What Can Laboratory Experiments Teach Us About Emissions Permit Market Design?

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The laboratory provides a test bed to inform many design choices for emissions permit markets. Experiments are sometimes strongly motivated and structured by specific theoretical models and predictions, but in other cases the experiment itself can be the model of the market and regulatory environment. We review specific experimental applications that address design issues for permit auction rules, permit expiration dates and banking, liability rules, and regulatory enforcement.

Key Words: cap-and-trade, auctions, liability, regulation, compliance, banking

Emissions trading has grown significantly in importance in the regulatory toolkit over the past few decades. The flexibility allowed by this approach, which is often referred to as cap-and-trade, is estimated to have saved billions of dollars as a key component of efforts in the United States to cut sulfur dioxide (SO_2) emissions in half during the 1990s. Emissions trading is now the centerpiece of many serious efforts worldwide to reduce greenhouse gas emissions. Emissions permits convey rights that can be exchanged between firms, subject to some constraints and rules chosen by the regulator, and these trades lower the overall cost of meeting an environmental goal by equalizing the marginal abatement costs across sources (Montgomery 1972). But what market rules and constraints are necessary, and which harm the performance of the emissions trading system? Should the regulator rely on trading institutions to emerge naturally, even if this results in relatively decentralized markets with high transaction costs, or instead take steps to encourage or even sponsor centralized trading institutions? The principle of emissions trading is elegant and simple, but market performance can depend on many design factors. The devil is in the details. Fortunately, laboratory experiments can create *real,* simplified, and controlled markets to help answer important questions like these.

The laboratory is useful because all markets are influenced by similar economic forces. Laboratory markets are populated by profit-motivated human agents, just as markets in the field are, and with induced incentives and other controls they are actual market microeconomic systems (Smith 1982). Different forces are stronger and more complex in different situations, of course, but they can be isolated and studied with careful experimental designs. Few economists would dispute that theoretical models are useful for providing insight into the factors that influence how markets perform. A theoretical model is a simplified abstraction constructed to help the researcher understand some real-world phenomenon. It is not intended to mirror every detail. An experiment is also a simplified construction, and it is often closely guided by a theoretical model. But the experiment is typically closer to the "real world" field than the theory is, because it includes

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human decision makers who may be boundedly rational or have nonstandard preferences that influence market outcomes in important ways. Experiments can thus serve as a bridge between theory and the field markets where our interest ultimately lies, since they indicate whether and how predictions developed through theoretical reasoning can be applied to more complex field conditions.

This article reviews some laboratory experiments that have been used to inform specific aspects of emissions permit design. One approach has been to develop theoretical models of the relevant market institutions and rules, and then evaluate the predictive value of these theoretical models using experiments that are constructed on the domain of the theories. The next section presents some examples of this approach. Sometimes theory provides less direct guidance, but the experiments can still provide a useful "test bed" to evaluate the researchers' or regulators' intuitions even when they are not modeled formally. The experiment itself is the model of the emissions trading system, and the impact of different design features can be investigated within the experimental model (Bardsley et al. 2009, Ch. 4). This article also presents some examples of this type. In all cases the point of these experiments is to evaluate *specific* features of the market or emissions property rights, and not a wide variety of design features simultaneously. The control of the lab is especially useful for answering particular design questions. The conclusion highlights some unanswered research questions, and discusses methodological extensions to further improve external validity of these types of experiments.

Theoretical Models and Emissions Experiments

In some cases the regulator has already chosen or even implemented some design features of an emissions trading system when an experiment is conducted to evaluate the implications of those features. This first example is based on the earliest emission permit auctions, which were for SO_2 allowances and started in 1993. The U.S. Environmental Protection Agency (EPA) followed guidance in the Clean Air Act Amendments of 1990 ("the Act") in implementing a new auction institution with some unusual incentive properties. This institution could be modeled theoretically under some simplifying assumptions. Although alternative, uniform price auction rules could be implemented without any additional regulatory burden, the EPA's initial interpretation of the Act was that the unusual rules were required. Therefore, the EPA did not consider running a field or lab experiment to determine whether the uniform price institution could perform better. The laboratory, however, can provide exactly this comparison under controlled conditions.

