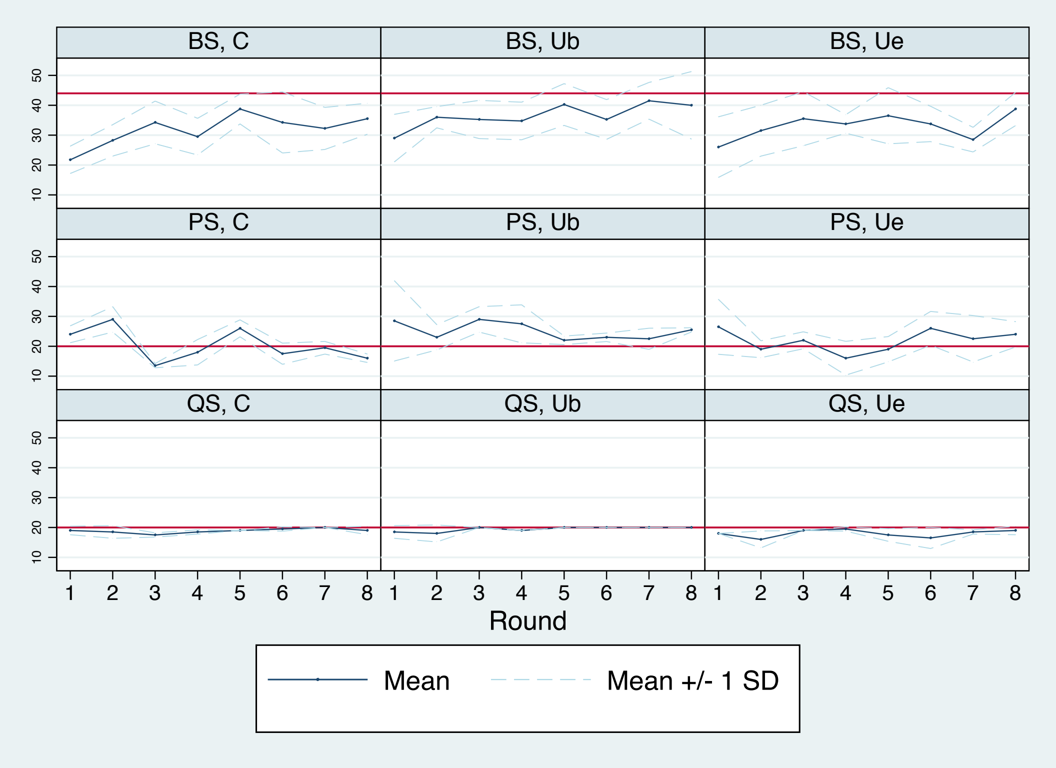
Notes: Standard errors in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Table 7: Hypothesis tests based on regression estimates for total number of units produced

	Certainty		Uncertainty-b		Uncertainty-e	
Difference	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8
$Q_{PS} - 20$	1.34	-0.43	7.23***	3.27*	1.42	3.31
$Q_{QS} - 20$	-1.67	-0.59	-1.14	-0.01	-1.58	-2.28
$Q_{PS} - Q_{QS}$	3.01	0.16	8.36***	3.28	3.00	5.59*

Notes: The theoretical prediction for units produced under both the quantity control scenario and the price control scenario is 20 units. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Figure 2: Total number of units produced per round by treatment combination



Notes: Each treatment consists of a policy treatment (BS, PS, or QS) combined with a marginal damage environment (C, Ub, or Ue). The solid blue lines indicate the mean and the dotted blue lines indicate one standard deviation above and below the mean. The red lines indicate the theoretical prediction for total number of units for each policy treatment.

in the price control (PS) and quantity control (QS) treatments on a dummy for the quantity policy treatment (*QS*), a dummy for the last 4 rounds (*last*), and an interaction between the dummy for the quantity policy treatment and the dummy for the last 4 rounds. We use a population-averaged linear panel model with a first-order autocorrelation error structure. The regressions are marginal benefit type specific and are reported in three separate tables, one for each marginal damage environment. These are Tables 8, 9, and 10, respectively. Each regression represents a subject type-treatment combination and therefore uses observations from eight subjects (two of each type in each of the four groups) over eight periods each, for a total of 64 observations. Table 11 shows the results of hypothesis tests for the differences between actual units produced and the theoretical prediction of units produced (1, 1, 3, and 5 for LO, ML, MH, and HI respectively) as well as for the difference between the observed outcomes under the two policies (the treatment effect) resulting from these regressions.

