



AgEcon SEARCH

RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.

An Experimental Investigation of Hard and Soft Price Ceilings in Emissions Permit Markets

David F. Perkins*

Department of Agricultural Economics
Purdue University
perkis@purdue.edu

Timothy N. Cason

Department of Economics, Krannert School of Management
Purdue University
cason@purdue.com

Wallace E. Tyner

Department of Agricultural Economics
Purdue University
wtyner@purdue.edu

**Selected Paper prepared for presentation at the Agricultural & Applied Economics
Association's 2012 AAEA Annual Meeting, Seattle, Washington, August 12-14, 2012**

** presenting author*

Copyright 2012 by David F. Perkins, Timothy N. Cason, and Wallace E. Tyner. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Abstract

Tradable emissions permits have been implemented to control pollution levels in various markets around the world and represent a major component of legislative efforts to control greenhouse gas (GHG) emissions in the United States. Because permits are supplied for a fixed level of pollution, allowing the market for permits to determine the price, there is a desire for price control mechanisms which would protect firms otherwise susceptible to price spikes caused by fluctuations in the demand for pollution abatement. We test permit markets in an experimental laboratory setting to determine the effectiveness of several price control mechanisms. Evidence suggests that both permit supply adjustments and traditional price ceilings (hard ceilings) effectively limit elevated prices in this setting. In contrast, reserve auctions (associated with soft ceiling designs) do not consistently control prices, especially when a minimum reserve permit price is applied. Furthermore, the grandfathering of permits allows permit sellers to realize significant welfare gains at the expense of buyers under a soft ceiling policy. Of the two ceiling options, our results point towards a hard ceiling as the preferred mechanism for controlling short term price increases.

(1) Introduction

Emissions permit markets have been established for many pollutants as a way to control environmental degradation. In its simplest form, a government supplies a set level of permits to the market, and firms must obtain and report permits equaling their pollution level at the time of demonstrating compliance. To minimize costs in a competitive emissions market, firms purchase permits at a price equal to their marginal cost of abatement, thus resulting in all firms having the same marginal cost of the last unit abated.

Price controls have been considered in many pollution markets as a mechanism to manage the price fluctuations of permits. Policies which introduce permits into the market at a fixed quantity, corresponding to the level of pollution allowed in the market, can in and of themselves contribute to large price adjustments (Fankhauser and Hepburn, 2010). Consider a group of firms in a permit trading market, each focused on minimizing the costs of emissions management. Their quantity of permits demanded is a function of the increasing marginal cost of abatement. As permit prices increase, abatement costs which at one time were prohibitively expensive would become affordable in comparison to higher permit prices, and the quantity of permits demanded would decrease, demonstrating a downward sloping demand curve for permits. Any supply shocks to the marginal cost of abatement will therefore cause fluctuations in the demand for permits. Given a controlled quantity of permits (Q_C), supply is perfectly inelastic so that fluctuations in demand for pollution abatement are realized by adjustments to the market price (P_m) and not quantity (barring the case where $P_m = 0$).

The purpose of price controls is to introduce elasticity in the supply curve over the range of non-zero prices, mitigating the effects on permit price of shocks or unexpected shifts in the cost of pollution abatement. Typical controls involve the use of a price collar, which combines a ceiling and a floor with permits trading at prices in between. Price ceilings help firms to avoid exorbitant costs associated with price spikes due to volatility or aggressive abatement targets. Price floors stimulate investment in emissions abatement technologies in an environment where low prices provide an insufficient incentive, thus encouraging lower emissions levels in the future (Burtraw et al., 2010). When targeting equal cumulative emissions in a dynamic

setting, a successful price collar would be more cost-effective than a price ceiling alone by encouraging low cost abatement during periods of declining prices (Fell and Morgenstern, 2010).

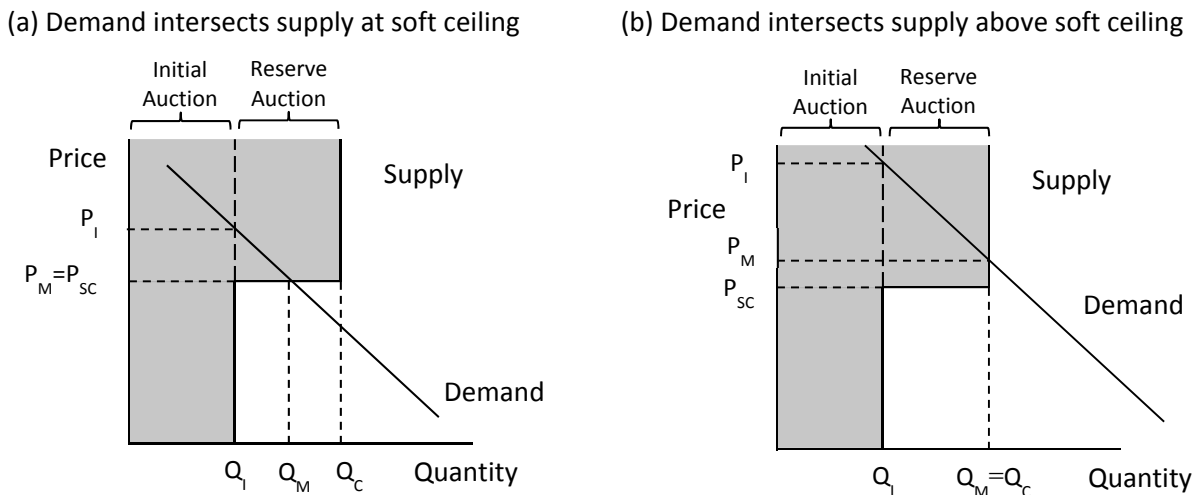
In the context of greenhouse gas (GHG) legislation in the United States, various price collars have been proposed which are only differentiated by their ceilings. Each policy has a hard price floor, not allowing purchases of permits below a minimum price. The various ceilings, however, fall into one of two policy definitions: hard ceilings which set an absolute maximum on permit prices and soft ceilings which introduce a minimally priced reserve of permits into the market beyond the original target quantity. This paper focuses on the short-term effectiveness of various ceiling mechanisms to control prices, ignoring the dynamic effects of a full price collar.