The Act stated that "allowances shall be *sold on the basis of bid price*, starting with the highest-priced bid and continuing until all allowances for sale at such auction have been allocated" (emphasis added).[1] The EPA interpreted this as implying a discriminative price auction, with winning buyers paying their own bid prices. Such discriminative (or "pay-as-bid") pricing rules are not unusual. The unusual feature of this auction is that individual sellers receive the bid prices of "matched" buyers, with higher priority and thus higher bid prices given to sellers who offered lower prices. The Act also required the EPA to offer a reserve onto this central auction of about 2.8 percent of the total allowances available, at an asking price of zero, to ensure that the auction provided some early price signals to this new market. The vertical arrows in Figure 1 illustrate how specific bids are transferred to specific sellers, as well as the priority of the EPA reserve allowances.

Cason (1993) showed that the bid-to-offer matching scheme of this new EPA auction creates incentives for all buyers and sellers to submit offers below their marginal cost of emissions abatement. Consequently, it can generate downwardly biased price signals—counter to Congress's goal to provide accurate price signals for this emerging market. By contrast, specialists on the New York Stock Exchange set the daily opening price for securities using a uniform price call auction, and such uniform price rules for sealed bid-offer auctions are common worldwide for securities that have low trading volume. Figure 1 illustrates this uniform price with a horizontal dashed arrow. Rustichini, Satterthwaite, and Williams (1994) showed that precisely because only the marginal

[1] Clean Air Act Amendments of 1990 (Public Law 101-549), Sec. 416(d)(2).

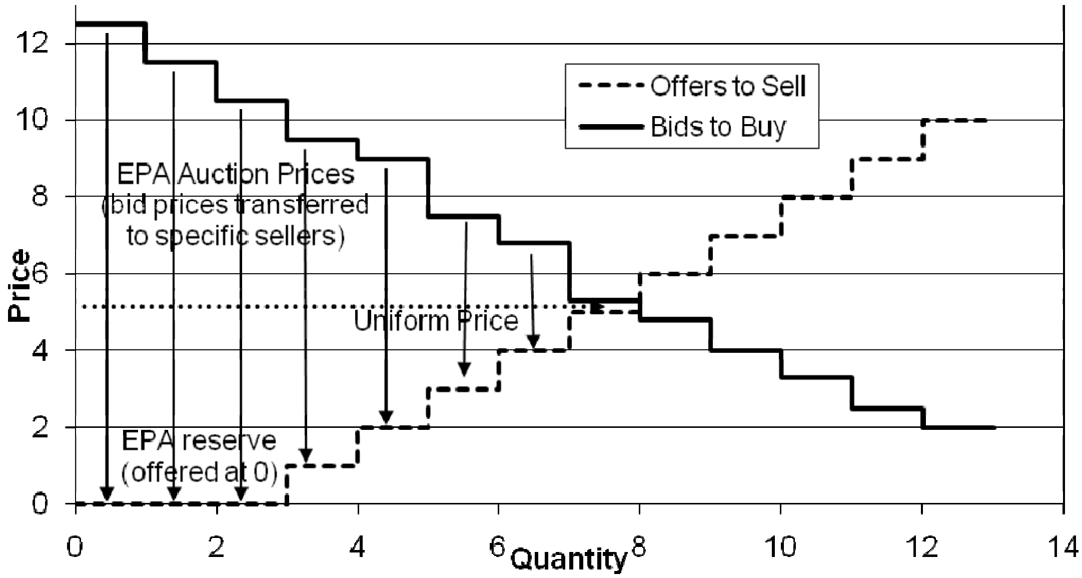


Figure 1. Example Offers and Bids to Illustrate the EPA Auction Rules

traders affect price under uniform price auction rules, both buyers and sellers in this trading institution have an incentive to almost fully reveal their true valuations (here, their marginal abatement costs) in their bids and asks. This truthful revelation allows the market to realize nearly all available gains from exchange, and provides more accurate price signals.

Cason (1995) confirmed that human subjects could recognize and bid according to the theoretical incentives of the EPA auction rules in an initial experiment that included only the seller side of the market and varied the number of traders. Cason and Plott (1996) included both buyers and sellers in their experiment, and also compared behavior and performance of the EPA auction to the more standard uniform-price auction rules. Sellers in these EPA auctions quickly recognized that they could obtain higher prices by offering permits well below cost, and the overall level of value and cost misrepresentation in the trader bids and offers far exceeded levels seen in other auction institutions. In the experiment the EPA auction rules generate lower market-clearing prices and extract fewer gains from exchange than the uniform price auction rules. The EPA auction also responds more slowly to changes in underlying market conditions. Compared to the uniform-price auction, prices in the EPA auction are less accurate reflections of underlying marginal abatement costs, and they therefore provide inferior signals for firms considering investments in emissions control.

