Policy Instrument Choice when Marginal Damages are Uncertain: Evidence from a Laboratory Experiment[a]

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September 7, 2015

Abstract

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 failures on the part of market participants that cause price and quantity instruments to lead to different outcomes. We 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. In terms of aggregate emissions, the quantity-equivalence of quantity and price instruments can not 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 failures 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 controls, tradable permit systems

***JEL* codes:** D03, D81, H23, Q58

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[a] Preliminary draft. Please do not cite, quote or distribute without authors' permission.

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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. 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). Furthermore, the literature largely agrees that uncertainty over marginal damages alone has no impact on the equivalence of price and quantity instruments: even in the presence of uncertainty over marginal damages, both price instruments and quantity instruments perform equally in terms of their ex post efficiency. In contrast, 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). 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 focus on the uncertainties related to marginal damages that regulatees experience and how these could affect their behavior. Even though uncertainty over marginal damages may not matter in theory, it may be important in practice since such uncertainty may lead to what Shogren and Taylor (2008) call *behavioral failures*. Within our context these are responses on the part of market participants that could be triggered in dissimilar fashion by the policy in place when marginal damages are uncertain, causing price and quantity instruments to lead to different outcomes.

For instance, under marginal damage uncertainty, decisions from regulatees who are also victims of the externality may 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 may weigh events by magnitudes that differ from their respective probabilities of occurrence, thus leading to different decisions under uncertainty. Loss aversion can be reflected in an overweighting of negative consequences of individuals' actions when marginal damages are uncertain, such that the impact of the externality could be overstated under both types of policy. Regarding the latter idea, Tversky and Kahneman (1991, p.1057) argue that: "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. 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 fairness considerations (Fehr and Schmidt 1999) and loss aversion (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. Fairness concerns have less of an effect on market participants under a price instrument, as 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. In contrast, fairness concerns and loss aversion may be important in a tradable permits policy in which individuals can buy permits to destroy them or show higher reluctance to sell. If there is a heterogeneous value attached to each permit beyond the profits from the production the permit enables, then inequity in permit holdings due to unequal contributions toward the exploitation of the resource and due to loss aversion could affect the equilibrium price of permits and the number of trades.

Thus, owing to behavioral responses, and in contrast with the 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 ameliorate behavioral failures, since each individual may then perceive that they have little impact on the behavior of others, just as they do in under a tax system, thus possibly restoring the equality between price and quantity instruments.

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 this study's setting, subjects acting as producers are given a marginal benefit schedule that shows the individual benefit from producing another unit of the good which at the same time amounts to creating another unit of externality. Behavioral failures aside, standard conclusions about the equivalence of the instruments should follow because certainty about the induced marginal benefits prevail in each of the treatments in which transaction costs are negligible.

In contrast to our study, previous experiments on emissions trading have not analyzed the underlying market for the good that creates the externality. Instead, they only analyze the permit market by providing a marginal abatement cost function per reduction (or marginal benefit function per emission) and a permit endowment to each participant (for an early review on the subject see Issac and Holt (1999)). An 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 in order to test its impact on the role that intuitions, customs, ethics, and instincts might play in determining the behavior of individuals.[1]

Our experimental design resembles situations in which generators of the externality are also affected by it. Common pool resources such as fisheries and the environmental services provided by the atmosphere are two examples. 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). In the case of the atmosphere, the debate over the optimal market-based policy for the correction of externalities has been revitalized due to the significant impacts on both physical and biological systems from global climate change caused by anthropogenic greenhouse gas emissions (see Nordhaus (2007), and Stavins (2008) for discussions of policy instrument choice in the context of climate change policy).

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 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, but not under a price control.[2]

Our results indicate that in terms of aggregate emissions, the quantity-equivalence of quantity and price instruments can not be rejected when marginal damages are known with certainty, possibly ruling out the presence of endowment effects and fairness concerns. 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 behav-

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[1] 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)).

[2] 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. As previously mentioned, 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.

ioral failures 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 for the different policy scenarios 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 Theoretical Model

We develop a theory model to compare the equilibria under different policy scenarios with and without behavioral responses. Our model is framed as a situation in which agents obtain net benefits from production of a good that generates a damage that affects themselves and the rest of agents.[3]

2.1 Standard model

In our model, the utility of a risk-neutral agent i is given by the profits from production minus the monetized damages.[4]

Profits $\pi_i(q_i)$ are increasing in externality-generated 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-generated output q_i can represent, for example, emissions. We assume that the damage to each agent i from group production ($Q = q_i + \sum_{j \neq i}^{N} q_j$) is eQ, where the marginal damages e are constant and the same for every agent.

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

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

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[3] By substituting consumption for production we could also refer to the case in which citizens are regulated such as in the personal trading systems. The production context is adopted in this section to keep consistency with the experimental design which is framed in terms of profits from production.

[4] Within the context of countries, the two components would be profits from firms and monetized damages suffered by citizens.

2.1.1 Social Optimum

A social planner that applies equal weight to the utility functions of each of the N agents would maximize the sum of such utilities yielding the following individual quantities produced that characterize the social optimum (SO):

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

At the social optimum, each agent i's marginal profit is equated to the sum of marginal damages on all the 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 for each agent i:

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

The set of conditions resulting from the competitive equilibrium implies that 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, where 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 first-order condition for each agent i yields the following individual quantities:

$$q_{PS,i} = \frac{A_i - e - t}{\alpha_i}, \tag{5}$$

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:

$$U_i = A_i q_i - \frac{\alpha_i q_i^2}{2} - eQ - \tau_i^b l_i^b + \tau_i^s l_i^s, \tag{6}$$

where τ_i^b is the price of each of the l_i^b permits that agent i buys and τ_i^s is the price of each of the l_i^s permits that agent i sells.

