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### 3 *Caveat emptor Kyoto*

#### Comparing buyer and seller liability in carbon emission trading

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##### Introduction

Tradable emission markets continue to be promoted as a cost effective tool to manage global public goods such as climate protection. A prominent example of such global emission trading systems is in the 1997 Kyoto Protocol (UNFCCC 1999). Recall the Kyoto Protocol required the leading industrialized countries to reduce their greenhouse gas (GHG) emissions by an average of 5 percent below 1990 levels by 2008–12.<sup>1</sup> These reductions are severe relative to current GHG emission rates and will likely be costly to achieve (e.g. see Nordhaus and Boyer, 2000; Shogren, 2004). To minimize control costs, Kyoto allows for some flexibility in GHG mitigation, including the international trading of GHG emission quotas (Article 17).

Emission trading allows regulated emitters to buy emission reduction efforts from other emitters – in effect, contracting other emitters whose abatement costs are less than their own to make reductions for them (see Crocker, 1966; Dales, 1968). Emission markets have several appealing properties over traditional “command and control” regulation, and chief amongst them is the fact that market outcomes can theoretically result in emission reductions occurring at least cost to society. Domestic trading programs in the United States indicate that realized cost savings can be substantial. Emission trade has also occurred at the international level, and was used successfully, though in a limited way to administer reductions in the use of ozone depleting substances demanded by the Montreal Protocol (see Solomon, 1999; Schmalensee *et al.* 1998; Stavins, 1998).

Global emission trading is central to cost effective climate policy because by some estimates it could halve compliance costs (e.g. CEA, 1998). The effectiveness of such global trading depends on the rules of enforcement and sanctions for nations that shirk on their emission commitments (e.g. Article 18 in Kyoto). Domestic trading programs in the United States and elsewhere have relied on strong enforcement and sanctioning frameworks to ensure market compliance. Demands posed by national sovereignty concerns, however, make the usual organization of emission permit markets problematic in an international setting, particularly with respect to Article 18 (see Rabkin, 1999; Barrett, 2003). In international treaties, it has been noted that “sanctioning authority is rarely

granted by treaty, rarely used when granted, and likely to be ineffective when used" (Chayes and Chayes, 1998, p. 32). As noted by Barrett (2003, p. 323) the Kyoto treaty "ignored enforcement. This was something that the negotiators thought they could add later. But this problem should be viewed from the other direction. . . . Enforcement is the main challenge, and it needs to be addressed directly".

The critical issue is who should be held liable for overselling permits beyond quotas – the seller or buyer country? Relatively weak under-compliance penalties and ineffective monitoring methods create the incentive for selling nations to oversell permits and shirk on their emission responsibilities due to the magnitude of the potential permit revenues. Proceeds from international GHG trading could be significant – the former Soviet Union countries projected emission trading revenues under Kyoto may be as high as \$17 billion (Edmonds *et al.*, 1999). Cason (2003) notes that this value, measured in 1992 dollars, is equivalent to three-quarters of Russia's trade surplus in 1997, or equal to the value of all lending between the US and Russia between 1990 and 1996. Overselling eliminates the benefits to emission trading in reducing GHG emissions. Kyoto and climate change provide our motivating example, but the problem of relatively weak enforcement holds for any proposed emission trading system that crosses the borders of sovereign nations. International enforcement of emission reductions inside a sovereign nation is unlikely to be authoritative if based strictly on moral suasion or threats of potential trade sanctions (see Rabkin, 1999).

To most economists, *seller liability* is the obvious choice if the goal is to minimize transaction costs because all permits have the identical value to buyers, and only one market is needed to transact all permits. In domestic non-climate emission trading programs, sellers are held liable for any permit shortfalls. To others, however, *buyer liability* is the choice given their objective – to make sure that the relatively rich buyer nations (e.g. US, Japan) are liable for any shortfalls in emission reductions made by the relatively poorer sellers (e.g. Russia, Costa Rica); see for instance Baron's (1999) description of liability rules that could be used to support international GHG trade. Here *caveat emptor* rules. Permits sold by non-compliant nations would be returned to the sellers, and the buyers would face the consequences of any resulting permit shortfalls. Conveniently, buyer liability avoids the difficult issues arising from the negotiation of tough enforcement measures while creating incentives for efficient market outcomes (e.g. see the Third Assessment Report of the IPCC, 2001).