Besides having poor incentive properties, the EPA auction is also risky for potential permit sellers. Sellers have the incentive to submit offers below cost, and if they are matched with low-bidding buyers they could potentially receive payments that fail to cover their cost. (This sometimes occurred in the experiments.) The auction also does not allow buyers to purchase a multi-year stream of permits to cover anticipated emissions for an investment such as a new or expanded power plant. These factors led to the virtual abandonment of the EPA auction by sellers (Joskow, Schmalensee, and Bailey 1998).[2] Other than the reserve allowances that the Act forces onto the auction, virtually no permits were sold in auctions held between 2003 and 2009.[3]

[2] Multi-year streams of permits could be included, however, in a centralized and low transaction cost market using a combinatorial auction (Porter et al. 2009).

[3] See http://www.epa.gov/airmarkt/trading/auction.html (accessed July 3, 2009).

Based in part on evidence provided by these experiments, the U.S. General Accounting Office recommended a switch to more standard uniform-price rules (GAO 1994). The EPA determined that the statutory language of the Act permitted it to switch to a uniform-price rule, and solicited comments to a proposal to make that change because this "may have the benefit of producing a less confusing price signal…."[4] Ultimately, however, EPA decided to retain the existing rules. Most trades now occur through brokers (with high transaction costs) and not through a centralized exchange. Nevertheless, the SO_2 program is generally regarded as a success, and as a model for other emissions trading programs (Ellerman et al. 2000). Fortunately, no other programs have adopted its unusual auction rules.

This is just one example of an emissions trading experiment that is strongly motivated by and designed around specific theoretical models and predictions. Another example is reported in Murphy and Stranlund (2007), who use an experiment to study compliance behavior in an emissions market with imperfect enforcement. Stranlund and Dhanda (1999) showed that compliance decisions in emissions trading programs are independent of any firm-level characteristics, since each firm faces the same marginal cost of compliance: the prevailing permit price. This implies that enforcement targeted towards specific firms, which is theoretically justified in command-and-control regulation, is theoretically misguided in emissions trading systems.

To test this important policy implication, Murphy and Stranlund (2007) studied compliance decisions by laboratory subjects who faced probabilistic inspections and fines for violating reporting rules. In one "regulatory" treatment they faced uniform emissions standards where enforcement targeting is justified, and in another treatment the subjects traded permits and it was not justified. Consistent with theory, violations were independent of subject characteristics only when they could trade permits. Nevertheless, those traders who had low permit endowments and thus were permit buyers in equilibrium tended to have higher violation rates. Overall, this experiment provides direct empirical evidence that enforcement targeting has limited value in emissions trading schemes because the flexibility provided by trading equalizes marginal compliance costs. Laboratory evidence like this can sometimes be more convincing to regulators than purely theoretical arguments.

Experimental Models and Emissions Experiments

Theoretical modeling is more prominent in economics than in many other social sciences. Empirical research in economics often begins with formal hypotheses derived within the structure of a theoretical model. The empiricist then tests these hypotheses with naturally occurring or experimental data. While this approach has its strengths, *experimental models* are also useful for providing insight into complex new design problems such as those faced by regulators implementing emissions trading systems. The idea is to create experimental designs to capture key aspects of the real-world market, and then vary features of the market to investigate how this affects outcomes (Bardsley et al. 2009, Ch. 4).

Experimental models are useful for institutional design in part because purely theoretical modeling is constrained by the theorist's imagination (Smith 2008). An experiment with human subjects leaves room for other, unimagined factors to influence outcomes. It can also serve as a test bed to try out new rules and institutions, even those guided not by specific theoretical predictions, but rather by the designer's intuitions. Importantly, experiments provide a very low-cost way to identify weaknesses and strengths of alternative design features.