The following results 5, 6, and 7 for individual units produced can be gleaned from Tables 8, 9, 10, and 11, and complement the previous analysis of aggregate units produced.

Result 5: Under the certain marginal damage environment (C):

(i) The quantity of individual units produced in the price control scenario (PS) is higher than the theoretical prediction for the medium-low marginal benefit subjects (ML) in late rounds but the difference between individual units produced and the theoretical prediction is not statistically significant for any other marginal benefit group in late rounds.

(ii) The quantity of individual units produced in the quantity control scenario (QS) is higher than the theoretical prediction for the low marginal benefit (LO) and medium-low marginal benefit (ML) subjects and lower than the theoretical prediction for the medium-high marginal benefit (MH) and high marginal benefit (HI) subjects.

(iii) The difference between the quantity of individual units produced in the price control scenario (PS) and the quantity of individual units produced in the quantity control scenario (QS) is negative for low marginal benefit (LO) and positive for medium-high marginal benefit (MH) subjects. In all other cases, the difference between the quantity of individual units produced under the price control scenario (PS) and that under the quantity control scenario (QS) is not statistically significant.

Support: (i), (ii), and (iii) are from the first, second, and third rows, respectively of each panel in Table 11 for the certain marginal damage environment (C).

Although result 5 shows that there are differences in individual units produced between the price control (PS) and quantity control (QS) treatments under the certain marginal damage environment (C), result 4 shows that these differences are not statistically significant at the aggregate level. This suggests that, at the aggregate level, the negative difference in individual units produced between the price control (PS) and quantity control (QS) treatments for low marginal benefit (LO) subjects may cancel the positive difference in individual units produced between the price control (PS) and quantity control (QS) treatments for the medium-high marginal benefit (MH) subjects.

Under the certain marginal damage environment (C), it is important to note that only the medium-low marginal benefit subjects (ML) deviate from the theoretical prediction under the price control scenario (PS), but all marginal benefit subjects deviate under the quantity control scenario (QS). The result provides possible evidence for an endowment effect as predicted in Table 4. Subjects with lower marginal benefits from producing are those with a larger permit endowment and may be more reluctant to sell permits, leading to a positive difference between individual units produced under the price and quantity control for MH subjects and negative difference for LO subjects.

Result 6: Under the balanced uncertain marginal damage environment (Ub):

(i) The quantity of individual units produced in the price control scenario (PS) is higher than the theoretical prediction for the low marginal benefit subjects (LO) in early rounds but the difference between the quantity of individual units produced and the theoretical prediction is not statistically significant for any marginal benefit group in late rounds.

(ii) The quantity of individual units produced in the quantity control scenario (QS) is higher than the theoretical prediction for the medium-low marginal benefit (ML) subjects and lower than the theoretical prediction for the high marginal benefit (HI) subjects in late rounds. The quantity of individual units produced is also lower than predicted for the medium-high marginal benefit (MH) subjects in early rounds.

(iii) The difference between the quantity of individual units produced in the price control scenario (PS) and the quantity of individual units produced under the quantity control scenario (QS) is positive for high marginal benefit (HI) subjects. In all other cases, the difference between the quantity of individual units produced under the price control scenario (PS) and that under the quantity control scenario (QS) is not statistically significant.

Support: (i), (ii), and (iii) are from the first, second, and third rows, respectively, of each panel in Table 11 for the balanced uncertain marginal damage environment (Ub).