Let us now separate the damage into the part generated by agent i itself, and the part generated by other agents:

$$U_i = A_i q_i - \frac{\alpha_i q_i^2}{2} - eq_i - e\sum_{j \neq i} q_j - \tau_i^b l_i^b + \tau_i^s l_i^s. \tag{7}$$

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

$$H_i = L_i + l_i^b - l_i^s. \tag{8}$$

Assuming all the permits are used, the damage to agent i generated by others is given by $L - H_i$, the total number of permits in the market minus the permits owned by agent i. This expression can take the place of $e\sum_{j \neq i}^N q_j$ in agent i's utility function, yielding:

$$U_i = A_i q_i - \frac{\alpha_i q_i^2}{2} - eq_i - e(L - H_i) - \tau_i^b l_i^b + \tau_i^s l_i^s. \tag{9}$$

Each of the N agents maximizes this utility function subject to the constrain that their permit holdings must cover their emissions:

$$L_i + l_i^b - l_i^s - q_i \geq 0, \tag{10}$$

which yields the following first-order conditions:

$$A_i - \alpha_i q_i - e - \mu_i = 0 \tag{11}$$

$$-\tau_i^b + e + \mu_i = 0 \tag{12}$$

$$\tau_i^s - e - \mu_i = 0, \tag{13}$$

where μ_i is the Lagrange multiplier associated with (10) and represents both the marginal willingness to pay and the marginal willingness to accept for a permit.

From (12) and (13), prices at which individual i buys and sells permits should be equal for all transactions and thus a single τ_i can be substituted in (11):

$$q_{QS,i} = \frac{A_i - \tau_i}{\alpha_i}. \tag{14}$$

Equation (14) characterizes every individual's production decision. The components of this function are all given except for τ_i which is endogenously determined in the market for permits. As can be seen from equations (12) and (13), the lower bound for the price of permits is e, which would be the price of permits when the cap is greater than the quantity that would be produced in the absence of any policy and therefore non-binding. When the cap is set below the unregulated level of production, then (10) is a binding constraint and it follows that $\sum_i^N L_i = \sum_i^N q_i$. The last equality allows us to predict the market equilibrium price for permits (τ_M) when it is combined with the equilibrium condition $\tau_i = \tau_M$ for all i. The N functions represented by (14) are added up and set equal to the total number of permits in the market to finally solve for the unique unknown τ_M.

Adding up the N functions in (14), setting them equal to $L = \sum_i^N L_i$ and solving for τ_M:

$$\tau_M = \frac{\sum_i^N \frac{A_i}{\alpha_i} - L}{\sum_i^N \frac{1}{\alpha_i}}. \tag{15}$$

Under no uncertainty about e and no other behavioral deviations, the different individual $\tau_i's$ should converge to a market price for the permits $\tau_M = eN$ when the cap is set at the optimal level. This result is obtained by adding up (3) across i yielding the optimal total production $Q_{SO} = \sum_i^N \frac{A_i}{\alpha_i} - eN\sum_i^N \frac{1}{\alpha_i}$. Substituting L in (15) for Q_{SO} produces an equilibrium permit price $\tau_M = eN$. If risk attitudes (in the case of uncertainty about e), and other behavioral responses based on fairness grounds and loss aversion depend on the policy/environment mix, convergence to $\tau_M = eN$ might be affected.

Note that the permit price at which each agent is willing to buy or sell incorporates the marginal damage from production, as it is derived from the potential use of the permit by others to produce and therefore generate an externality. This is the reason why the equilibrium permit price $\tau = eN$ is above the optimal tax rate $t = e(N-1)$.[5] Nevertheless, the quantities produced by each agent would remain as they would be under the tax policy.

Summarizing, the optimal level of emissions could 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 even when behavioral failures are absent. The latter result is due to the potential to reduce emissions from other parties by

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

holding a permit, which causes the permit price that emerges from a tradable permit system capped at the optimal level of emissions to be higher than the optimal tax.

Finally, although the participation of affected parties in the permit market could result in destruction of some permits, this would not occur as long as all market participants are affected equally by the externality and the cap is binding: $L < \sum_i^N q_{BS,i}$. This result follows because all agents would have a marginal willingness to pay for a permit at least equal to the marginal damage and no agent would produce beyond the point at which the marginal benefit is lower than their own marginal damage. Since our model assumes equal marginal damages to all agents and imposes a cap equal to the optimal aggregate production level, this type of behavior could only be triggered by other motivations such as those examined below.

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, endowment effects, if present, could increase the value of each permit compared to the case when the value of the permit is only linked to the benefits that can be obtained by generating the externality. This could ultimately reduce the externality because a holder of a permit might not find attractive to use the permit or to sell it at the prevailing market price. Endowment effects may therefore be important in a tradable permits policy in which individuals can buy permits to destroy them or show higher reluctance to sell.

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 (or 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).[6] 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 could be a temporary phenomenon in markets.

As argued above, endowment effects can only arise under a quantity control. Incorporating $\delta_i \geq 0$ as the marginal disutility from selling a permit into equation (9) yields:

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[6] 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)

$$U_{QS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - eq_i - e(L - H_i) - \tau_i^b l_i^b + \tau_i^s l_i^s - \delta_i l_i^s. \tag{16}$$

Maximizing (16) with respect to q subject to (10) yields the following first-order conditions:

$$A_i - \alpha_i q_i - e - \mu_i = 0 \tag{17}$$

$$-\tau_i^b + e + \mu_i = 0 \tag{18}$$

$$\tau_i^s - e - \mu_i - \delta_i = 0. \tag{19}$$

Combining (19) with (17) we obtain:

$$q_{QS,i} = \frac{A_i - \tau_i^s + \delta_i}{\alpha_i}. \tag{20}$$

Note that in this step we used τ_i^s which in principle differs from τ_i^b. However, they are equal whenever δ_i is zero in a sale and whenever the individual is buying. Hereinafter τ_i stands for the permit sales price. Equation (20) characterizes every individual's production decision. The components of this function are all given except for τ_i which is endogenously determined in the market for permits and δ_i's which are unknown.