Consider, for example, the banking or expiration date rules for emissions permits. For some environmental problems, most prominently greenhouse gas emissions, atmospheric concentrations are largely cumulative and so the timing of emissions is immaterial. Future emissions are never worse than current emissions of the same amount. The timing of emissions is important and must be regulated for other environmental problems, such as ground-level ozone, nitrogen and sulfur oxide (NO_X and SO_X) emissions, and many waterway discharges. One way to ensure that emissions occur only in a specific time period is to limit when

[4] Federal Register, Environmental Protection Agency (40 CFR), Part 73, "Acid Rain Program, SO_2 Allowance Auction and Electronic Allowance Transfer; Advanced Notice of Proposed Rulemaking," pp. 28995–28998 (June 6, 1996).

emissions permits can cover releases. Unfortunately, this can lead to considerable price volatility in a permit market, especially when actual emissions are uncertain and are correlated across sources. Emissions correlation can arise for a variety of reasons, such as weather (e.g., an unusually hot or cold season spread over a large geographic area) or macroeconomic factors (e.g., the business cycle, or exchange rate fluctuations affecting the competitiveness of imports and exports).

Carlson et al. (1993) illustrated the potential volatility of emission permit prices due to emissions correlation in a pair of experimental sessions that were instrumental in leading the South Coast Air Quality Management District to adopt innovative rules for permit expiration in the RECLAIM NO_X and SO_X emissions permit system in Southern California. All permits had the same annual expiration date in the original proposed plan. Carlson et al.'s experiment showed that this rule led to dramatic price spikes in periods with positive shocks in emissions, as traders competed to obtain scarce permits in order to maintain compliance. Conversely, following negative emissions shocks, prices crashed to near zero as traders dumped unneeded permits on the market.

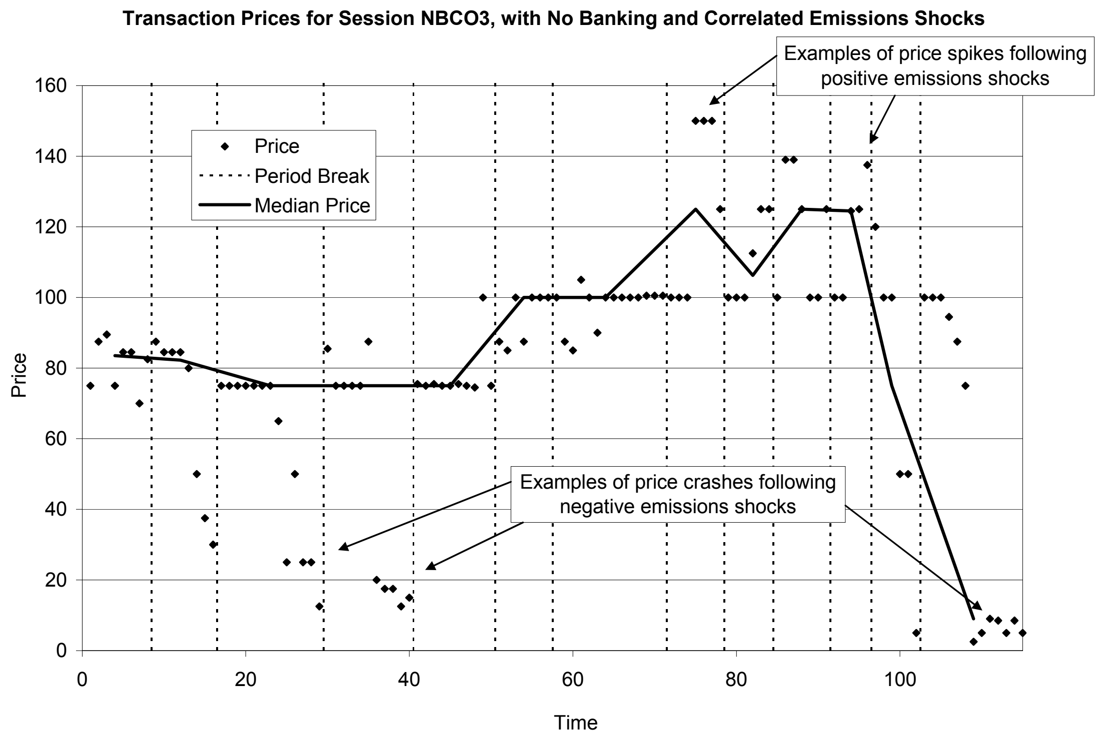
To avoid this problem the researchers proposed and tested a system with overlapping expiration dates of annual permits. All permits could be redeemed to cover emissions over a 12-month interval, but some permits expired on December 31 and some expired on June 30. Emissions at any point in time could thus be covered by two different types of permits. The researchers conducted an experimental session with these rules, with traders facing the same pattern of positive and negative correlated emissions shocks that led to price spikes and crashes with the regulator's original plan for a common expiration date. Permit prices were substantially less volatile in this session, since the substitutability of the two alternative permit types allowed the market to buffer and smooth out the emissions shocks. No formal theoretical modeling was necessary, and the experimental demonstration of this simple intuition was sufficient to convince the regulator to adopt the proposal for overlapping expiration dates.