A hard price ceiling is simply a traditional price ceiling, which sets the absolute maximum on permit prices. When trying to avoid undesirably high prices (P_I), a ceiling caps prices at a maximum (P_C), and buyers can purchase as many permits as desired at this price (Refer to Figure 2 in Section 2 below). When demand is sufficiently high, the market price (P_M) is pegged against the ceiling and the market quantity (Q_M) is elevated relative to the initial permit allotment (Q_I). In such a situation, the price ceiling is binding, working effectively as a tax (t) with $t = P_C$. By implementing perfectly elastic supply, a hard ceiling places utmost importance on controlling prices at the expense of releasing as many permits as required into the market to keep prices below the ceiling. The most notable example of such a price ceiling in Federal GHG legislation was proposed by Senators Cantwell and Collins (Cantwell, 2009) as part of the Carbon Limits and Energy for America's Renewal (CLEAR) Act. This act proposed a definitive hard price ceiling with scheduled annual increases set automatically as a function of the real discount rate.

In contrast, a soft price ceiling does not set an absolute limit on the high end price of permits. In fact, the term "soft price ceiling" is not a ceiling by definition, but the accepted nomenclature for a reserve auction of permits with a minimum reserve price (Murray et al., 2009). Such a reserve auction was passed in the House of Representatives as part of the permit

trading market proposed in H.R. 2454 by Congressmen Waxman and Markey ((Waxman and Markey, 2009). In a permit market with a soft ceiling (Figure 1), an initial quantity of permits (Q_I) is introduced to the market equal to desired emissions levels. At the time when permit holders are expected to demonstrate compliance, an additional quantity of permits called the allowance reserve is offered at auction with a minimum reserve price (P_{SC}), potentially allowing those with insufficient permits to make up for their shortage. The aggregate of the initial and reserve auction permits represents a quantity control on the total market (Q_C).

Figure 1: Controlling high prices with a soft ceiling
(Shaded regions represent allowable trades.)



The soft ceiling receives its name from the intended impact of the minimum reserve price on the initial auction by introducing elasticity into the supply of permits. Referring to Figure 1, if demand were to intersect supply such that $P_M < P_{SC}$, the market price is not affected and none of the reserve would be purchased. As demand increases, P_M increases until $P_M = P_{SC}$ (Figure 1a). Under such conditions, firms coordinating prices across auctions would desire to keep bids in the initial auction close to or below P_{SC} in expectation of having to pay at least P_{SC} for the reserve. In other words, while P_{SC} is not binding, it acts as a sort of soft ceiling. As demand continues to increase, the market price would eventually rise above the soft ceiling by

design and the reserve allotment would be exhausted (Figure 1b). Nonetheless, prices are still lower than if there were no reserve. This design is appealing to policy-makers primarily concerned with climate change because unlike hard ceilings it allows for an absolute cap on emissions (Q_C), while still providing some, if not absolute, control of prices.

Studies comparing the effects of hard and soft ceilings on prices and total emissions are limited. A macroeconomic analysis of proposed legislation predicts that permits in the initial market would be purchased at the ceiling price for many years in order to bank permits in expectation of higher future prices (Williams, 2010). Fell et al. (2010) perform a dynamic numerical analysis, comparing the two mechanisms with banking of permits available. When targeting identical cumulative emissions goals in the presence of shocks to baseline emissions levels, they find the intuitive result that the hard ceiling decreases price volatility more than a soft ceiling, and the hard ceiling level required for emissions parity with the soft ceiling is higher.¹

While such findings are helpful for policy-makers in determining the optimal level and pathway for price ceilings, they do not address the behavior of individual agents who may deviate from theoretical assumptions of how optimization occurs. For instance, since a soft ceiling has no hard limit in the initial auction, it is only effective assuming that costs are minimized by balancing marginal costs with the price of permits across both the initial and reserve auctions. This would assume perfect foresight with respect to subjects' abilities to synthesize and predict information about permit prices and quantities in the reserve auction while trading initial allocations. It is therefore important to determine whether agents act with perfect foresight within a period, optimize based on the initial allocation only, or act as if using some combination of the two.

The main objective of this research is to determine the effectiveness of a reserve auction's soft ceiling to control prices in the initial auction for permits when prices would be higher than desired in the absence of a price control mechanism. We utilize an experimental

¹ Fell et al. (2010) study a price collar, which provides a hard price floor in the initial auction in conjunction with either a hard or soft ceiling.

laboratory setting in order to identify market behaviors which deviate from the outlined theoretical predictions. To isolate the impact of the soft ceiling, we consider stationary repetition of identical single period environments (i.e., no banking or borrowing of permits) and adjust only the price control mechanism across sessions. We take as a starting assumption a level of permits, Q_i , which leads to an undesirably high equilibrium price, P_i , when no price control is present. We then test hard and soft ceilings intended to achieve a lower target price (P_T). Because each policy is structured to target an identical equilibrium price and quantity combination, any differences in outcomes can be attributed to the behavior of agents in the experiment in reaction to policy conditions.

While hard ceilings have been studied extensively in the experimental literature in order to isolate convergence effects over repeated identical periods, soft ceilings have not yet benefited from such scrutiny. For instance, Isaac and Plott (1981) show that a non-binding hard ceiling decreases price bids in an experimental dual auction when compared to markets with no price ceiling. This effect is strongest in the initial periods amongst subjects with less experimental experience. Later work by Smith and Williams (2008) confirms this effect, noting that surplus is shifted from sellers to buyers due to the price decrease. These studies demonstrate that experimental results can deviate from theoretical predictions for a hard ceiling, often in early periods but in some cases over the entire experiment.

Cost and price controls have also been investigated in experimental permit markets.² When studying interactions between permit banking and emissions enforcement, Cason and Gangadharan (2006) find that banking diminishes price volatility in the presence of emissions shocks. However, emissions are greater when banking is allowed due to lower permit compliance rates. Stranlund et al. (2010) extend this analysis by explicitly separating compliance and reporting violations as two separate events. They find that the bulk of enforcement efforts to encourage permit compliance should be applied to untruthful reporting since large fines applied directly to non-compliance of emissions has little effect. In either case, banking of permits allows subjects to allocate permits reasonably well over time, even in the

² For a comprehensive outline of the usefulness of testing emissions permit market structures in an experimental setting, see Cason (2010).

presence of noncompliance. In a later paper, Stranlund et al. (2011) consider the ability of banking and hard ceilings to dampen volatility, finding that both tools are capable of individually controlling price volatility, even though the hard ceiling contributes most of the dampening effect when the two are implemented in tandem.