The argument for buyer liability arises from a belief that buying implies a commitment by the purchaser to ensure emission compliance, and this commitment creates an incentive for buyers to seek out sellers likely to comply with their emissions obligations thus increasing overall market compliance (see Victor, 2001). While opponents contend that buyer liability will undermine efficient emission trading by depressing market prices and trade volume due to its increased risk, proponents counter that fears of thin markets due to high transaction costs are exaggerated.

Buyer liability rules increase the complexity of global emission markets. Differences in the perceived likelihood of sellers being in compliance would result in buyers having different valuations for permits based on their origin, and the need for separate markets for permits offered by each seller. Differences in permit prices across sellers and incomplete information regarding the likelihood of seller compliance could both decrease the economic efficiency of using emission markets to achieve emission goals and increase the economic and environmental risks faced by buyers. Such concerns have been downplayed by some groups lobbying for particular types of liability rules in global emission trade negotiations. For example, the Environmental Defense Fund (1998) said:

in view of the limited set of enforcement tools available to an international regime, nations should adopt a limited but effective form of "buyer liability" to create incentives in favor of compliance and to ensure that the environment is made whole.

The idea is that buyer liability results in buyers purchasing from those sellers they believe will honor commitments, an outcome that helps the climate. Other observers, while less optimistic about the cost savings, note "buyer liability increases the environmental performance of the system by reducing the probability of invalid permits circulating" (Kopp and Toman, 1998). The working thesis is that buyer liability leads to greater climate protection, as markets form to capture the gains from trade and reputations work to police market behavior (e.g. European Business Council for a Sustainable Energy Future, 2000). Also see Woerdman (2001) who argues:

from the perspective of environmental effectiveness, buyer liability is preferable to seller liability, since it would strengthen compliance incentives by discouraging buyers to purchase emission reductions from (entities in) countries which appear to be heading towards non-compliance. Both from an economic and environmental perspective, buyer liability is still preferable to a quantitative restriction on trade, because such a restriction crudely reduces the overall cost saving potential, whereas buyer liability increases transaction costs but leaves the efficiency untouched.

This chapter explores the relative efficiency of a *caveat emptor* carbon trading program. Using a stylized Kyoto emission market double auction experiment in which liability rules are the treatment, we show that buyer liability under relatively weak international enforcement leads to the worst possible outcome – less climate protection at greater costs.

To our knowledge, no empirical studies have attempted to compare buyer and seller liability outcomes in markets. While not directly comparing seller liability and buyer liability, Cason (2003) finds that in experimental buyer liability markets where sellers can make a commitment to honor their obligations, market performance is enhanced relative to when such commitments cannot be made or

are unobservable. Hailes and Missfeldt (2001), using a simulation study, find that introduction of supplementary rules such as reserve accounts and minimum eligibility requirements for market participation can be sufficient to induce market formation and increase market efficiency in international emission markets. They may not, however, eliminate all losses such rules impose on the market.

We consider relatively weak enforcement levels to reflect the view held by many observers, in which potential sanctions on sovereign nations over international emissions trading are likely to be meager (see for example Cooper, 1998; Schelling, 1997). Our findings indicate buyer liability lowers economic efficiency, distorts permit prices and market production patterns. We find such rules also significantly worsen environmental performance through greater non-compliance. Adoption of buyer liability with relatively weak enforcement renders emission trading inadequate by subverting the goals of Kyoto – creating less environmental protection at greater economic cost.

We test the robustness of this result by creating a setting more likely to produce spontaneous “good seller” reputations in the permit market such that buyer liability would be more likely to succeed. We increased the monitoring probability and introduced a random ending point in the markets. Overall, we find that our main finding was relatively robust. Higher enforcement reduces output and increases emission compliance under seller liability, as predicted. But contrary to prediction, permit trade occurred under buyer liability as some sellers reduced production to support trade. A random ending point led to outcomes similar to those observed with a fixed end point. Under buyer liability, although the results were not inconsistent with a weak reputation effect, we still observed more permit trading and production than expected.

Our laboratory design is a test of concept experiment (see e.g. Plott, 1983). We do not calibrate the experimental parameters to exact features one might expect in a climate treaty; rather we test the concept of buyer liability within a global emission market. We work with climate but several environmental policy initiatives have considered buyer liability rules. Examples include the EPA Open Market Rule (since withdrawn), several proposed effluent markets in the US, the PERT emission trading market in Canada and in a proposed emission market for SO<sub>2</sub>/NO<sub>x</sub> in southern Ontario (Ontario Government Ministry of the Environment, 2001; PERT, 2000). To date, however, no studies exist to determine how the choice of liability rules affects market outcomes. Herein the choice of liability rule is a treatment variable to investigate the impact of the choice of liability rules, in which the general implications apply to a wide variety of settings.