Under the balanced uncertain marginal damage environment (Ub), combining result 4 for aggregate production and result 6 for individual production suggests that high marginal benefit (HI) subjects drive the positive difference in aggregate units produced between the price control (PS) and the quantity control (QS) in early rounds, whereas the large (although not statistically significant) negative difference in individual units produced between the price control (PS) and the quantity control (QS) in the medium-low marginal benefit (ML) subjects in later rounds likely counterbalances the high marginal benefit (HI) subjects' positive difference, causing the difference in units produced between the price control (PS) and the quantity control (QS) not to be statistically significant at the aggregate level.

The result that the quantity of individual units produced under the quantity control scenario under the balanced uncertain marginal damage environment (Ub) is higher than the theoretical prediction for ML subjects but lower than the theoretical prediction for HI subjects may be indicative of the presence of an endowment effect as reported in Table 4. Subjects with lower marginal benefits from producing are those with a larger permit endowment and may be more reluctant to sell permits, leading to a positive difference between the individual units produced under the price and quantity control for HI subjects. Result 6 provides possible evidence for prospect theory as well, since risk seeking to avoid losses and risk aversion in gains may be respectively large and small for ML subjects, and the opposite for HI subjects.

Result 7: Under the unbalanced uncertain marginal damage environment (Ue):

(i) The quantity of individual units produced in the price control scenario (PS) is higher than the theoretical prediction for the low marginal benefit subjects (LO) but the difference between the quantity of individual units produced and the theoretical prediction is not statistically significant for any other marginal benefit group.

(ii) The quantity of individual units produced in the quantity control scenario (QS) is higher than the theoretical prediction for the low marginal benefit (LO) and medium-low marginal benefit (ML) subjects and lower than the theoretical prediction for the high marginal benefit (HI) subjects.

(iii) The difference between the quantity of individual units produced in the price control scenario (PS) and the quantity of individual units produced in the quantity control scenario (QS) is positive for high marginal benefit (HI) subjects. In all other cases, the difference between the quantity of individual units produced under the price control scenario (PS) and that under the quantity control scenario (QS) is not statistically significant.

Support: (i), (ii), and (iii) are from the first, second, and third rows, respectively, of each panel in Table 11 for the unbalanced uncertain marginal damage environment (Ue).

Result 7 for the unbalanced uncertain marginal damage environment (Ue) shows that the large positive difference between the quantity of individual units produced in the price control scenario (PS) and the quantity of individual units produced in the quantity control scenario (QS) in the high marginal benefit (HI) subjects drive the statistically significant positive difference in the total number of units produced between the price control and quantity control scenarios in later rounds from result 4.

The result that the quantity of individual units produced under the quantity control scenario under the unbalanced uncertain marginal damage environment (Ue) is higher than the theoretical prediction for LO and ML subjects but lower than the theoretical prediction for HI subjects may be indicative of the presence of an endowment effect. Result 7 provides possible evidence for prospect theory as well, since risk seeking to avoid losses and risk aversion in gains may be respectively large and small for LO and ML subjects, and the opposite for HI subjects.

4.2 Prices

Table 12 shows average permit prices and permit sales for the last four rounds. Both appear close to their theoretical prediction of 24 and 10, respectively, in every case except for sales under the balanced uncertain marginal damage environment (Ub).

We analyze the impact of the marginal damage environment on the permit market outcomes using data on the prices at which each permit was traded. More specifically, we perform a regression analysis suitable for long panels that allows a more flexible error structure. We regress the natural log of the permit price on the marginal damage environment, the round, and characteristics of the buyer and seller, including marginal benefit type, age, gender, years of

Table 8: AR1 population-averaged panel regressions of individual units produced under Certainty (C)

	Dependent variable: Individual units produced			
Explanatory variables	LO	ML	MH	HI
QS	0.994 *	0.792	-1.388 *	-1.378
	(0.450)	(0.802)	(0.556)	(0.928)
Last	0.050	0.504	0.123	0.133
	(0.346)	(0.593)	(0.507)	(0.899)
QS*Last	0.124	-0.504	0.254	0.170
	(0.489)	(0.840)	(0.717)	(1.272)
Constant	1.135 ***	1.795 **	2.809 ***	4.320 ***
	(0.318)	(0.567)	(0.393)	(0.656)
Observations	64	64	64	64
Groups	8	8	8	8