We now explore two cases: (1) all permits are used, and (2) some permits remain unused.

2.2.1 All permits are used

If $\sum_i^N L_i = \sum_i^N q_i$, we can predict the market equilibrium price for permits (τ_M) when it is combined with the equilibrium condition $\tau_i = \tau_M$ for all i. The N functions represented by (20) are added up and set equal to the total number of permits in the market to finally solve for τ_M.

Adding up the N functions in (20), setting them equal to $L = \sum_i^N L_i$ and solving for a single τ_M yields:

$$\tau_M = \frac{\sum_i^N \frac{A_i}{\alpha_i} - L + \sum_i^N \frac{\delta_i}{\alpha_i}}{\sum_i^N \frac{1}{\alpha_i}}. \tag{21}$$

As shown earlier, the individual quantities under the social optimum would yield the optimal total production $Q_{SO} = \sum_i^N \frac{A_i}{\alpha_i} - eN \sum_i^N \frac{1}{\alpha_i}$. Substituting L in (21) for Q_{SO} produces an equilibrium permit price:

$$\tau_M = eN + \frac{\sum_i^N \frac{\delta_i}{\alpha_i}}{\sum_i^N \frac{1}{\alpha_i}}. \tag{22}$$

The components of this last equation are all given except for δ_i's which are unknown. However, we can see from this equation that the equilibrium price of permits would be higher compared to the standard case in which $\tau_M = eN$

as long as at least one individual experiences endowment effects (i.e., $\delta_i > 0$). Here it was assumed that all permits were used and therefore the aggregate quantity would not be smaller than that from the optimal tax. However the final allocation of permits across individuals may be different compared to the standard case.

Substituting (22) back into (20), we obtain the following solution:

$$q_{QS,i} = \frac{A_i - eN - \frac{\sum_i^N \frac{\delta_i}{\alpha_i}}{\sum_i^N \frac{1}{\alpha_i}} + \delta_i}{\alpha_i}. \tag{23}$$

Comparing this solution to the one from the standard case $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$, the relationship between an individual's parameters and the others generates any difference between solutions.

Two intuitive results can be drawn from looking at equation (23). 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. The difference for any individual j would be given by $\frac{1}{\alpha_j}(\delta_j - \frac{\sum_i^N \frac{\delta_i}{\alpha_i}}{\sum_i^N \frac{1}{\alpha_i}})$.

2.2.2 Some permits remain unused

Since in our case the cap is set at the optimal aggregate quantity which is below the unregulated one, the shadow value of a permit (μ) is positive for every individual under the standard case. However, with endowment effects, from (19) μ could be zero for some individual i if $\tau_M = e + \delta_i$. That is, if the permit price in the market is just enough to only cover the damage represented by e and the desutility from selling a permit represented by δ_i, then at least one permit remains unused.

Since now in this case $\sum_i^N L_i > \sum_i^N q_i$, it is not possible to solve for τ_M as in equations (21) and (22).

2.3 Fairness concerns

A second behavioral response we examine are fairness concerns. In contrast to endowment effects, fairness concerns could in principle also affect the outcome under a price instrument. However, 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 either the amount of externality generated by others or the distribution of gains. 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". Tax policies do not provide room to disadvantaged players to affect outcomes. Under a quantity control however, disadvantaged players can affect the outcome through their decisions in the permit market where they could incur 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, 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). 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 in terms of permit holdings linearly into the utility function. We furthermore assume that advantageous inequity does not have an impact in the utility of agent *i*. The utility of agent *i* is then defined as follows:

$$U_{QS,i} = A_i q_i - \frac{\alpha_i q_i^2}{2} - eq_i - e(L - H_i) - \tau_i^b l_i^b + \tau_i^s l_i^s - \gamma_i \left(max \left\{ \frac{L - NH_i}{N-1}, 0, \right\} \right). \tag{24}$$

Maximizing (24) with respect to q subject to (10) yields the following first-order conditions:

$$A_i - \alpha_i q_i - e - \mu_i = 0 \tag{25}$$

$$-\tau_i^b + e + \mu_i + \gamma_i \frac{N}{N-1} = 0 \tag{26}$$

$$\tau_i^s - e - \mu_i - \gamma_i \frac{N}{N-1} = 0. \tag{27}$$

From (26) and (27), the prices at which individual i buys and sells permits should be equal for all transactions and thus a single τ_i can be substituted in (25) as follows:

$$q_{QS,i} = \frac{A_i - \tau_i + \gamma_i \frac{N}{N-1}}{\alpha_i}. \tag{28}$$

Equation (28) characterizes every individual's production decision. The components of this function are all given except for τ_i which is endogenously determined in the market for permits and γ_i's which are unknown.

We now explore two cases: (1) all permits are used, and (2) some permits remain unused.

2.3.1 All permits are used

If $\sum_i^N L_i = \sum_i^N q_i$, we can predict the market equilibrium price τ_M for permits when it is combined with the equilibrium condition $\tau_i = \tau_M$ for all i. The N functions represented by (28) are added up and set equal to the total number of permits in the market to finally solve for τ_M.