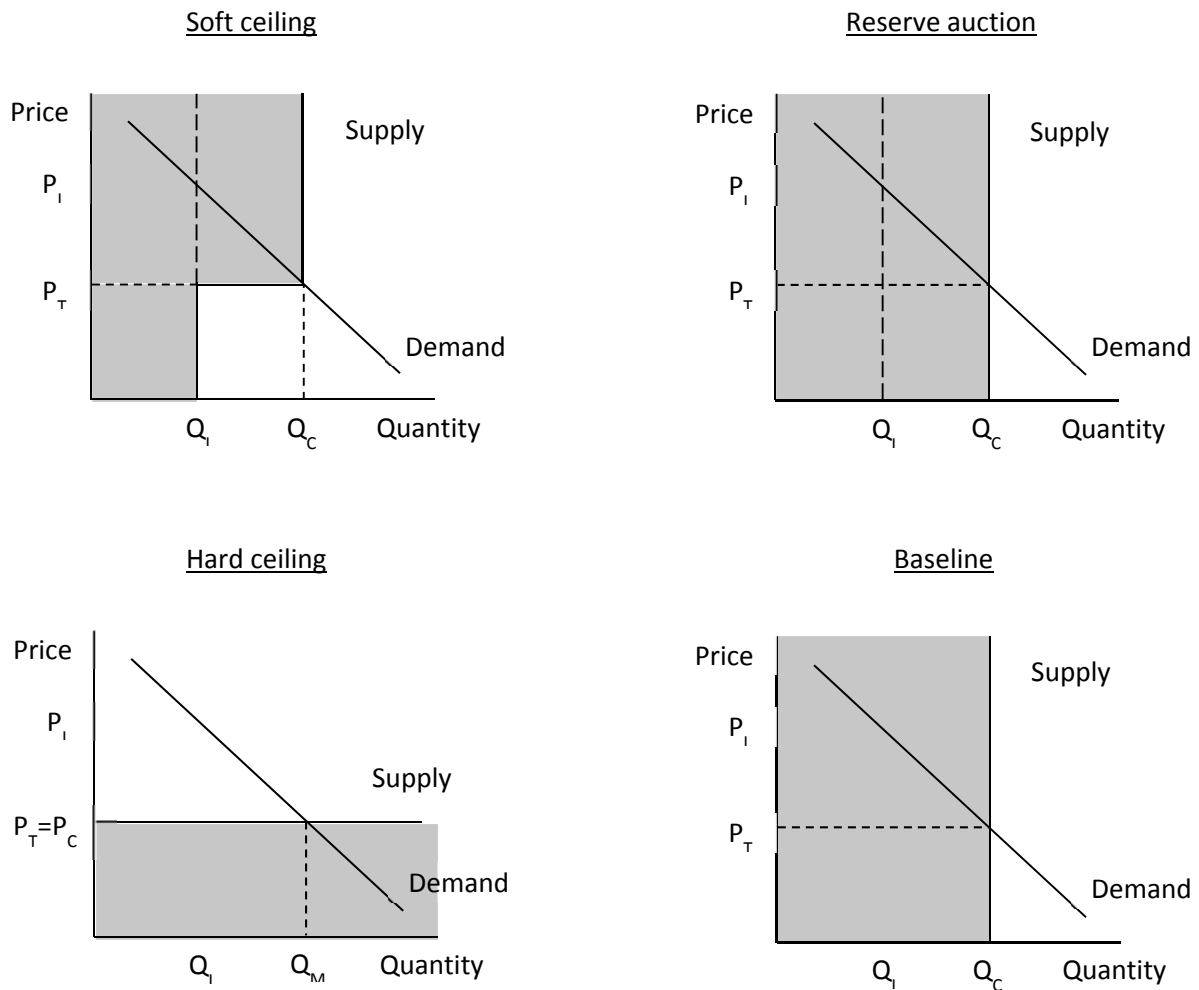
While the literature pertaining to cost and price controls in experimental permit markets is growing, there are no laboratory studies which test the effectiveness of either a reserve auction or soft ceiling to control prices in emissions permit markets. By isolating the effects of the structural components of a soft price ceiling on market prices, we hope to gain a better understanding of how recent legislation could impact price volatility and to inform future experiments which would combine price ceilings with other control measures.

(2) Methodology

We conduct 16 experimental sessions across four treatments consisting of a soft ceiling, a reserve auction with no soft ceiling, a hard ceiling, and a baseline permit adjustment for comparison. Figure 2 depicts the four policy choices tested. In each case, we assume an initial auction yields an equilibrium price and quantity of P_I and Q_I respectively, with $P_I > P_T$ where P_T is the target maximum price in the auction for permits. As stated earlier, each policy targets the same price, quantity combination such that any differences in actual price outcomes are caused by subject behavior and not policy targets. Starting in the upper left-hand corner of Figure 2, we test the soft ceiling, defined as a reserve auction with the key structural components outlined in Waxman and Markey, a reserve floor price and substantial grandfathering of permits (Soft ceiling). Moving clockwise, we test the same structure, but relax the minimum price floor in the reserve auction, thus eliminating the soft ceiling (Reserve auction). The purpose is to test whether price deviations from equilibrium can be attributed to coordination failures across the two auctions, strategic behavior affected by the soft ceiling, or a combination of both. We then test increasing the quantity to the same total cap (Q_C) as the first two policies, but without the use of a reserve auction (Baseline). We would expect this treatment to converge to equilibrium (P_T) and provide a control for the other treatments.

Finally we test a hard price ceiling (P_C) where the ceiling price equals the target price of the other three policies (Hard ceiling). The hard ceiling treatment was conducted in only 1 of the 16 sessions in order to confirm that prices would converge to the ceiling price.

Figure 2: Four policy treatments tested as price controls in an experimental market. (Shaded regions represent allowable trades.)



We employed 8 subjects per session for a total of 128 subjects from a group of undergraduate students at Purdue University with no prior experience in experiments related to emissions permit markets. In addition to a \$5.00 show-up fee, subjects earned experimental