Notes: Standard errors are in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Table 9: AR1 population-averaged panel regressions of individual units produced under Uncertainty-b (Ub)

	Dependent variable: Individual units produced			
Explanatory variables	LO	ML	MH	HI
QS	-1.723	0.523	-0.432	-2.875 **
	(1.137)	(0.908)	(0.517)	(0.939)
Last	-1.368	-0.407	0.547	-0.626
	(1.007)	(0.567)	(0.511)	(0.799)
QS*Last	1.250	0.939	0.469	0.149
	(1.424)	(0.802)	(0.722)	(1.130)
Constant	3.618 ***	1.615 *	2.690 ***	5.736 ***
	(0.804)	(0.642)	(0.366)	(0.664)
Observations	64	64	64	64
Groups	8	8	8	8

Notes: Standard errors are in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Table 10: AR1 population-averaged panel regressions of individual units produced under Uncertainty-e (Ue)

	Dependent variable: Individual units produced			
Explanatory variables	LO	ML	MH	HI
QS	0.154	0.262	0.036	-1.951 *
	(0.522)	(0.474)	(0.664)	(0.944)
Last	-0.109	-0.148	0.167	0.815
	(0.486)	(0.451)	(0.579)	(0.726)
QS*Last	-0.276	0.553	-0.848	-0.896
	(0.688)	(0.638)	(0.818)	(1.026)
Constant	2.247 ***	1.459 ***	2.860 ***	4.287 ***
	(0.369)	(0.335)	(0.470)	(0.668)
Observations	64	64	64	64
Groups	8	8	8	8

Notes: Standard errors are in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Table 11: Hypothesis tests based on regression estimates for individual units produced

		Certainty		Uncertainty-b		Uncertainty-e	
Subject type	Difference	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8
LO	$q_{PS}-1$	0.13	0.18	2.62***	1.25	1.25***	1.14**
	$q_{QS}-1$	1.13***	1.30***	0.89	0.78	1.40***	1.02**
	$q_{PS}-q_{QS}$	-0.99*	-1.12*	1.72	0.47	-0.15	0.12
ML	$q_{PS}-1$	0.80	1.30*	0.62	0.21	0.46	0.31
	$q_{QS}-1$	1.59**	1.59**	1.14	1.67**	0.72*	1.13***
	$q_{PS}-q_{QS}$	-0.79	-0.29	-0.52	-1.46	-0.26	-0.82
MH	$q_{PS}-3$	-0.19	-0.07	-0.30	0.24	-0.14	0.03
	$q_{QS}-3$	-1.58***	-1.20**	-0.74*	0.27	-0.10	-0.78
	$q_{PS}-q_{QS}$	1.39*	1.13*	0.43	-0.04	-0.04	0.81
HI	$q_{PS}-5$	-0.68	-0.81	0.74	0.11	-0.71	0.10
	$q_{QS}-5$	-2.06**	-2.02**	-2.14***	-2.62***	-2.66***	-2.75***
	$q_{PS}-q_{QS}$	1.38	1.21	2.87**	2.73**	1.95*	2.85**

Notes: The theoretical predictions of units produced are 1, 1, 3, and 5 for LO, ML, MH, and HI respectively. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Table 12: Mean and standard deviation of price and permit sales by marginal damage environment