Adding up the N functions in (28), setting them equal to $L = \sum_i^N L_i$ and solving for a single τ_M yields:

$$\tau_M = \frac{\sum_i^N \frac{A_i}{\alpha_i} - L + \frac{N}{N-1} \sum_i^N \frac{\gamma_i}{\alpha_i}}{\sum_i^N \frac{1}{\alpha_i}}. \tag{29}$$

Substituting L in (29) for Q_{SO} produces the following equilibrium permit price:

$$\tau_M = eN + \frac{\frac{N}{N-1} \sum_i^N \frac{\gamma_i}{\alpha_i}}{\sum_i^N \frac{1}{\alpha_i}}. \tag{30}$$

The components of this last equation (30) are all given except for the γ_i's, which are unknown. However, we can see from this equation that the equilibrium price of permits would be higher compared to the standard case in which $\tau_M = eN$. In this section we assumed that all permits were used and therefore the aggregate quantity would not be smaller than the optimal; however, as with endowment effects, the final allocation of permits may be different compared to the standard case.

Substituting (30) back into (28), we obtain the following solution:

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

Comparing this solution to the one from the standard case $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$, the relationship between an individual's parameters and the others generates any difference between solutions.

Two intuitive results can be drawn from looking at equation (31). First, if every individual has the same γ, 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 for individual i in the standard case and in the case incorporating fairness concerns is given by the following expression:

$$\sum_{j \neq i}^N \frac{1}{\alpha_j} (\gamma_i - \gamma_j). \tag{32}$$

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 and everyone else's γ but it would be unambiguously positive (negative) if $\gamma_i > \gamma_j$ ($\gamma_i < \gamma_j$) for all j.

Those with a lower permit endowment are expected to present a relatively large γ 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, the aggregate quantity remains as in the standard case because it was assumed that all permits are used

2.3.2 *Some permits remain unused*

Since in our case the cap is set at the optimal aggregate quantity which is below the unregulated one, the shadow value of a permit (μ) is positive for every individual under the standard case. However, with fairness concerns, from (3) or (4) μ could be zero for some individual i if $(\tau_M - e) = \gamma_i \frac{N}{N-1}$. That is, if that individual i's parameter measuring fairness concerns is large enough to make that equality hold, then at least one permit remains unused. Since now in this case $\sum_i^N L_i > \sum_i^N q_i$, it is not possible to solve for τ_M as in equations (29) and (30).

2.4 *Prospect theory risk attitudes*

The third behavioral response we consider are propect 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 may weigh events by magnitudes that differ from their respective probabilities of occurrence, thus leading to different decisions under uncertainty. Loss aversion can be reflected in an overweighting of negative consequences of individuals' actions when marginal damages are uncertain, such that the impact of the externality could be overstated under both types of policy.

Under the expected utility framework, the outcomes would be the same for risk-neutral decision-makers if there is uncertainty in the level of marginal damages $\tilde{e}$ and if the mean of $\tilde{e}$ is equal to e:

$$E[\tilde{e}] = pe^h + (1-p)e^l = e, \tag{33}$$

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

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 (not necessarily overestimated) by individuals (something that could be reinforced 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 from a reference point. The initial wealth of the agent M serves as this reference.

Let us consider the following value function (W) that separates the losses and the gains from M:

$$W_{QS,i} = U_i(\pi_i(q_i) + \tau_i^s l_i^s) + V_i(-e_i q_i - e_i(L - H_i) - \tau_i^b l_i^b), \tag{34}$$

where $U'() > 0$, $U''() < 0$, $V'() > 0$, $V''() > 0$ as required in prospect theory for gains and losses respectively. Furthermore, $U(0) = V(0) = 0$ and $U(x) < -V(-x)$ for any $x > 0$. The perceived marginal damages e_i which vary across subjects are given by:

$$e_i = w_i(p)e^h + w_i(1-p)e^l, \tag{35}$$

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 $w_i(p) + w_i(1-p) = 1$.

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 low probability but highly damaging events across individuals.[7]

Maximizing (34) with respect to q subject to $L_i + l_i^b - l_i^s - q_i \geq 0$ yields the following first-order conditions:

$$U_i'\pi' - V_i'e_i - \mu_i = 0 \tag{36}$$

$$-V_i'\tau_i^b + V_i'e_i + \mu_i = 0 \tag{37}$$

$$U_i'\tau_i^s - V_i'e_i - \mu_i = 0, \tag{38}$$

where μ_i is the Lagrange multiplier associated with the individual permit constraint and represents both the marginal willingness to pay and the marginal willingness to accept for a permit.

Combining equations (36) and (38), we obtain:

$$\pi_i' = \tau_i^s = \frac{V_i'}{U_i'}\tau_i^b. \tag{39}$$

Assuming $\pi_i(q_i) = A_i q_i - \frac{\alpha_i q_i^2}{2}$, we obtain:

$$q_{QS,i} = \frac{A_i - \frac{V_i'}{U_i'}\tau_i^b}{\alpha_i}. \tag{40}$$

Note that in this step we used τ_i^b which in principle differs from τ_i^s. However, they are equal whenever $V_i' = U_i'$. Hereinafter τ_i stands for the permit buying price. Equation (40) characterizes every individual's production decision

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[7] 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 $\eta > 1$.

but it is not possible to predict the endogenously determined τ_i^b because U_i', V_i' and e_i are unknown. Not only are the perceived marginal damages e_i unknown, but the function V_i, for which e_i is an argument, is unknown as well.

We now explore two cases: (1) all permits are used, and (2) some permits remain unused.

2.4.1 All permits are used

If $\sum_i^N L_i = \sum_i^N q_i$, we can obtain an equation for the market equilibrium price τ_M for permits when it is combined with the equilibrium condition $\tau_i = \tau_M$ for all *i*. The *N* functions represented by (40) are added up and set equal to the total number of permits in the market to finally solve for τ_M.