Allowing unused permits to be banked for future use is another way to smooth out price variation that can arise from uncertain and correlated emissions. If emissions are lower than expected, unused permits can be banked and do not need to be dumped on the market before the end of the compliance period. The banked permits also provide a reserve that can be drawn down when emissions are higher than anticipated, avoiding price spikes. Cason and Gangadharan (2006) implemented emissions shocks by adding or subtracting an independent shock to each trader's chosen emissions target. The shocks were correlated in some sessions by making all shocks either nonnegative or nonpositive in certain periods. The experiment included permit markets conducted in the exact same underlying environment, except that banking was allowed in some sessions and not allowed in others.

Figure 2 illustrates the difference in price volatility for two sessions with correlated emissions shocks. The two panels display the time series of individual permit transaction prices for a sequence of compliance periods (differentiated by the vertical lines), as well as the median transaction price for each period connected with the thick solid line. The top panel highlights some periods in which large negative or positive aggregate shocks led to substantial transaction price swings. Notice that the very low or high prices occur towards the end of the trading periods (i.e., just before the vertical period break line). These trades occur after the emissions shocks are reported to the traders, and the excess supply or demand of permits causes prices to drop by as much as 90 percent or rise by up to 50 percent.[5] By contrast, the lower panel features permit banking, and even though the same underlying stochastic process generated correlated emission shocks, the price volatility is significantly lower.

The lower panel, however, also illustrates a negative consequence of banking. In this experiment traders reported their emissions voluntarily, and they faced probabilistic inspection and financial penalties for misreporting. As emissions trading systems expand beyond cases like SO_2 emissions that can be monitored electronically and continuously, imperfect enforcement can lead to

[5] Price crashes can also arise when permits are overallocated and no banking is allowed. A dramatic example occurred in the field at the end of Phase I (2007) in the European Union's greenhouse gas Emissions Trading Scheme. Permits were generously allocated by many EU member countries, and they were not bankable for use in Phase II. When market participants recognized this overallocation, permit prices collapsed to near zero. This price crash would not have occurred if permits had been bankable.