### Experimental environment, design and hypotheses

The laboratory is an effective means to test economic institutions, and has been used extensively in the development of emission trading programs. See for instance Muller and Westelman (1998) for an overview of emission permit

experiments conducted to evaluate American and Canadian program proposals. Bohm and Carlen (1999) and Carlen (1999) report experiments testing institutional issues other than liability in international GHG trade (also see Soberg, 2000). Cason (2003), for example, considers how buyer liability rules affect market outcomes when firms commit to technologies that ensure emission compliance to reduce uncertainty about their ability to sell permits.<sup>2</sup> Our design extends this work by comparing how buyer and seller liability affects market outcomes. We compare the performance of three liability rules: (i) *seller liability* – seller non-performance inflicts sanctions on the seller only, (ii) *buyer liability* – seller non-performance inflicts sanctions on buyers only, causing trades to be canceled and forfeiture of buyer's permit costs, and (iii) *buyer liability with refund* – seller non-performance inflicts sanctions on buyers only, while sellers forfeit any permit revenues. For buyer liability, it has been suggested the incentive for sellers to oversell permits could be eliminated with the creation of “escrow accounts” (see Baron, 1999). Expenditures for permit purchases are deposited in these accounts and not released to sellers until it had been verified they had not overproduced. We include a refund treatment to test this hypothesis explicitly. Since an international trading framework remains unspecified, our laboratory environment purposefully focuses on the essential features of liability choice in a market under relatively weak international enforcement of emission shirking by sovereign nations.

### Experimental environment, treatments and procedures

The 12 experimental sessions reported were conducted, each using a different set of student subject volunteers. To investigate the effect of alternative liability rules on market outcomes, one seller and two buyer liability treatments were considered using an ABA crossover design. Each session conducted three treatment rounds as described in Table 3.1. Each treatment “round” consisted of eight market periods, requiring 24 market periods to be conducted in each experimental session.

The laboratory environment in each session was designed to replicate the market incentives that would be present in possible emission trading markets without exactly replicating the decisions required in any particular market setting that might occur. Each session involved eight experimental subjects who were informed they represented a firm producing and selling a product at an announced market price. Production costs varied across subjects, though production capacity did not. All costs were subjects' private information and production profits earned “lab-dollars”. In each period, each subject would choose a level of *production*; however, each was aware that their actual production level could be either one more, one less or the exact level they chose with an equal probability. Subjects recorded production choices on their own computer terminal. Subjects were further informed that while production of each unit of output was expected to occur only if they held a permit to do so, it was possible to produce without a permit – but each faced a fixed and known probability of

Table 3.1 Experimental design

Session	Symbol	Round			
		0	1	2	3
		Treatment	Treatment	Treatment	Treatment
011003	SBS-1	Practice	Seller liability	Buyer liability	Seller liability
011004	SBS-2				
011017	BSB-1	Practice	Buyer liability	Seller liability	Buyer liability
011018	BSB-2				
011010	SRS-1	Practice	Seller liability	Buyer liability w/refund	Seller liability
011011	SRS-2				
011012	RSR-1	Practice	Buyer liability w/refund	Seller liability	Buyer liability w/refund
011015	RSR-2				
011022	BRB-1	Practice	Buyer liability	Buyer liability w/refund	Buyer liability
011023	BRB-2				
011025	RBR-1	Practice	Buyer liability w/refund	Buyer liability	Buyer liability w/refund
011026	RBR-2				
020307	SBS-HM-1	Practice	Seller liability	Buyer liability	Seller liability
020315	SBS-HM-2		High enforcement	High enforcement	High enforcement
020415	BSB-HM-1	Practice	Buyer liability	Seller liability	Buyer liability
020418	BSB-HM-2		High enforcement	High enforcement	High enforcement
020604	SB-RE-1	Practice	Seller Liability	Buyer liability-Random end point	N/A
020607	SB-RE-2				
020615	SB-RE-3				

being monitored individually to determine if they held enough permits to cover their production. If found to have produced without enough permits to cover production, individual subjects faced a fixed fine for every unit produced in excess of their permit inventory.