Adding up the N functions in (40), setting them equal to $L = \sum_i^N L_i$ and solving for a single τ_M yields:

$$\tau_M = \frac{\sum_i^N \frac{A_i}{\alpha_i} - L}{\sum_i^N \frac{V_i'/U_i'}{\alpha_i}}. \tag{41}$$

As shown earlier, in the absence of risk seeking and weighting of probabilities (i.e., when $e_i = e$ for all i) the individual quantities predicted under the optimal tax $t = (N-1)e$ would yield the optimal total production $Q_{SO} = \sum_i^N \frac{A_i}{\alpha_i} - eN\sum_i^N \frac{1}{\alpha_i}$. Substituting L in (41) for Q_{SO} produces the following equilibrium permit price once risk seeking and overweighting of low probability events are allowed for:

$$\tau_M = eN\frac{\sum_i^N \frac{1}{\alpha_i}}{\sum_i^N \frac{V_i'/U_i'}{\alpha_i}}. \tag{42}$$

The components of this last equation are all given except for U_i''s and V_i''s which are unknown. However, we can see from this equation that the equilibrium price of permits would only be equal to that in the standard case in which $\tau_M = eN$ if $\sum_i^N \frac{1}{\alpha_i} = \sum_i^N \frac{V_i'/U_i'}{\alpha_i}$. 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, it is more likely to observe permit prices in equilibrium with extreme events that are larger than those based on the standard and balanced events cases.

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 (42) back into equation (40) we obtain the following solution:

$$q_{QS,i} = \frac{A_i - \frac{V_i'}{U_i'}eN\frac{\sum_i^N \frac{1}{\alpha_i}}{\sum_i^N \frac{V_i'/U_i'}{\alpha_i}}}{\alpha_i}. \tag{43}$$

Comparing this solution to the one from the standard case $q_{QS,i} = \frac{A_i - eN}{\alpha_i}$, the relationship between an individual's parameters and the others generates any difference between solutions. In general, the sign of the difference is given by the following expression:

$$1 - \frac{V_i'}{U_i'} \frac{\sum_i^N \frac{1}{\alpha_i}}{\sum_i^N \frac{V_i'/U_i'}{\alpha_i}}. \tag{44}$$

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

$$\frac{\sum_j^N \frac{V_i'/U_i'}{\alpha_j}}{\sum_i^N \frac{V_i'/U_i'}{\alpha_i}}. \tag{45}$$

Therefore the sign of the expression (44) depends on the magnitudes of the numerator and denominator in expression (45). The difference would be negative, zero or positive if the former expression is greater, equal or smaller than one which translates into the following expression being greater, equal or smaller than zero:

$$\sum_{j \neq i}^{N} \frac{1}{\alpha_j} \left(\frac{V_i'}{U_i'} - \frac{V_j'}{U_j'}\right). \tag{46}$$

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 over 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 viceversa. It should be noted that subjects that overweight more the probability of the largely-damaging scenario, would have smaller V'. Thus, overweighting would tend to increase the individual quantity (i.e., by reducing V') while risk-seeking would push in the opposite direction (i.e., by increasing V').

2.4.2 Some permits remain unused

Since in our case the cap is set at the optimal aggregate quantity which is below the unregulated one, the shadow value of a permit (μ) is positive for every individual under the standard case. However, under prospect theory, from (37) μ could be zero for some individual i if $\tau_M = e_i$. That is, if the permit price in the market is just enough to only cover the expected damage represented by e_i, then at least one permit remains unused.

Since now in this case $\sum_i^N L_i > \sum_i^N q_i$, it is not possible to solve for τ_M as in equations (41) and (42).

2.4.3 Price control

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

$$W_{PS,i} = U_i(\pi_i(q_i)) + V_i(-e_iQ - tq_i). \tag{47}$$

First-order conditions with the specification for π used in the paper yield:

$$q_{PS,i} = \frac{A_i - (e_i + t)\frac{V_i'}{U_i'}}{\alpha_i}. \tag{48}$$

Whether this quantity differ from the standard case in which $q_{PS,i} = \frac{A_i - e - t}{\alpha_i}$ depends on the magnitude by which e_i exceeds e and the relative slopes of the value function over the gains and losses. Importantly, as overweighting gets more severe, the slope of the value function in losses will be smaller due to the convexity of the value function in the loss domain. That implies that although overweighting tends to reduce the quantity produced under a price control, risk-seeking over losses will tend to increase production. Ultimately, these simultaneous effects moving in opposite directions will determine the quantities produced in the presence of a regulation through price instruments.

2.5 *Predicted impacts of behavioral responses*

Table 1 summarizes the results from our theoretical models for aggregate quantities (or emissions) and permit prices. In the case of tradable permits the impacts reported are those for the case in which all permits are used. When there is destruction of permits, no prediction can be made regarding the prices of permits. However, for such a case to occur it is necessary that at least one individual experiences very large endowment effects, fairness concerns or overweighting of low probability events as reported in the theoretical section.

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: Risk seeking in losses	↑Q	↓P
4. Prospect theory: Overweighting of low probability events	↓Q	↑P

The predicted increases in permit prices for the first two hypotheses follow from equations (22) and (30).

The results for aggregate quantities under the tax instrument in the presence of risk seeking and overweighting follow from the discussion in section (2.4.3), while the result for permit prices is based on equation (42). 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 combined with overweighting of low probabilities events would imply that: (a) bad states with assigned weights larger than their probability of occurrence would reduce both permit prices P and emissions Q on the one hand; but (b) the convexity of the utility function over losses would imply risk-seeking behavior which would increase both permit prices P and emissions Q on the other. This type of behavior under uncertainty can affect permit prices P and emissions Q under both price and quantity instruments. However, under quantity instruments, alternative potential damages can be further reduced by individual actions. As with actions to improve fairness, this requires that individuals regard themselves as capable of affecting the relevant outcomes, or that the large numbers translate into a small numbers case due to cooperation among the affected parties.