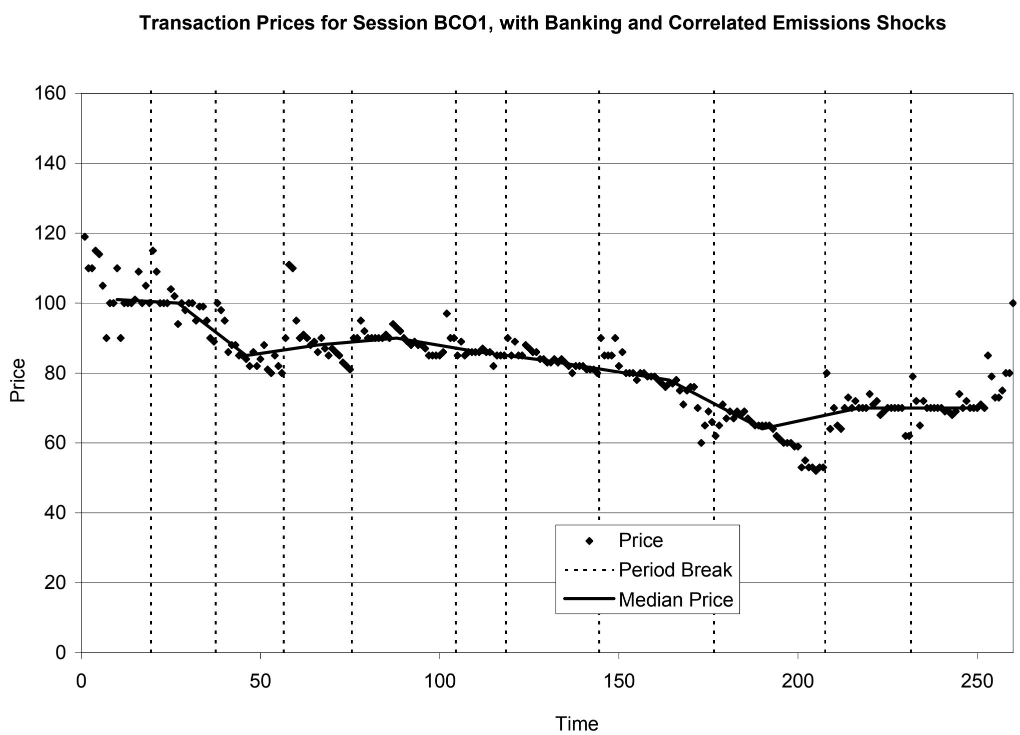


Figure 2. Impact of Allowing Permit Banking When Emission Shocks Are Correlated Across Sources

various types of noncompliance. For the permit supply and marginal abatement costs in the environment underlying Figure 2 (not shown), equilibrium prices under full compliance are in the range [88, 91]. Noncompliance causes the effective supply of permits to increase and lowers transaction prices. This noncompliance is a proximate cause of the progressively lower prices observed in the lower panel of Figure 2.[6]

Banking increases the incentive to underreport emissions because lower reported emissions allow the firm to carry over "unused" permits. These permits have a financial value when banking is allowed because they can be used or sold in subsequent periods. Cason and Gangadharan (2006) found that banking significantly increased noncompliance, while also reducing price volatility. Price stability is important to equalize marginal abatement costs across firms and provide clear incentives for R&D into new emission control technologies, but regulatory compliance is also obviously important. The regulator faces a trade-off when deciding whether to allow banking, and if enforcement is weak (perhaps due to statutory limits on fines) then banking limitations may be warranted, even though this comes at the cost of some price volatility.

Stranlund, Costello, and Chavez (2005) modeled the relationship between banking and compliance, drawing a distinction between permit violations (i.e., failing to hold sufficient permits to offset emissions) and reporting violations (i.e., misrepresenting actual emission levels to the regulator). Consistent with theory, Stranlund, Murphy, and Spraggon (2009) provide some preliminary experimental evidence that high compliance rates are possible with a low permit violation penalty provided that reporting violations are penalized more strongly.

Although enforcement policies have a direct influence on compliance incentives, these incentives are also influenced by the liability rules that apply when noncompliance can lead to permit "default." If party A sells permits to party B, then A is responsible for limiting her emissions to comply with a smaller number of permits. If both trading parties are subject to the same regulatory authority, then the regulator can view the purchased permits by B as valid and simply penalize A if she fails to limit her emissions. The matter is more complicated, however, if A and B are subject to different regulatory authorities and their interaction is not overseen by a strong system of legal enforcement. Key examples include the international trading of emission permits, or emission offsets that are traded through systems such as the UNFCCC's Clean Development Mechanism. In these cases the parties may be regulated in different countries, and legal commitments are difficult to enforce without ongoing international cooperation. Sanctioning authority is usually not granted in treaties. In this case if A fails to limit emissions sufficiently, a seller liability rule may not be available to penalize A to ensure that the buyer B holds valid permits and is in compliance.

Cason (2003) studied the effectiveness of an alternative buyer liability rule in promoting compliance in these circumstances. Traders set emission reduction targets, but they had to make costly investments to increase the likelihood that their targets were met. In one treatment their "reliability investments" were unobservable, and in another treatment they could have these investments inspected and revealed to potential buyers in the market. Similar to bonds that have a higher default risk trading at a price discount, permits that were sold with unknown reliability traded at a discount to reflect their greater default risk. This price discount apparently motivated sellers to invite inspection of their reliability investments, and consequently overall efficiency was greater in the treatment with the inspection option.

Godby and Shogren (2008) compared buyer liability and seller liability rules in a different experimental environment, but without the opportunity for permit sellers to invite inspections of their reliability investments. They did, however, include conditions that allowed sellers to acquire good reputations through market interactions that repeated with an unknown endpoint. In contrast to the main result in Cason (2003), buyer liability performed poorly and led to widespread market failure. Prices and trading volume were much lower with buyer liability than with seller liability rules. This is similar to what occurred in the treatment in Cason (2003) with buyer liability when reliability investments could not be inspected. This suggests that the difference in buyer

[6] Weaker enforcement has a direct negative effect on compliance incentives because of its lower likelihood of penalties. Murphy and Stranlund (2006) highlight that weaker enforcement makes compliance less expensive, however, since it leads to lower transaction prices, and this generates a positive indirect effect on compliance.

liability performance could be due to the availability of credible reliability inspections. Thus, a tentative conclusion that could be drawn across these independent studies is that when seller liability is problematic due to limits on international sanctioning, authorities should promote the development of objective and credible international certification of projects intended to reduce emissions.