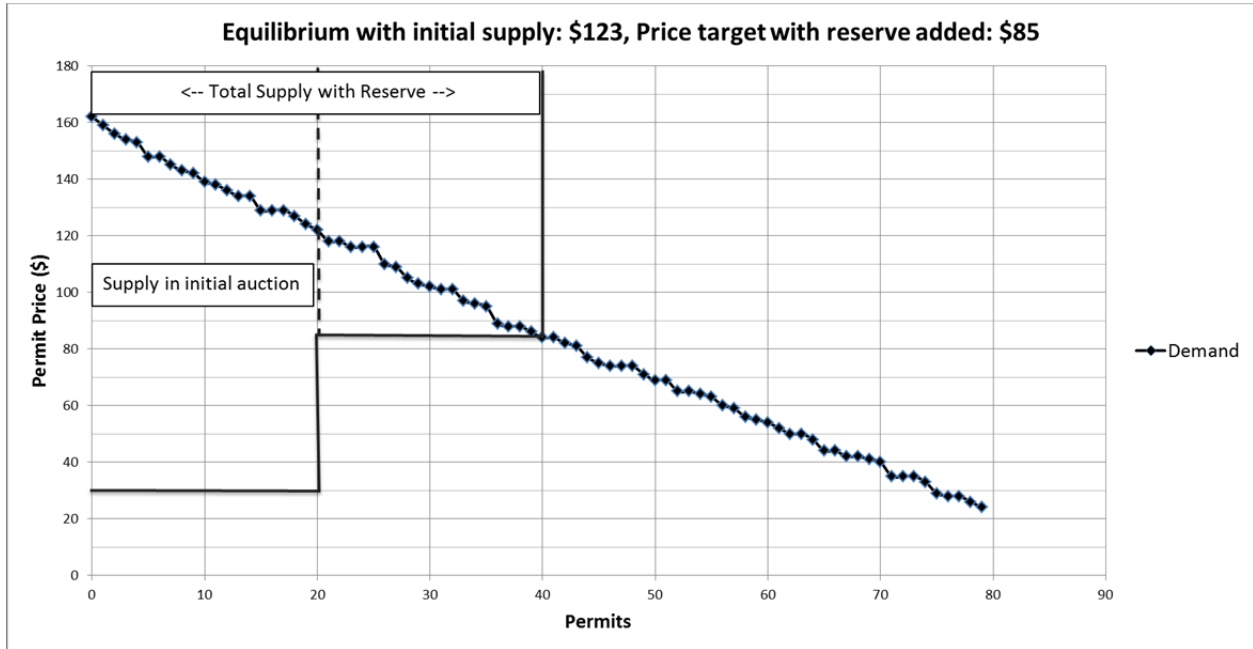
dollars which were converted immediately to U.S. Dollars at the conclusion of their experimental session. Average total earnings were \$26.69, with a standard deviation of \$6.37.

Subjects were provided the opportunity to manage a firm with an existing level of pollution and a fixed revenue stream. They were incentivized, through monetary payments, to minimize costs while accounting for all pollution through some combination of abatement and permit purchases. While this research focuses on pollution abatement, subjects did not view any environmental terminology. For example, the level of abatement of pollution was written as “units of an experimental good produced” and emissions permits were called “coupons.” All experiments were conducted over a computerized network, with subjects interacting in markets through a client interface programmed in Z-tree (Fischbacher, 2007).

For each session, 8 subjects participated in 14 identical and separate periods, the first 2 of which were practice with no payment. Within each period, all subjects were required to abate up to 10 units of pollution with increasing marginal costs of abatement or obtain permits to substitute for pollution not abated. At the end of each period, the sum of permits held and pollution abated were required to equal 10 for compliance. Each subject had a unique set of marginal costs, which when aggregated together determined the market demand for permits as illustrated in Figure 3.

For all treatments, 40 permits were distributed to the market in each period, with half being distributed before the initial auction and half before the reserve auction. (The one exception occurred in the Baseline treatment in which all permits were distributed before a single auction.) While a typical soft ceiling design would likely distribute a smaller proportion of the permit allotment in the reserve, we distributed 50% in order to increase the disparity between equilibrium prices with and without the reserve, and thus magnify behavioral effects on prices in our experimental market setting. The predicted equilibrium price in the initial auction is \$123. A successful price control would decrease the price in the initial auction down to a new equilibrium of \$85 as shown in Figure 3.

Figure 3: Demand and supply for permits in emissions market (Soft ceiling).



After initial permits were allocated, subjects were free to purchase and sell permits with each other in a double auction. We used this method to simulate the heavy grandfathering of permits built into the early years of the Waxman and Markey legislation. We utilized a trading institution similar to Cason and Gangadharan (2006) in which any subject could continuously make or accept single permit price bids for both selling and purchasing of permits.³ Several modifications were implemented on each subject's computer screen in order to present complete information to all subjects. First, we added an indicator for the abatement level corresponding to the number of permits held by a subject at any given time. Additionally, we posted all price ceilings and floors at the top of the screen during trading, both for the initial auction and the future reserve auction when applicable.

After completing the initial auction, reserve permits were distributed (except for the baseline treatment which ended at this point in each period). Subjects then traded within another double auction similar to the first. We used a double auction after grandfathering

³ Experimental instructions for the soft ceiling treatment are provided as supplemental materials. Instructions for other treatments are available from the corresponding author upon request.

reserve permits for two reasons: (1) the auction format already placed a high level of cognitive demand on subjects who had to constantly re-calculate derived values and costs from their marginal cost of abatement schedules. Learning two completely different auction formats would have likely been an unfair expectation on subjects. (2) Given that the reserve constituted 50% of all permits in our design, it was desirable for them to be grandfathered and traded rather than purchased from the regulator in order to more closely approximate the allocation methods of Waxman and Markey across all permits.

Before all auctions, permits were heavily distributed towards the 4 lowest cost producers with the 4 highest cost producers receiving a bulk of the revenue. The purpose of this design was to induce a high volume of trading and create active markets.

(3) Non-parametric tests comparing treatment prices

We have implemented four treatments designed to achieve equal emissions levels and targeting the same equilibrium price in order to determine the effectiveness of a soft ceiling in maintaining a maximum price. We test two reserve auction treatments, one with a minimum reserve price and one without, against two controls: a baseline treatment in which the reserve amount is added to the initial auction and a hard ceiling treatment which will maintain a maximum price by definition.

Based on previous research studying the effects of binding hard ceilings, one would expect prices to converge to the ceiling price over the course of the experiment. This appears to be the case as demonstrated by the mean of trading prices shown in Figure 4, with the hard ceiling price quickly approaching the maximum target of \$85 by the 8th period and averaging \$84.6 over the final five periods. Since the hard ceiling effectively achieves the objectives of controlling the price at the target, this treatment serves as a useful benchmark against which to evaluate other treatments.

The Baseline treatment is intended to determine whether subjects are able to achieve the desired equilibrium in a setting where values and costs are not stated, but derived from

their respective marginal cost of abatement schedules. Auctions with stated values and costs in which subjects take the role of either a buyer or a seller have been studied and used extensively both for research and teaching. In such experiments, it is common for subjects to converge to theoretical equilibrium prices after several periods. While our initial permit distribution was tilted in order to encourage subjects into the role of a buyer or seller, instructions clearly stated that they could achieve their objective of minimizing costs by potentially buying and/or selling coupons. This places two additional requirements on subjects compared to stated value and cost auctions: (1) determining whether to buy or sell at any given time and (2) re-calculating costs and values for the last permit held each time total permit levels are adjusted. Given these important deviations from the more basic auction format, it was not safe to assume that the Baseline treatment would necessarily converge to the equilibrium.