	Price		Permit sales	
MD environment	Rounds 1-4	Rounds 5-8	Rounds 1-4	Rounds 5-8
Certainty (C)	29.62	23.61	9.38	13.00
	(10.28)	(9.89)	(5.71)	(8.54)
Uncertainty-b (Ub)	22.20	23.55	15.25	13.88
	(4.97)	(1.78)	(4.20)	(4.32)
Uncertainty-e (Ue)	24.63	26.21	11.5	8.38
	(5.88)	(7.62)	(4.24)	(2.67)

college, major, experience in experiments, and two variables that measure subjects' social and environmental concern. The characteristics of both sellers and buyers for each transaction were included. We use a generalized least squares model with a group-specific first-order autocorrelation error structure. The time variable in the permit price regressions is given by the order in which trades were completed within a group during the whole treatment (i.e., the time variable is not reset every round). Table 13 only reports the estimated coefficients for the marginal damage environment (the certainty treatment being the baseline case) and the round. Result 8 below summarizes our findings based on tests of the equality of the coefficients for marginal damage environment (C, Ub, Ue).

Result 8: Permit prices are higher under uncertain marginal damage environments.

Support: Hypothesis tests for differences in prices under different marginal damage environments based on the results

Table 13: Permit prices: Generalized least squares with group-specific AR1 error

	Dependent variable: Natural log of permit price	
Explanatory variables	Rounds 1-4	Rounds 5-8
Ub	-0.064	0.387***
	(0.130)	(0.076)
Ue	-0.006	0.605***
	(0.129)	(0.094)
Round	-0.019	0.038*
	(0.024)	(0.015)
Constant	3.467***	2.408***
	(0.248)	(0.183)
Plus other variables controlling for characteristics of sellers and buyers[b]		
Observations	289	282
Groups	6	6

Notes: Standard errors are in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

[b] These variables are marginal benefit type, age, gender, years of college, major, experience in experiments, and two variables that measure subjects' social and environmental concern. The characteristics of both sellers and buyers for each transaction were included.

presented in Table 13 show that these prices are significantly different from each other. In later rounds, prices are highest under the unbalanced uncertain marginal damage environment (Ue) and lowest under the certain marginal damage environment (C).

According to our theory model, under uncertain marginal damage environments, the overweighting of high damage events combined with risk seeking to avoid losses from prospect theory would have a positive effect on the permit price, while risk seeking to avoid losses from prospect theory alone should have a negative effect on the permit price, as seen in Table 1.

The results suggest that under the balanced uncertain marginal damage environment (Ub), the positive effect of combining overweighting of high damage events and risk seeking to avoid losses prevails, yielding a higher price with respect to that under the certain marginal damage environment (C).

Under the unbalanced uncertain marginal damage environment (Ue), there may be a further positive effect on prices due to a higher reluctance to sell from low marginal benefit (LO) and medium-low marginal benefit (ML) subjects, who may be more prone to overweight the probability of the bad state given the small potential gains from individual production and the relatively large potential losses from group production.

As shown in section 2.3, the presence of fairness concerns increases the shadow price of both a permit bought and a permit sold by the same amount. In contrast, in the presence of endowment effects, the shadow price of a permit sold is higher than that of a permit bought (the difference being δ_i). In Table 14, we present results from random effects Tobit regressions in which the dependent variable is the bid-ask spread for each subject. The bid-ask spread is the price asked to sell a permit minus the bid price to buy one. A positive spread would suggest the presence of endowment effects, while no spread rules out endowment effects. The number of observations is limited by the number of subjects that offered both to buy and sell permits in a single round (about 20% of the total number of subjects in each regression). Our panel is unbalanced because not all of these subjects offered to buy and sell in all rounds.

Table 14: Bid-ask spread: Random effects Tobit

	Dependent variable: Individual bid-ask spread		
Explanatory variables	Certainty	Uncertainty-b	Uncertainty-e
ML	3.791	1.019	6.137
	(5.161)	(2.457)	(5.405)
MH	0.343	-2.417	-0.705
	(5.659)	(2.621)	(5.432)
HI	0.553	-2.373	6.433
	(4.938)	(2.689)	(5.329)
Round	-1.011 **	-0.793 ***	-0.303
	(0.392)	(0.212)	(0.296)
Constant	13.006 ***	11.183 ***	8.867 *
	(3.856)	(2.075)	(4.059)
Observations	49	75	66
Groups	19	22	23

Notes: Standard errors are in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

Result 9: The bid-ask spread is positive under all marginal damage environments but declines over time under the certain marginal damage environment (C) and the balanced uncertain marginal damage environment (Ub).