Experimental models are obviously simplifications, but they include the factors that the experimenter believes are relevant to the market design or research question. The experiments focus on capturing the underlying market incentives, and the words to describe the items being traded are not considered in standard economic models to be part of those incentives. Consequently, all of the experiments summarized to this point used neutral framing to describe the laboratory markets. Pollution, emissions trading, and the environment were never mentioned. For example, subjects often traded abstract "coupons" and had to "choose a number" (the number choice corresponded to the level of emissions abatement).

This neutral framing is common for laboratory experiments across most subfields in economics, and it is often justified by the experimenter's desire to obscure the experiment's context and purpose from subjects. The goal is to increase experimental control by limiting subjects' ability to invoke mental scripts.[7] Advocates of field experiments, however, sometimes argue that neutral framing can reduce control if it leads subjects to invent their own context for an abstract, neutrally framed experimental task. The subjects' personal context is, in this case, unobserved by the experimenter (Harrison and List 2004). Whether the use of a neutral context affects behavior and market outcomes is, of course, an empirical question that is perfectly suited for experimental investigation.

Raymond and Cason (2009) manipulate framing as a treatment variable in an emissions trading experiment in order to assess the strength of affirmative motivations on compliance, such as the personal sense of a law's legitimacy or morality. This contrasts with the negative motivations—fear of costly punishments for violations—that is the foundation of economics research on compliance. The experiment also varied these motivations by changing the enforcement strength: emissions were audited with a 25 percent probability in the low enforcement treatment, and with a 50 percent probability in the high enforcement treatment. In the environmentally framed treatment, subjects were told to imagine themselves as managers of a fossil fuel burning electricity plant who could buy permits to legally emit pollution or incur pollution abatement costs to reduce emissions. We expected that this environmental framing would prime affirmative motivations relative to traditional neutral framing. We also assessed subjects' compliance, environmental, and emissions trading attitudes through pre- and post-experiment surveys.

Figure 3 shows that both the level of enforcement and the environmental framing significantly affected compliance rates. (Here, compliance is measured by the percentage of subjects' reports that accurately describe to the regulator the level of emissions for the period.) While increased enforcement leads predictably to more compliance, the environmental framing led to *less* compliance than neutral framing. This unexpected finding is robust across enforcement levels and other factors such as equal versus unequal initial permit endowments that were also manipulated in this experiment. At least in the context of the experimental model, changing the framing had as large an impact on compliance as doubling the random monitoring rate from 25 to 50 percent. This should be troubling to experimental economists who often believe that framing effects are minor, at least for market experiments. This belief is often based on faith, rather than facts derived from controlled experimentation. These new results challenge that belief for emissions permit market compliance.

Conclusion

The examples reviewed here illustrate how experiments can evaluate the performance of specific trading institutions, such as new auction institutions implemented specifically for emissions trading, and how permit banking affects price volatility when emissions cannot be con-

[7] See Alm (1999) for a discussion of these issues for laboratory experiments on tax compliance.