Figure 4: Mean of last 8 trades in initial auction for each period (all sessions)

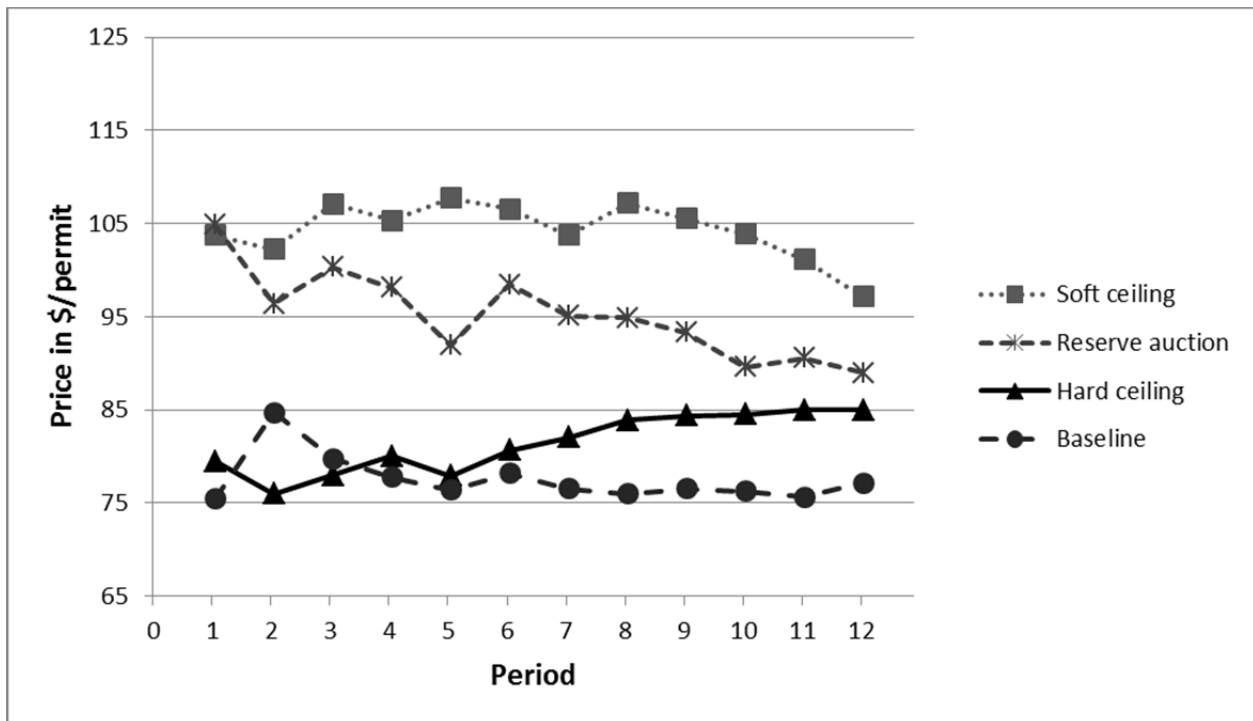
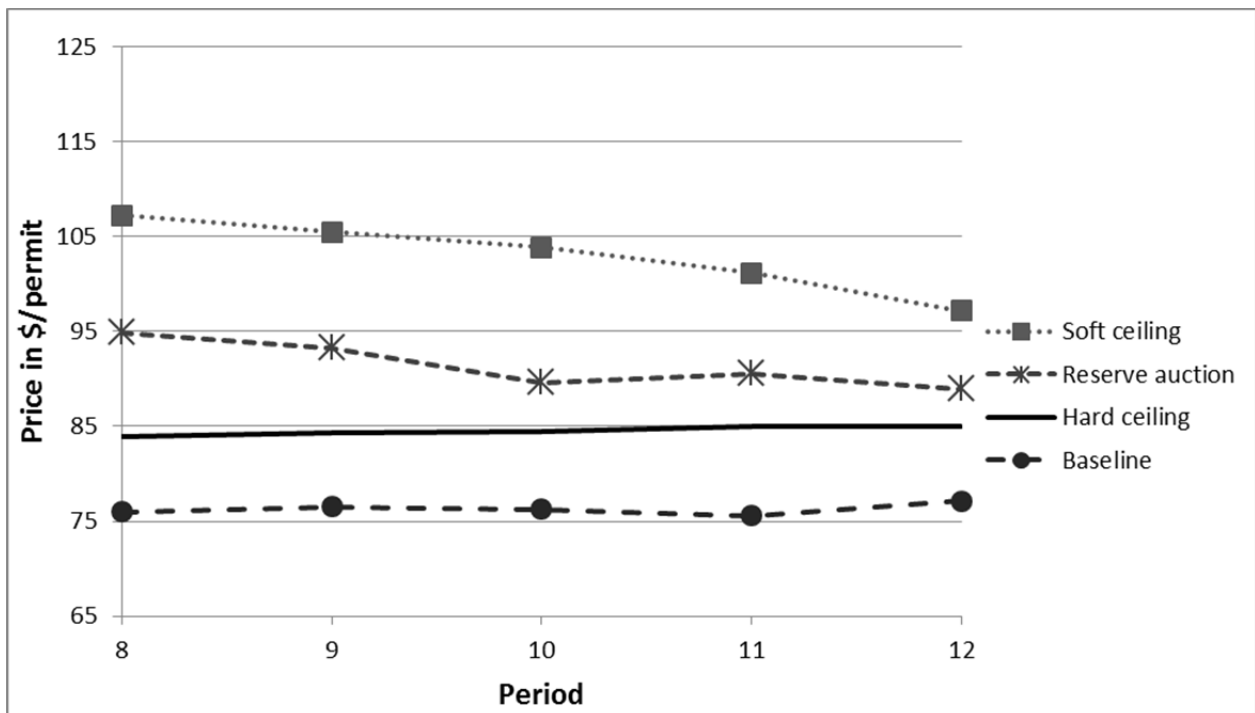


Figure 4 provides evidence that while the price ceiling encourages convergence to the target price, the conditions of the baseline treatment may not. Figure 5 highlights the last 5 periods of each treatment, demonstrating the spread between the baseline means and the expected equilibrium of \$85. While it would appear that they may be different by visual inspection, a non-parametric Wilcoxon Signed Rank test does not reject the null hypothesis that mean prices equal the equilibrium level at the 5% level, although equality is rejected at the 10% level (Table 1).