3 Experimental Design

3.1 General design and procedures

The central hypothesis to be tested in this experiment is the hypothesis 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 expose groups of individuals to different policies and marginal damage (MD) environments, and then compare 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 where the marginal damage was uncertain.

The experiment was programmed and conducted with the experimental software z-Tree (Fischbacher 2007). Experimental subjects received detailed and identical instructions which 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) (only under PS), to buy permits (l) (only under QS) or for them to keep. They also received a marginal benefits schedule listing the profits they would receive from the production of units of a fictitious good. Participants were given one of four types of these profit 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.[8] Table 3 shows the unit profits for the four types of marginal benefit, as well as the permit and experimental cash endowment, and quantity produced from theoretical predictions for each policy scenario. Subjects only knew their own valuations that remained constant during the 9 rounds of each of the policy treatments.

Importantly, the number of units each member of the group decided to produce created negative impacts on the rest 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

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

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 that included a USD 5 fee for showing up to the experiment. The rest of their earnings depended on their cumulative performance in the three games. Experimental subjects were only allowed to participate in one session.
Groups	Twelve 8-person independent groups.
Sessions	Seven 1-hour sessions conducted in a computer room at the University of California, Davis. Five 2-group sessions and two single-group sessions (groups U3 and U4).
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 $q_i's$ were restricted to positive integers (see Table 3).
Treatments	Each treatment consists of a policy treament (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.

was made depending on the marginal damage environment). 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 and 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), however, the expected value of e under the uncertainty treatments was 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).

All twelve groups were first exposed to the baseline scenario (BS) after which half of them played PS and the other half QS. Under trade regimes, 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 nonmonopolized double-auction markets.

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. 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.[9] 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).[10] 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

Unit	LO	ML	MH	HI
1	25	25	45	45
2	15	20	35	40
3	5	15	25	35
4	0	10	15	30
5	0	5	5	25
6	0	0	0	20
7	0	0	0	15
8	0	0	0	10
9	0	0	0	5
10	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 results from adding the inverse marginal benefit schedules of the eight subjects. Setting the aggregate demand for units equal to the aggregate marginal damage of 24 (3 tokens times 8 subjects), the

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[9] Plott and Gray consider that this type of market institutions require eight seconds per equilibrium transaction (Plott and Gray 1990). This study's design implies ten equilibrium transactions complying with this suggestion. From Table 3, each LO subject sells three units, and each ML subject sells two.

[10] 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 in Zetland (2008, Ch.7) within the context of water rights in southern California.

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. Note that the tax could not be equal to aggregate marginal damage (24) for subjects internalize the marginal damage inflicted 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 based on the parameters of their respective marginal benefit, and the personal deduction of $e = 3$ on each unit produced. The policy scenarios are further described in the following:

- *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 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). After each of the nine rounds, participants could observe for ten seconds what Q was and how their earnings were calculated. The final individual payout in each 30-second round is given by equation (2) plus the initial endowment (M_i). As it was mentioned before, subjects were allowed only to produce units in whole numbers. The individual optimal predicted q_i 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 individuals' earnings would be reduced by tq_i and augmented by M_i compared to equation (2). The rest of characteristics from BS remained equal. The individual optimal predicted q_i is given by equation (5).
- *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. A number of permits that give the right to produce units was distributed to every member of each group according to the quantities 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 (10) 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. After the permit market closed each round, individuals had 20 seconds to decide how many units of the good they wanted to produce just as in BS and PS. The individual optimal predicted q_i is given by equation (14) and per round earning are given by equation (9) plus M_i.

As summarized in Table 1, we predict that behavioral responses from fairness concerns and endowment effects would have no effect under a price instrument (tax) but would increase permit prices *P* under a quantity instrument (tradeable permits), both when marginal damages are certain and when marginal damages are uncertain. Furthermore, the net effects of prospect theory on permit prices *P* and emissions *Q* are not conclusive from the theoretical models.

Table 4 summarizes the results from our theoretical models for the individual quantities in our experiment. From our experimental design, endowment effects and fairness concerns have opposite impacts on individual quantities. The prediction with endowment effects follows from the discussion around equation (23). In our design, LO and ML subjects have a larger permit endowment than MH and HI subjects, thus are more likely to present endowment effects. The result for individual quantities with fairness concerns follow from the discussion around equations (31).

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

Hypothesis	LO	ML	MH	HI
Tradable permits:				
1. Endowment effects	↑q	↑q	↓q	↓q
2. Fairness concerns	↓q	↓q	↑q	↑q
Tax:				
3. Prospect theory: Risk seeking in losses	↑q	↑q	↑q	↑q

The result for individual quantities with risk seeking in losses follows from the discussion around equation (43) and (48). Notice that the relative slopes increase as subjects have higher marginal benefits (because the marginal utility of the gain decreases as the gain increases), and thus, the increase in individual quantity would be larger for HI than for LO subjects.

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 resources such as fisheries, groundwater exploitation, and road congestion. 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 and the damages from the generation of greenhouse gas emissions.

In common with previous emissions permit experiments, this study's experimental design resembles a market with a large number of participants all of which are equally affected by the externality.[11] Although the experimental design generates guidance about the causes producing a potential deviation from the equivalence of the instruments,

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[11] Each of the experimental markets are 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. The studies included in Issac and Holt (1999) are not an exception to this convention.

in some cases it does not allow us to separately identify them. By looking at Table 1 it is clear that deviations from the instruments' equality could be due to more than one hypothesis.[12] Despite this caveat, the main goal of the study is to compare the market outcomes of each policy intervention under certainty and uncertainty about the marginal damage function.