Support: Coefficient estimates from Table 14 show a statistically significant positive coefficient for the constant term and a negative coefficient for *Round* under C and Ub.

The positive bid-ask spread suggests the presence of endowment effects. The declining spread under the certain marginal damage environment (C) and the balanced uncertain marginal damage environment (Ub) suggests the presence of a learning effect or a declining endowment effect consistent with findings in Baldurson and Sturluson (2011), Kujal and Smith (2008b), List (2004) and Plott and Zeiler (2005). The bid-ask spread does not decline in groups that were exposed to the unbalanced uncertain marginal damage environment (Ue).

5 Conclusions

Standard economic theory predicts that, when regulating environmental externalities, quantity instruments such as tradable permits and price instruments such as taxes will produce identical outcomes when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator, even when marginal damages are uncertain from the perspective of the regulator. Even though uncertainty over marginal damages may not matter in theory, it may be important in practice since such uncertainty may lead to behavioral responses on the part of market participants that cause price and quantity instruments to lead to different outcomes. These behavioral responses include endowment effects, fairness concerns, and attitudes towards risk deviating from the expected utility framework.

In this paper, we develop a theory model to compare the equilibria under price and quantity instruments with and without behavioral responses. We then conduct a laboratory experiment to evaluate the equivalence of price and quantity instruments when marginal damages are uncertain but marginal abatement costs are known with certainty. Our experiment resembles a common pool resource situation in which regulated agents suffer the damages from the externality generation. Examples of this type of situation are fisheries, groundwater exploitation, road congestion, air pollution, and climate change.

Greenhouse gas emissions that may cause global climate change have marginal damages that are uncertain and are being regulated through different mechanisms, including taxes and emission permits. Carbon taxes are already in place in several countries. Examples of tradable permit systems in climate change policy that resemble our model include: (1) permit trading among European countries for emissions not covered under the European Union Emissions Trading Scheme and (2) personal carbon trading. The former is an ongoing enforceable policy, while the latter is a proposal originated in the United Kingdom that has been explored in recently published studies.

There are several interesting results from our experiment. In terms of aggregate emissions, the quantity-equivalence of quantity and price instruments cannot be rejected when marginal damages are known with certainty. However, when marginal damages are uncertain, the implementation of an optimal tax leads to more emissions compared to those achieved with a tradable permit system capped at the optimal amount of emissions. This latter finding could be the result of overweighting of high damage events combined with risk seeking to avoid losses, whose combined effect pushes production upwards. Although such motivation is present regardless of the policy in place, under a tradable permits policy the aggregate limit can not be exceeded, whereas under a tax policy regulated agents can produce as much as they wish provided the tax is paid. As a consequence, prospect theory risk attitudes cause the emissions resulting from a quantity control to differ from those resulting from a price control.

Our findings based on aggregate outcomes are complemented by our analysis of individual decisions, which enables us to further distinguish among the different behavioral responses. When marginal damages are certain, aggregate production under price and quantity instruments were not statistically different from each other, thus suggesting the absence of endowment effects and fairness concerns. However, the analysis of individual production shows that low marginal benefit subjects experienced endowment effects. It is also the low and medium-low marginal benefit subjects that are more affected by overweighting of high damage events combined with risk seeking to avoid losses under uncertain damages, putting upward pressure on production in the tax treatment.

In contrast with previous studies that compared carbon reductions under a personal carbon trading and a tax based on survey exercises, our experiment involving real stakes shows that these reductions could be different depending on the knowledge of the damages and whether the relevant level of analysis is the individual or the group.

A final set of results from our experiment emerge from an analysis of the permit prices. The data reveals that the combined effect of overweighting of high damage events and risk seeking to avoid losses dominate risk seeking to avoid losses alone under the quantity instrument, which is reflected in higher prices under the two uncertain marginal damage environments, making the prices the highest when the bad state involves a small probability but extremely bad event. These findings are in agreement with those from the analysis on aggregate quantities summarized above.