Figure 5: Mean of last 8 trades in initial auction for last 5 periods (all sessions)



The reserve auction treatment increases the complexity of the baseline in that cost minimization efforts must be balanced across two separate auctions. The more myopic the subjects in the initial auction, the more the price will be anchored near \$123, the equilibrium price without a reserve. If subjects learn from each period, they will eventually converge towards the target maximum price of \$85.

For the reserve auction treatment, we compared mean prices averaged over the last 5 periods for each session to the equilibrium prediction of 85 using the Wilcoxon Signed Rank test and to the baseline treatment using the non-parametric Mann-Whitney Test (Table 1). Both tests assume independence between sessions. While the graph suggests that prices are elevated for the reserve auction with no price floor, no significant difference in initial auction prices could be established when compared to the equilibrium or the baseline treatment.

Table 1: p-values for treatment comparison by non-parametric Mann-Whitney Test and Wilcoxon Signed Rank Test

Treatment	Soft Ceiling	Reserve Auction	Baseline
Mean Price (\$/permits)	103.0	91.5	76.3
vs. Reserve Auction	0.2738		
vs. Baseline	0.0040**	0.1548	
vs. Equilibrium (85)	0.0312*	0.2188	0.0938#

significant at 10% for one-sided test

* significant at 5% for one-sided test

**significant at 1% for one-sided test

Finally, adding the price floor of the reserve auction provides the last layer of complexity required for the soft ceiling policy of Waxman and Markey. To function properly, the price floor in the reserve auction is intended to dissuade purchases above this price in the initial auction when demand intersects with the elastic portion of the supply curve. However, subjects already possessing permits from grandfathering could be incentivized to hold out for higher prices, knowing that prices in the reserve auction will be limited by the floor. Referring again to Figures 4 and 5, it appears that prices are elevated compared to all other treatments. Non-parametric tests confirm this by strongly rejecting price equivalency of the soft ceiling approach when compared to both the equilibrium and the baseline treatment (Table 1).

(4) Subject experience and treatment effects on price

The non-parametric tests reported above focus only on the last 5 periods to highlight the later trades of each experimental session. Unfortunately, taking averages across only these periods can obscure visible downward trends in both the soft ceiling and reserve auction treatments (Figure 4), and these time trends in the data could be indicative of traders' incomplete convergence on an equilibrium price that was cut short in the final periods due to the limited length of the laboratory markets. It is therefore desirable to determine price outcomes using information from all periods in an analysis which can factor in experience, manage trends, and account for potential convergence patterns in the final periods.

The following model, introduced by Noussair et al. (1995) and adopted in several applications to test for convergence of adjusting prices in experimental markets (Cason and Noussair, 2007), is employed here for its ability to account for changes in experience over time:

$$\text{Price}_{jt} = \left(\sum_{i=1}^n (\beta_{i1} D_i (1/t) + \beta_{i2} D_i (1 - 1/t)) \right) + \varepsilon_{jt},$$

where i indexes the treatment, j indexes the session, t indexes the period,

$\text{Price}_{jt} \equiv$ mean of the last 8 prices of the initial auction in period t , session j ,

$\beta_{i1} \equiv$ the parameter for the starting price in treatment i ,

$\beta_{i2} \equiv$ the parameter for the asymptotic price outcome in treatment i ,

$D_i \equiv$ the dummy variable for treatment i , and

$\varepsilon_{jt} \equiv$ the error term for session j in period t .

This model accounts for the time pattern of prices using the terms $(1/t)$ and $(1 - 1/t)$. In the first period when $t = 1$, $(1 - 1/t) = 0$ and $1/t = 1$ so β_{i1} provides an estimate for the price at the start of the markets for treatment t . As t grows larger, $(1/t) \rightarrow 0$ so β_{i2} provides an estimate for the price outcome approached in the limit for treatment i assuming highly experienced traders.

Accounting for interdependencies between periods within each session requires the use of panel data regression methods. We define each of the 15 experimental sessions (excluding the single session testing the hard price ceiling) as a data cluster. A generalized linear model

procedure is employed which provides robust standard errors based on autoregressive behavior in order to account for correlated errors within each cluster.

Table 2 provides the desired estimates and the difference between the β_{i1} and β_{i2} coefficient estimates for each treatment i . The same conclusions drawn from non-parametric tests also hold in this regression analysis. The baseline treatment β_{i2} estimate is not significantly different from the equilibrium prediction of 85. The soft ceiling mechanism of Waxman and Markey elevates prices compared to the hard ceiling and baseline treatments. Finally, the reserve auction alone produces directionally higher prices on average, although they are not statistically significantly higher than equilibrium.

Table 2: Means and standard errors for price estimates of 3 treatments in the model^{a,b}

$$\text{Price}_{jt} = \beta_{11}D_1(1/t) + \beta_{12}D_1(1-1/t) + \beta_{21}D_2(1/t) + \beta_{22}D_2(1-1/t) + \beta_{31}D_3(1/t) + \beta_{32}D_3(1-1/t) + \varepsilon_{jt}$$

Treatment Parameter	$\beta_{i1}, t = 1$	$\beta_{i2}, t \rightarrow \infty$	$\beta_{i2} - \beta_{i1}$
	Mean Price	Mean Price	Price Change
	(\$/permit)	(\$/permit)	(\$/permit)
Soft ceiling ($\beta_{1.}$)	103.1 (2.1)	102.1 (2.4)	-1.0 (2.9)
	< 0.0001**	< 0.0001**	0.3664
Reserve auction ($\beta_{2.}$)	104.4 (6.9)	90.6 (8.4)	-13.8 (5.4)
	< 0.0001**	< 0.0001**	0.0053**
Baseline ($\beta_{3.}$)	70.7 (3.0)	81.4 (4.4)	10.7 (5.9)
	< 0.0001**	< 0.0001**	0.0347*

a Mean prices and price changes are provided with standard errors in parentheses and one sided p-values below.

b Robust standard errors are assumed based on session level clusters with an autoregressive correlation structure.

* significant at 5% for one-sided test

**significant at 1% for one-sided test

To summarize:

Result 1: In the baseline treatment with no price controls, prices attain the equilibrium price when the entire supply is provided in a single market.

With experience, subjects appear to manage the complication of constantly updating their marginal values and costs required by emissions permit markets. The estimated asymptotic price of \$81.4 (Table 2) is not significantly different from the target equilibrium price of \$85.0 as shown in Table 3 ($p=0.2072$).