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 1 presents graphs of the mean and standard deviation of the number of total units as a function of treatment round for each of the different treatment combinations. The solid blue line indicates 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 shows estimates from panel regressions of total number of units produced by marginal damage environment explained by indicator variables for the quantity policy treatment (QS), last rounds of the experiment ($last$), and an interaction between the former two. The regressions use group observations from all rounds (trial round excluded) of the policy treatments yielding four groups with eight periods each. We report estimates from a population-averaged linear panel model with a first-order autocorrelation error structure.

Based on the regression estimates from Table 6, we conduct hypothesis testing on the total number of units produced by policy treatment. 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 results can be gleaned from Table 5, Table 7 and Figure 1.

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[12] Yet, another cause for deviation from instruments' equality 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. In a tradable permit systems this conditions 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.

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 1 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 1 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 effects of prospect theory on permit prices P and emissions Q when damages are uncertain are ambiguous. Prospect theory's S-shaped value function on gains and losses combined with overweighting of low probabilities events would imply that: (a) bad states with assigned weights larger than their probability of occurrence would reduce both permit prices P and emissions Q on the one hand; but (b) the convexity of the utility function over losses would imply risk-seeking behavior which would increase both permit prices P and emissions Q on the other.

The two possible outcomes under the balanced uncertain marginal damage environment (Ub) do not involve extreme events and therefore the behavior described in (a) is unlikely to be observed. However, risk-seeking over losses as described in (b) applies to both extreme and non-extreme events. Since the good state is in fact very good in the balanced uncertain marginal damage environment (i.e., zero damage), risk-seeking could be pushing production upwards, which is consistent with our result that the total number of units produced is larger than predicted under the balanced uncertain marginal damage environment in the price control scenario (PS).

The result that the number of units produced is equal to the theoretical prediction in the price control scenario (PS) under the unbalanced uncertain marginal damage environment (Ue) suggests that the negative effect on production of overweighting of the probability of the bad extreme event may be canceling out the positive effect on production of risk-seeking.

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 1 suggest this result which is confirmed by the non-statistically significant deviations $Q_{QS} - 20$ reported in the second row in Table 7.

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 1 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.

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)

The set of results based on aggregated production suggest the absence of large endowment effects and fairness concerns that could results in destruction of permits. On the other hand, 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. According to Tables 1 and 4 this mediators of behavior could be reflected in permit prices and individual units produced. An empirical analysis that makes use of the variation across individual observations under the two policy interventions was also conducted. Our estimates are based on the units produced by each subject each round in the PS and QS treatments. This strategy allows us to implement panel data methods identical to those from the previous section. The regressions

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		
Groups	8		

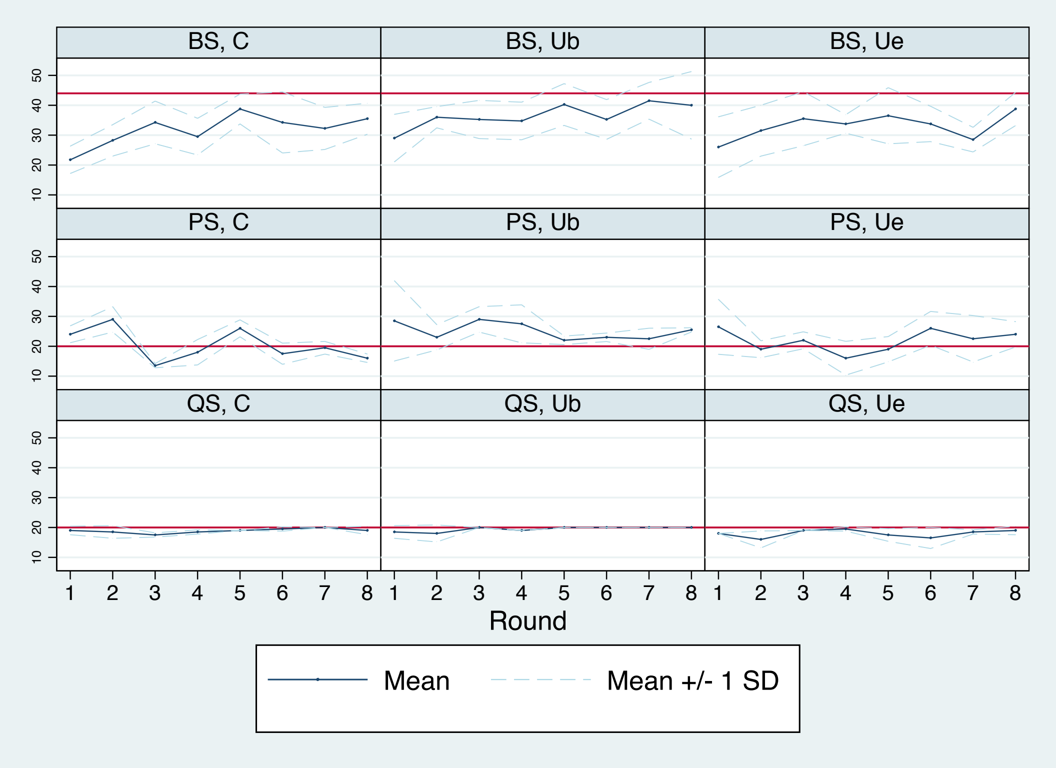
Standard errors in parentheses. Significance codes: *p<0.05, **p<0.01, ***p<0.001

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 1: Total number of units produced per round by treatment combination



are marginal benefit type specific and are reported in three separate tables for each marginal damage environment. These are Tables 8, 9 and 10, respectively. Each panel is the result of a subject type-treatment combination and therefore we have eight subjects (two of each type in each of the four groups) with eight periods each. 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 for treatment effects ($q_{PS} - q_{QS}$) can be gleaned from Tables 8, 9, 10, and 11. Results 5, 6, and 7 for individual units complement the previous analysis on group units.