We indirectly test for the presence of endowment effects using data on those subjects who bid to both buy and sell permits. The results provide evidence for the presence of endowment effects. Endowment effects decrease over time in environments with certain damages and uncertain but non-extreme events. Conversely, when the possibility of an extreme event is present, reluctance to sell due to overweighting may cause the endowment effects to persist over time.

The results from the analysis of individual decisions and permit prices therefore provide evidence for behavioral responses from endowment effects and risk attitudes proposed by prospect theory which cause price and quantity instruments to lead to different outcomes. Further research is needed to understand the effects of the interaction between endowment effects and the overweighting of high damage events.

Our results have important implications for the design of policy. If price and quantity instruments are no longer equivalent when marginal damages are uncertain because of behavioral responses, policy-makers should consider the possibility of behavioral responses in the design of policy and in their choice of whether to use a price or quantity instrument.

References

Adar, Z., and J. Griffin. 1976. “Uncertainty and the choice of pollution control instruments.” *Journal of Environmental Economics and Management* 3:178–188.

Baldurson, F., and J. Sturluson. 2011. “Fees and the efficiency of tradable permit systems: An experimental approach.” *Environmental and Resource Economics* 48:25–41.

Bohm, P., and B. Carlen. 2002. “A cost-effective approach to attracting low-income countries to international emissions trading: Theory and experiments.” *Environmental and Resource Economics* 23:187–211.

—. 1999. “Emission quota trade among the few: laboratory evidence of joint implementation among committed countries.” *Resource and Energy Economics* 21:43–66.

Bristow, A., M. Wardman, A. Zanni, and P. Chintakayala. 2010. “Public acceptability of personal carbon trading and carbon tax.” *Ecological Economics* 69:1824–1837.

Cason, T., and L. Gangadharan. 2003. “Transactions costs in tradable permit markets: An experimental study of pollution market designs.” *Journal of Regulatory Economics* 23:145–165.

Fawcett, T., and Y. Parag. 2010. “An introduction to personal carbon trading.” *Climate Policy* 10:329–338.

Fehr, E., and S. Gachter. 2000. “Cooperation and punishment in public goods experiments.” *The American Economic Review* 90:980–994.

Fehr, E., and K. Schmidt. 1999. “A theory of fairness, competition, and cooperation.” *The Quarterly Journal of Economics Letters* 114:817–868.

Fischbacher, U. 2007. “z-Tree: Zurich toolbox for ready-made economic experiments.” *Experimental Economics* 10:171–178.

Franciosi, R., P. Kujal, R. Michelitsch, V. Smith, and G. Deng. 1995. “Fairnes: Effect on temporary and equilibrium prices in post-offer markets.” *The Economic Journal* 105:938–950.

Friedman, D. 1991. “The double auction market institution: A survey.” In D. Friedman and J. Rust, eds. *The double auction market: Institutions, theories, and evidence*. Adison-Wesley Publishing Company, pp. 3–20.

Issac, R.M., and C. Holt. 1999. “Emissions permit experiments.” In R. M. Isaac, ed. *Research in Experimental Economics*. JAI Press Inc., vol. 7.

Kachelmeier, S., S. Limberg, and M. Schadewald. 1991. “Fairness in markets: A laboratory investigation.” *Journal of Economic Psychology* 12:447–464.

Kahneman, D. 2003. “Maps of bounded rationality: Psychology for behavioral economics.” *The American Economic Review* 93:1449–1475.

Kahneman, D., J. Knetsch, and R. Thaler. 1990. “Experimental tests of the endowment effect and the Coase theorem.” *Journal of Political Economy* 98:1325–1348.

Kahneman, D., and A. Tversky. 1979. “Prospect theory: An analysis of decisions under risk.” *Econometrica* 47:313–327.

Klaasen, G., A. Nentjes, and M. Smith. 2005. “Testing theory of emissions trading: Experimental evidence on alternative mechanisms for global carbon trading.” *Ecological Economics* 53:47–58.