Table 3: Comparison of prices from regression parameter estimates ($\beta_{i2}, t \rightarrow \infty$)^a

Treatment	Soft ceiling	Reserve auction	Baseline
Mean Price (\$/permits)	102.1	90.6	81.4
vs. Reserve auction	11.6 (8.7)		
	0.0928 #		
vs. Baseline	20.7 (5.0)	9.2 (9.5)	
	< 0.0001**	0.1665	
vs. Equilibrium (85)	17.1 (2.4)	5.6 (8.4)	3.6 (4.4)
	< 0.0001**	0.2531	0.2072

a Differences between means are provided with standard errors in parentheses and one sided p-values below.

significant at 10% for one-sided test

* significant at 5% for one-sided test

**significant at 1% for one-sided test

Result 2: The hard price ceiling controls prices as intended.

Figure 5 demonstrates that the hard ceiling treatment price converges towards the target of \$85.0, with the average market price in the final two periods equaling the ceiling price exactly. Past research assessing price ceilings in experimental markets has demonstrated eventual convergence of price with the ceiling, with more experienced subjects converging more quickly. Our subject pool was drawn from students with no experience in emissions permit markets, and showed convergence times commensurate with inexperienced subjects in other studies.

Result 3: The soft price ceiling does not control prices as intended.

Mean prices in the initial auction are significantly elevated above the equilibrium price when utilizing a soft ceiling design similar to Waxman and Markey (Table 3). The null hypothesis that prices are equal to the equilibrium price of 85 ($p < 0.0001$) or the baseline treatment ($p < 0.0001$) are clearly rejected.

Result 4: The reserve auction alone appears to control prices amongst experienced subjects in this setting. However, prices are elevated compared to the equilibrium at the beginning of the price discovery process.

Table 4: Comparing 1st period reserve auction treatment price to end of session prices^a

Treatment	Mean Price (\$/permits)	Difference vs. Reserve auction (t=1)
Reserve auction (t=1)	104.4	
Soft ceiling (t → ∞)	102.1	2.3 (7.3) 0.3783
Reserve auction (t → ∞)	90.6	13.8 (5.4) 0.0053**
Baseline (t → ∞)	81.4	23.0 (8.2) 0.0024**
Equilibrium (85)	85.0	19.4 (6.9) 0.0024**

a Differences between means are provided with standard errors in parentheses and one sided p-values below.

**significant at 1% for one-sided test

When implementing a reserve auction with no minimum reserve price (no soft ceiling), prices are elevated in the early periods (\$104.4) compared to the equilibrium (Table 4), rejecting the null hypothesis that prices equal the target price of 85 ($p=0.0024$). The reserve auction alone therefore produces price outcomes in the beginning of trading sessions similar to

the soft ceiling design (Table 2). As subjects gain experience, the prices decrease significantly ($p=0.0053$, Table 2) to \$90.6, which cannot be rejected as being equivalent to the equilibrium price ($p=0.2531$, Table 3). Thus, while the reserve auction alone does not provide absolute control of prices, it yields prices similar to the target once subjects have gained experience over numerous identical periods.

(5) Welfare gains from trade

Finally, welfare gains are calculated to determine if experimental prices lead to welfare advantages for net sellers or buyers of permits. Please recall that permits were more heavily allocated to the 4 traders with low marginal costs of abatement in order to create active markets. Such traders became net sellers of permits while the other 4 traders with small initial permit allotments became net buyers. For each period, a subject's welfare gains are calculated as:

$$\begin{aligned} & \text{Revenue from permits sold} - \text{Marginal abatement costs realized from selling permits} \\ & - \text{Cost of permits purchased} + \text{Marginal abatement costs avoided from buying permits} \end{aligned}$$

Welfare gains differ from total profits in that they do not include fixed period revenues or initial abatement costs before trading. Thus, welfare gains are completely determined by the efforts of subjects.

In an efficient market for this experiment, net buyers would purchase enough permits at the equilibrium price (\$85) to avoid any marginal abatement costs above this price. Similarly, net sellers would sell enough permits at the equilibrium price to incur any marginal costs below this price. With these assumptions, the theoretical welfare gains for an efficient market can be calculated for the aggregate of net sellers and net buyers separately. The proportion of efficient welfare gains realized is then determined by calculating the ratio of actual realized welfare gains to theoretical efficient welfare gains. Note that this proportion can be greater than 1. For instance, if net buyers are able to consistently purchase permits below the

equilibrium price, they could realize welfare gains greater than the efficient level at the expense of net sellers.

The same regression model and panel data methods used to analyze prices are also used for welfare analysis, with the proportion of efficient welfare gains replacing average price as the dependent variable. We are interested in late period welfare gains for experienced subjects.

Result 5: With the soft ceiling policy, net sellers of permits realize greater welfare gains than efficient levels at the expense of net buyers.

Under the soft ceiling, net sellers realize welfare gains 1.31 times the efficient level (Table 5). This is significantly different at the 5% level and 1% level than the proportions for the reserve auction (0.87) and baseline (0.82) treatments respectively. As deadweight losses for the soft ceiling are not statistically different than the other two treatments (ranging from 0.14 to 0.20⁴), this large welfare gain occurs at the expense of net buyers, who realize a gain of only 0.5 times their efficient level. This gain for net buyers in the soft ceiling is significantly different at the 10% level and 1% level from the proportions for the reserve auction (0.74) and baseline (0.91) treatments respectively.

(6) Conclusions

A hard ceiling provides an absolute maximum for prices, allowing the number of permits, and therefore the amount of emissions, to increase as much as needed when prices hit the ceiling. Some scientists, economists, and policy-makers concerned with the ecological effects of GHGs have gravitated towards reserve auctions and soft ceiling designs which have the desirable property of placing an absolute cap on emissions levels, while still providing some level of price control in theory. Their concern is that a hard price ceiling could increase emissions considerably if the market price is consistently pegged against the ceiling. To date,

⁴ Deadweight losses are a proportion of efficient welfare gains from trade, and are considerably smaller when reported as a proportion of efficient total profits.

the only GHG legislation which has been passed in either house of the United States Congress includes a soft ceiling design.