Each subject was endowed with an initial lab-dollar balance at the beginning of the experimental session. At the start of each period in the session, some subjects were also endowed with *permits* while others were not. After production decisions were made, subjects with permits (referred to as *seller's*) had the opportunity to sell permits to those who were not endowed any (*buyers*) using a computer-mediated double auction, which opened for a fixed period of time. These markets were open for 150 seconds in rounds 1 and 2, and 120 seconds in round 3 of each session. Subjects' permit endowments and auction roles each period remained constant throughout the experiment. Once purchased, permits could not be resold to other subjects and could not be carried over to future periods. After this market closed, subjects were informed of their actual production levels, production profits earned, their permit revenues or expenditures, whether they were monitored and any monitoring fines incurred and their earnings in the period, and then a new period began. At the end of the experiment, subjects were paid privately in cash an amount based on their accumulated lab-dollar earnings, converted to US dollars at a fixed and announced exchange rate. Individual subject earnings ranged from \$27 to \$73, with a mean payment of \$45.70 and standard deviation of \$7.02.

We imposed three treatments on the market, two in each experimental session (see Table 3.1). In *seller liability* (SL) treatments, any subject found to have produced without enough permits was fined for each unit produced without a permit. *Buyer liability* (BL) treatments imposed per unit fines on any buyer found to have produced without permits, while sellers faced no such fine. Instead, if sellers were monitored and found to have overproduced, any permit sales made in the period were canceled in reverse order until they either had enough permits to cover their production or until all sales had been canceled. After permit sales were canceled, sellers were not fined even if their production exceeded their permits. Buyers who had to return permits were then monitored and fined for each unit produced without a permit. Sellers also kept any permit sales revenues, even if permits were returned. Under *buyer liability with refund* (BLR) treatments, the same rules applied as those just described, with the exception that permit expenditures for canceled trades were refunded to buyers. Under both buyer liability treatments, any buyers forced to return permits to a seller were informed of this outcome on their computer. Using a whiteboard at the front of the laboratory, any seller who had sales canceled was identified by their ID number, the period the cancellation occurred and the number of sales canceled.

A total of 96 subjects were recruited to participate in one of the 12 experimental sessions, each lasting 2.5–3 hours. Of these subjects, 87 were undergraduates, primarily from business disciplines, while nine were first or second year graduate students in Finance or Economics. One session included three graduate

students, while six other sessions included one graduate student. Since none had previous experience with the market environment or decisions they faced, experimental sessions began with each subject being given a folder and randomly assigned to an experimental role and ID number. Following standard experimental protocol, each folder contained worksheets and experimental instructions particular to that session describing how to use the computer software developed for the experiment and subjects' experimental tasks. Subjects were asked to follow along as the instructions were read aloud. All instructions are available by request. An instruction phase followed that lasted approximately 45 minutes and included two unpaid practice periods, one using the training parameters and one unpaid and unreported practice session using the actual experiment parameters. Seller liability was used in practice sessions, since it is a familiar setting to subjects.

To aid subjects in their production choices, a *profit calculator* was provided on their computer to explore their potential profits for various production and permit holding levels if they were or were not monitored. Table 3.2 reports the actual subject production costs, initial permit endowments, redemption values (production price) of output, probability of being monitored and fine per unit of excess production used in the experiment. For purposes of analysis, we assume that one unit of emissions was created for each unit of output produced. We never mentioned pollution or production emissions during the experiment and we used context-neutral terms in the instructions to avoid potential framing effects.

Figure 3.1 shows the general experimental procedure in each session. Experiment instructions included details regarding the number of periods in each round and the number of rounds in the session. Under seller liability conditions, buyers should be indifferent to the origin of any permits purchased so only one auction market opened. In buyer liability treatments, we expected buyers to be concerned with the source of the permit and how many permits any seller had sold since buyers might expect different sellers to have different probabilities of overproducing. Buyer's valuations for permits could differ across sellers thus we accommodated these concerns by simultaneously opening four permit auctions in which each seller could sell permits only in the market corresponding to their own their own ID number. All sessions used the same set of random monitoring and stochastic production outcomes in each period to ensure session outcomes were comparable. A monitoring probability of one in six was maintained for each subject in every period.