Kujal, P., and V. Smith. 2008a. *Handbook of Experimental Economics Results, Volume I*, North-Holland, chap. Fairness and short run price adjustment in posted offer markets. pp. 55–61.

—. 2008b. *Handbook of Experimental Economics Results, Volume I*, North-Holland, chap. The endowment effect. pp. 949–955.

Lin, C.-Y.C., and E.J. Muehlegger. 2013. “On the use of heuristics to approximate competitors’ private information.” *Journal of Economic Behavior and Organization* 86:10–23.

List, J. 2004. “Neoclassical theory versus propect theory: evidence from the marketplace.” *Econometrica* 72:615–625.

Muller, R.A., and S. Mestelman. 1998. “What have we learned from emissions trading experiments?” *Managerial and Decision Economics* 19:225–238.

Murphy, J.J., and J.K. Stranlund. 2007. “A laboratory investigation of compliance behavior under tradable emissions rights: Implications for targeted enforcement.” *Journal of Environmental Economics and Management* 53:196–212.

Nordhaus, W. 2007. “To tax or not to tax: Alternative approaches to slowing global warming.” *Review of Environmental Economics and Policy* 1:26–44.

Plott, C., and P. Gray. 1990. “The multiple unit double auction.” *Journal of Economic Behavior and Organization* 13:245–258.

Plott, C., and K. Zeiler. 2005. “The willingness to pay-willingness to accept gap, the "endwoment effect", subject misconceptions and experimental procedures for eliciting valuations.” *The American Economic Review* 95:530–545.

Plott, C.R. 1983. “Externalities and corrective policies in experimental markets.” *The Economic Journal* 93:106–127.

Shogren, J., and L. Taylor. 2008. “On behavioral-environmental economics.” *Review of Environmental Economics and Policy* 2:26–44.

Smith, V.L. 1976. “Experimental economics: Induced value theory.” *The American Economic Review* 66:274–279.

Smith, V.L., and A. Williams. 1983. “An experimental comparison of alternative rules for competitive market exchange.” In R. Englebrecht-Wiggans, M. Shubik, and R. M. Stark, eds. *Auctions, bidding, and contracting: Uses and theory*. New York University Press.

Starkey, R. 2012a. “Personal carbon trading: A critical survey. Part 1: Equity.” *Ecological Economics* 73:7–18.

—. 2012b. “Personal carbon trading: A critical survey. Part 2: Efficiency and effectiveness.” *Ecological Economics* 73:19–28.

Stavins, R.N. 2008. “Addressing climate change with a comprehensive US cap-and-trade system.” *Oxford Review of Economic Policy* 24:298–321.

—. 1996. “Correlated uncertainty and policy instrument choice.” *Journal of Environmental Economics and Management* 30:218–230.

—. 1995. “Transaction costs and tradeable permits.” *Journal of Environmental Economics and Management* 29:133–148.

Thaler, R. 2016. “Behavioral economics: Past, present, and future.” *The American Economic Review* 106:1577–1600.

Tversky, A., and D. Kahneman. 1991. “Loss aversion in riskless choice: A reference-dependent model.” *The Quarterly Journal of Economics* 106:1039–1061.

Weitzman, M.L. 1974. “Prices vs. quantities.” *The Review of Economic Studies* 41:477–491.

Weitzman, M.L. 2014. “Fat tails and the social cost of carbon.” *The American Economic Review* 104:544–546.

Wilen, J., J. Cancino, and H. Uchida. 2012. “The economics of Territorial Use Rights Fisheries, or TURFs.” *Review of Environmental Economics and Policy* 6:237–257.

Zanni, A., A. Bristow, and M. Wardman. 2013. “The potential behavioural effect of personal carbon trading: results from an experimental survey.” *Journal of Environmental Economics and Policy* 2:222–243.

Zetland, D. 2008. “Conflict and cooperation within an organization: A case study of the Metropolitan Water District of Southern California.” Ph.D. dissertation, University of California at Davis.