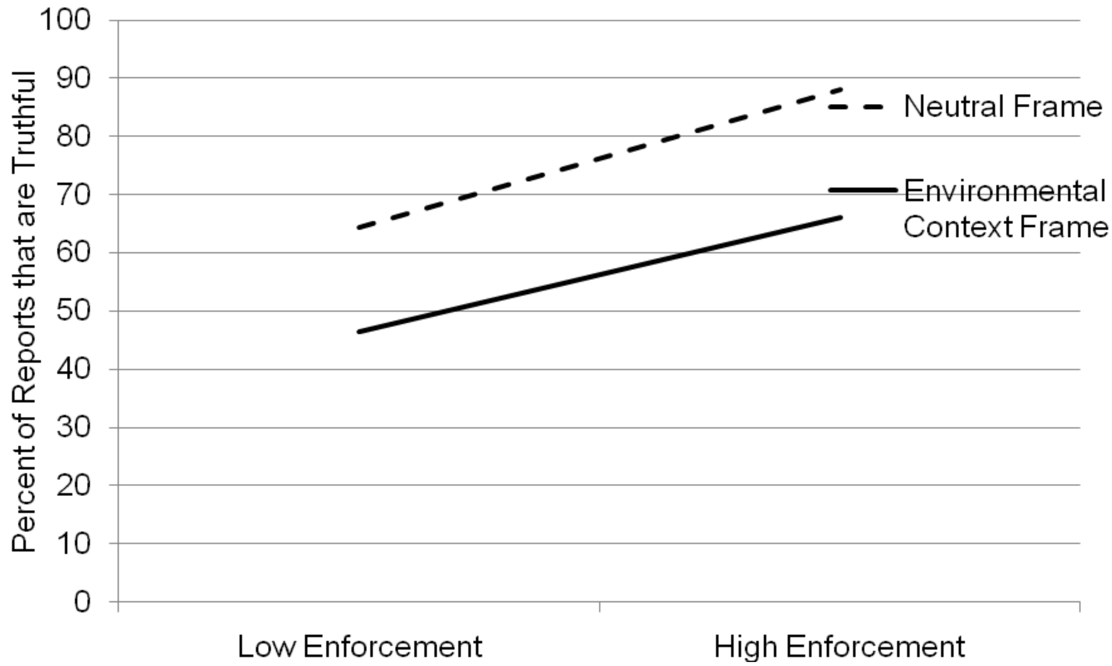


Figure 3. Percentage of Emission Reports That Are Truthful, by Enforcement Level and Experiment Framing

trolled perfectly. They can also identify conditions in which different types of liability rules can improve the information provided through market prices, so that efficient international trading can occur even without a strong legal framework for addressing permit defaults.

This review is necessarily selective, and scores of other articles and book volumes report additional examples of applied permit market design research using laboratory experiments (e.g., Isaac and Holt 1999, Cherry, Kroll, and Shogren 2008). Nevertheless, many important research questions remain unaddressed. Some are inspired by current debates in the United States and Europe regarding permit allocation methods, even though the allocation is generally considered by economists as merely a distributional, political issue. As of this writing, it appears that in a possible tradable permit system in the United States for greenhouse gas emissions, initially most (80+ percent) permits will be grandfathered to existing emitters with only a small fraction auctioned. These grandfathered permits will trade in an aftermarket along with auctioned permits, and experiments can determine how this interaction affects the speed and accuracy of price discovery in both the primary auction and secondary aftermarket. Economists are also skeptical of political claims that grandfathered permits will lower the burden of increased costs downstream for final consumers of energy. Even though grandfathered permits are received without an explicit cost, they are a tradable asset with an opportunity cost.[8] Experiments can test the theoretical prediction that downstream prices rise by the same amount regardless of whether permits are grandfathered or auctioned.

Although laboratory experiments are useful for providing some initial answers to questions about permit market design, they are only one tool. Field experiments of various kinds are also necessary, and existing research suggests that such experiments could provide qualitatively different insights. Most emissions trading experiments employ student subjects and a neutral, non-environmental context, although a few exceptions exist (e.g., Bohm and Carlén 1999). As noted above,

[8] In the case of regulated utilities, one critical factor is how this cost is included in the rate base.

framing effects appear to be large even for student subjects, and previous research has found that context framing is most useful for expert subjects participating in field experiments, since the context allows them to draw on past experience (Cooper et al. 1999, Alatas et al. 2009). It is important to extend permit market experiments to include environmental managers and other decision makers in affected industries as subjects, such as in Poe, Suter, and Vossler (2009), particularly for research investigating non-economic incentives for compliance with emissions trading rules and regulations.

As more emissions trading programs are implemented in the field, researchers will use data from these field markets, and conclusions drawn from these data can be compared to parallel data from designed field and laboratory experiments. Naturally occurring data from the field and data from experiments are complements, not substitutes. Even if emissions markets become widespread, however, an important role will still exist for experiments to provide a low-cost test bed to initially evaluate alternative market designs and rules. Besides using professional subjects more often, additional innovations can improve the external validity of such experiments. These include incorporating additional realistic institutional details, such as the political processes leading to permit allocations and market rules. Future experiments can also add real environmental consequences, such as actual emission increases that depend on subjects' decisions in the experiment. This would be particularly useful to study social motivations for market participants' compliance decisions when enforcement is imperfect.

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