Table 5: Comparison of welfare gains from trade for end of session ($\beta_{i2}, t \rightarrow \infty$)^a

Treatment	Soft ceiling	Reserve auction	Baseline
Proportion efficient gain realized	1.31	0.87	0.82
Sellers			
Difference vs. soft ceiling		-0.44 (0.22)	-0.49 (0.13)
Sellers		0.0222*	0.0001**
Proportion efficient gain realized	0.50	0.74	0.91
Buyers			
Difference vs. soft ceiling		0.24 (0.16)	0.41 (0.09)
Buyers		0.0697#	< 0.0001**

a Differences between means are provided with standard errors in parentheses and one sided p-values below.

significant at 10% for one-sided test

* significant at 5% for one-sided test

**significant at 1% for one-sided test

Our experimental evidence demonstrates that while a hard price ceiling can act as an effective price control, the reserve auction and soft ceiling designs may not control prices at target levels due to the behavior of market participants that leads to deviations from theoretical predictions. This result holds for both reserve auction designs in the early trading periods when subjects are less experienced with the trading mechanisms of emissions permit markets and price discovery has just begun. Once subjects have gained experience in the market, significantly elevated prices are observed only for the soft ceiling design.

One potential explanation for elevated prices may pertain to the heavy grandfathering of permits inherent in the soft ceiling legislation. The grandfathering of permits has been shown to elevate prices compared to the direct auctioning of permits by the government (Goeree et al., 2009). This effect could be augmented by the minimum reserve price. If permits are grandfathered in an initial auction, and traders are aware that the reserve will have a

minimum price, they would be reticent to sell below this price when they can hold out and compete against the higher reserve prices. Our evidence lends credence to this theory as net sellers are able to obtain welfare gains larger than efficient levels at the expense of net buyers. Further testing of the soft ceiling in an environment without grandfathering of permits would help to solidify whether sellers are holding out for the higher minimum reserve price.

While these experimental markets show that the soft ceiling is ineffective in controlling prices at theoretical targets, advocates of soft ceilings may consider this an acceptable tradeoff to avoid the lack of absolute control over emissions levels afforded by the hard ceiling. Nonetheless, hard ceilings are useful to provide short term price stability, and the ceiling price could be adjusted periodically to achieve cumulative emissions targets. Unlike other pollutants which may be toxic based on flow levels to the environment within each period, the deleterious nature of GHGs is generally impacted by stock amounts within an ecological system. This affords regulators utilizing a hard ceiling system the flexibility to manage GHG levels across periods without extreme concern for emissions spikes within a given period. In such a system, quantity control adjustments of the hard price ceiling would replace the discount rate adjustments currently proposed in most legislation. The rule for making adjustments would be well-defined and clearly communicated so as not to introduce additional uncertainty to permit markets.

A similar approach has been recommended by Metcalf (2009) for emissions taxes, with the tax adjusted yearly to a greater or lesser extent as a function of proximity to cumulative emissions benchmarks. Adjusting a hard price ceiling yearly using similar criteria would avoid the artificially inflated prices of the soft ceiling while providing for control of cumulative emissions over time. Furthermore, allowing the market to set prices within a controlled price range would provide more information regarding price discovery than Metcalf's variable tax.

Acknowledgments

This research was funded by the National Science Foundation Human and Social Dimensions Grant 0729348. Cason acknowledges support from the U.S. Environmental Protection Agency's National Center for Environmental Research (NCER) Science to Achieve Results (STAR) program (EPA grant number R833672).

References

- Burtraw, D., Palmer, K., Kahn, D., 2010. A symmetric safety valve. *Energy Policy* 38, 4921-4932.
- Cantwell, M., 2009. The Carbon Limits and Energy for America's Renewal (CLEAR) Act: A Simple, Transparent, and Equitable Approach to Energy Independence and Climate Change Mitigation. The Office of Senator Maria Cantwell, Washington, DC.
- Cason, T.N., Gangadharan, L., 2006. Emissions variability in tradable permit markets with imperfect enforcement and banking. *Journal of Economic Behavior & Organization* 61, 199-216.
- Cason, T.N., Noussair, C., 2007. A Market with Frictions in the Matching Process: an Experimental Study. *International Economic Review* 48, 665-691.
- Fankhauser, S., Hepburn, C., 2010. Designing carbon markets. Part I: Carbon markets in time. *Energy Policy* 38, 4363-4370.
- Fell, H., Burtraw, D., Morgenstern, R., Palmer, K., Preonas, L., 2010. Soft and Hard Price Collars in a Cap-and-Trade System, RFF Discussion Paper. Resources for the Future, Washington, DC.
- Fell, H., Morgenstern, R.D., 2010. Alternative Approaches to Cost Containment in a Cap-and-Trade System. *Environmental & Resource Economics* 47, 275-297.
- Fischbacher, U., 2007. z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics* 10, 171-178.
- Goeree, J.K., Holt, C.A., Palmer, K., Shobe, W., Burtraw, D., 2009. An Experimental Study of Auctions versus Grandfathering to Assign Pollution Permits, Discussion Paper 09-39, Resources for the Future. Resources for the Future.
- Isaac, R.M., Plott, C.R., 1981. Price Controls and the Behavior of Auction Markets: An Experimental Examination. *American Economic Review* 71, 448-459.
- Metcalf, G.E., 2009. Cost Containment in Climate Change Policy: Alternative Approaches to Mitigating Price Volatility, NBER Working Paper Series. National Bureau of Economic Research, Cambridge, MA.
- Murray, B.C., Newell, R.G., Pizer, W.A., 2009. Balancing Cost and Emissions Certainty: An Allowance Reserve for Cap-and-Trade. *Review of Environmental Economics and Policy* 3, 84-103.
- Noussair, C., Plott, C., Riezman, R., 1995. An Experimental Investigation of the Patterns of International Trade. *American Economic Review* 85, 462-491.

Smith, V.L., Williams, A.W., 2008. Chapter 5 Effect of Non-binding Price Controls in Double Auction Trading, in: Plott, C.R., Smith, V.L. (Eds.), Handbook of Experimental Economics Results. Elsevier, pp. 46-53.

Stranlund, J.K., Murphy, J.J., Spraggon, J.M., 2010. An Experimental Analysis of Compliance in Dynamic Emissions Markets.

Stranlund, J.K., Murphy, J.J., Spraggon, J.M., 2011. Price Controls and Banking in Emissions Trading: An Experimental Evaluation, Association of Environmental and Resource Economists, Inaugural Summer Conference, Seattle, WA.

Waxman, H.A., Markey, E.J., 2009. House Passes Historic Waxman-Markey Clean Energy Bill. Congressman Edward Markey Press Release.

Williams, E., 2010. An Analysis of the Carbon Limits and Energy for America's Renewal (CLEAR) Act and Comparison to Waxman-Markey, in: Solutions, N.I.f.E.P. (Ed.). Duke University, Durham, NC.