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).

From result 5, under the certain marginal damage environment (C), the negative difference in units produced between the quantity control (QS) and price control (PS) treatments for low marginal benefit (LO) subjects cancels out the positive difference in units produced between the quantity control (QS) and price control (PS) treatments for the medium-high marginal benefit (MH) subjects, causing the difference at the group level not to be statistically significant as reported in result 4.

Under the certain marginal damage environment (C), it is important to note that only the medium-low marginal benefit subjects (ML) deviate from prediction under the price control scenario (PS) but all marginal benefit subjects deviate under the quantity control scenario (QS). This is because under price control, it is clearer to individuals they could incur in a loss by overproducing or foregoing a profit by underproducing. However, under quantity control, the extra profit an individual could make by selling a permit instead of using it is probably less salient to low (LO) and medium-low (ML) marginal benefit subjects. The result provides evidence for an endowment effect.

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), result 6 indicates that high marginal benefit (HI) subjects drive the positive difference in group units in early rounds, whereas the large (although not statistically significant) negative difference in the medium-low marginal benefit (ML) subjects in later rounds counterbalance high marginal benefit (HI) subjects' positive difference, causing the difference in the total number of units produced not to be statistically significant as indicated in result 4.

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 which results in under-production from higher marginal benefit subjects under the quantity control scenario, ultimately leading to a positive difference between units produced under the price and quantity control for HI subjects. Result 6 also provides possible evidence for prospect theory as well, since risk-seeking behavior on production may have a higher impact on ML subjects due to the relative magnitudes between potential gains and losses. This behavior in turn has an impact on the availability of permits for HI subjects who produce less than predicted in the quantity control.

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.

As under Ub, 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 also provides possible evidence for prospect theory as well, since risk-seeking behavior on production may have a higher impact on low marginal benefit (LO) and medium-low marginal benefit (ML) due to the relative magnitudes of potential gains and losses. This behavior in turn has an impact on the availability of permits for high marginal benefit (HI) subjects who produce less than predicted in the quantity control.

Table 8: AR1 population-averaged panel regressions of individual units produced under 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			
Groups	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 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			
Groups	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 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			
Groups	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

4.2 Prices

Table 12 shows average permit prices and permits 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).

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)

We analyze the impact of the marginal damage environment on the permit market outcomes based on the prices at which each permit was traded. More specifically, we perform regression analysis suitable for long panels that allows a more flexible 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., not re-started every round). Although the regressions in Table 13 control for several characteristics of both the seller and the buyer of each transaction, we only present the coefficients for the marginal benefit type. Tests of linear hypothesis were implemented for C=Ub, C=Ue and Ub=Ue in every case (C being the baseline case). Result 8 below summarizes our findings.

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)
ML buyer	-0.047	0.098
	(0.076)	(0.060)
ML seller	-0.025	-0.132***
	(0.055)	(0.040)
MH buyer	-0.018	-0.011
	(0.071)	(0.054)
MH seller	-0.247***	-0.151**
	(0.073)	(0.054)
HI buyer	-0.137	-0.085
	(0.076)	(0.067)
HI seller	-0.202**	-0.104*
	(0.078)	(0.050)
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 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.

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 results presented in Table 13 show that these 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).

The results suggest that under the balanced uncertain marginal damage environment (Ub), risk-seeking behavior from prospect theory should have a negative effect over the permit price as reported in Table 1. However, the positive effect of overweighting 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 production and 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. Whereas 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 where the dependent variable is the bid-ask spread for each subject (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 but can not provide evidence regarding the presence of fairness concerns. 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-offer spread: Random effects Tobit

	Dependent variable: Individual bid-offer 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: 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 negative coefficient for *Round* under C and Ub.

A declining spread over time under certainty treatments 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 spread also declines under balanced uncertain marginal damages (Ub), but it remains throughout the whole experiment in groups that were exposed to the unbalanced uncertain marginal damage environment (Ue).

5 Conclusions

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 failures on the part of market participants that cause price and quantity instruments to lead to different outcomes. These behavioral failures include endowment effects, fairness concerns, and attitudes towards risk deviating from the expected utility framework. However, having a large number of participants in the permit market could ameliorate behavioral failures, since each individual may then perceive that they have little impact on the behavior of others, thus possibly restoring the equality between price and quantity instruments.

We 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 environment are fisheries, groundwater exploitation, road congestion, and climate change.

Greenhouse gas emissions that may cause global climate change are being regulated through different mechanisms, including taxes and emission permits. Carbon taxes are already in place in several countries. Examples of tradeable 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.

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, even when behavioral failures are absent. The latter result is due to the potential to reduce emissions from other parties by holding a permit, which causes the permit price that emerges from a tradable permit system capped at the optimal level of emissions to be higher than the optimal tax.

There are several interesting results of the experiment. In terms of aggregate emissions, the quantity-equivalence of quantity and price instruments can not be rejected when marginal damages are known with certainty, possibly ruling out the presence of endowment effects and fairness concerns. 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 risk-seeking behavior in losses that pushes production upwards. Although such motivation is present regardless of the policy in place, under tradable permits 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, risk-seeking behavior in losses causes the emissions resulting from a quantity control to differ from those resulting from a price control.

Our findings based on group outcomes are complemented by our analysis of individual decisions. Although aggregate production in price and quantity instruments under certain damages was not statistically different, thus suggesting the absence of endowment effects and fairness concerns, 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 risk-seeking behavior 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.

The final set of results from the experiment reported here emerge from the analysis of permit prices. The data reveals that overweighting of probabilities of bad states dominate risk-seeking in 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 that bid to both buy and sell permits. The results indicate that 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 results in the persistence of endowment effects.

The results from the analysis of individual decisions and permit prices therefore provide evidence for behavioral failures 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.

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