Prior to the experiment, random production outcomes were generated using a random number generator drawing over the unit interval. To determine which subjects were monitored in any period, a dice roll was used, with the number rolled on the dice determining the subject monitored in the period. Since there were eight subjects in each period, two different subjects were excluded from each period's dice roll thus every three periods another dice roll was necessary to determine which of six excluded subjects would be also be monitored to maintain the stated monitoring probability. The monitoring probability of one in

Table 3.2 Experiment conditions and producer costs

Marginal costs of production subject	Seller 1	Seller 2	Seller 3	Seller 4	Buyer 5	Buyer 6	Buyer 7	Buyer 8
<i>SL treatments</i>								
Production unit	128	125	60	60	8	5	2	2
1	133	136	139	142	133	136	139	142
2	154	151	148	145	154	151	148	145
3	157	161	164	167	157	161	164	167
4	175	185	195	205	205	225	235	245
5	325	315	305	295	285	275	265	255
6								
<i>BLR treatments</i>								
Production unit	115	115	105	105	25	25	25	25
1	133	136	139	142	133	136	139	142
2	154	151	148	145	154	151	148	145
3	157	161	164	167	157	161	164	167
4	175	185	195	205	215	225	235	245
5	325	315	305	295	285	275	265	255
6								
<i>BLR treatments</i>								
Production unit	115	115	105	105	25	25	25	25
1	133	136	139	142	133	136	139	142
2	154	151	148	145	154	151	148	145
3	157	161	164	167	157	161	164	167
4	175	185	195	205	215	225	235	245
5	325	315	305	295	285	275	265	255
6								
Initial permits	3	3	3	3	0	0	0	0
Initial balance	500	500	500	500	3000	3000	3000	3000
Exchange rate	0.70	0.70	0.70	0.70	1.00	1.00	1.00	1.00
Production price:	170							
Monitoring fine/unit:	240							
Monitoring probability:	1/6 (0.167)							

six was used intentionally, under the presumption that subjects would have experience with rolling dice. The analogy to dice rolls could then be used to ensure the random nature of monitoring and the concept of statistical independence was more likely to be understood by all subjects. Subjects were also told the approximate odds of being monitored every period of a round and of not being monitored in any period of a round.

After eight periods in each treatment round were completed, subjects opened a new set of instructions that described the next liability treatment. Earnings made in the previous round carried forward; accumulative earnings could affect risk taking behavior if people have decreasing or increasing absolute risk aversion over wealth. To ensure that subjects did not focus on previous market outcomes, production costs were changed in each round without affecting aggregate production cost conditions. As shown in Table 3.1, cost conditions were similar across treatments, with only the first unit costs being changed to equalize predicted earnings differences across treatments. In the third round of each session, which reintroduced the liability and cost conditions used in the first round, the costs subjects 3 and 4 faced in the first round were switched with those of subjects 1 and 2, while the costs of subjects 5 and 6 were switched with subjects 7 and 8. Subjects were unaware that the overall market cost structure was the same as that used in the first round, and only told their costs had changed. Induced permit demand and supply curves were also shifted by paying different fixed "permit subsidies" in each round. Subsidies were paid to all subjects holding permits at the end of a period regardless of whether their permits covered production.

#### Experimental predictions

In our laboratory environment, predictions of market outcomes under the alternative liability rules considered can be identified using expected profit maximization under the assumption of risk neutrality. Table 3.3 summarizes our predicted market outcomes:<sup>3</sup>

*Prediction 1: Permit prices will be lower under buyer liability than under seller liability. Prices under buyer liability will be higher if refunds are possible than when they are not, but less than those under seller liability, thus the following permit price predictions arise:  $P_{SL} \geq P_{BLR} \geq P_{BL}$ .*

Firms that produce without a permit face a potential fine. Under seller liability, all agents value permits for this reason. Their valuation of each permit depends on the expected market fine if they are non-compliant, or on the marginal profit generated by the unit of output the permit is to be applied to, whichever is less. In contrast, buyer liability removes the need for sellers to value permits, which reduces total permit market demand. Buyers face higher risk and lower expected profits under these rules since their probability of being monitored increases when they buy permits from a seller that overproduces. A buyer's valuation now depends on the risk of overproduction they perceive of each seller, and this may depend on their priors, and also on the number of permits these sellers have already sold. Refunds raise buyers' expected profits, but do not remove the discount buyer liability creates. For these reasons, permit price predictions under seller liability (between 33 and 40) exceed those under the buyer liability with refund (between zero and three) and buyer liability (between zero and two) treatments in Table 3.3.

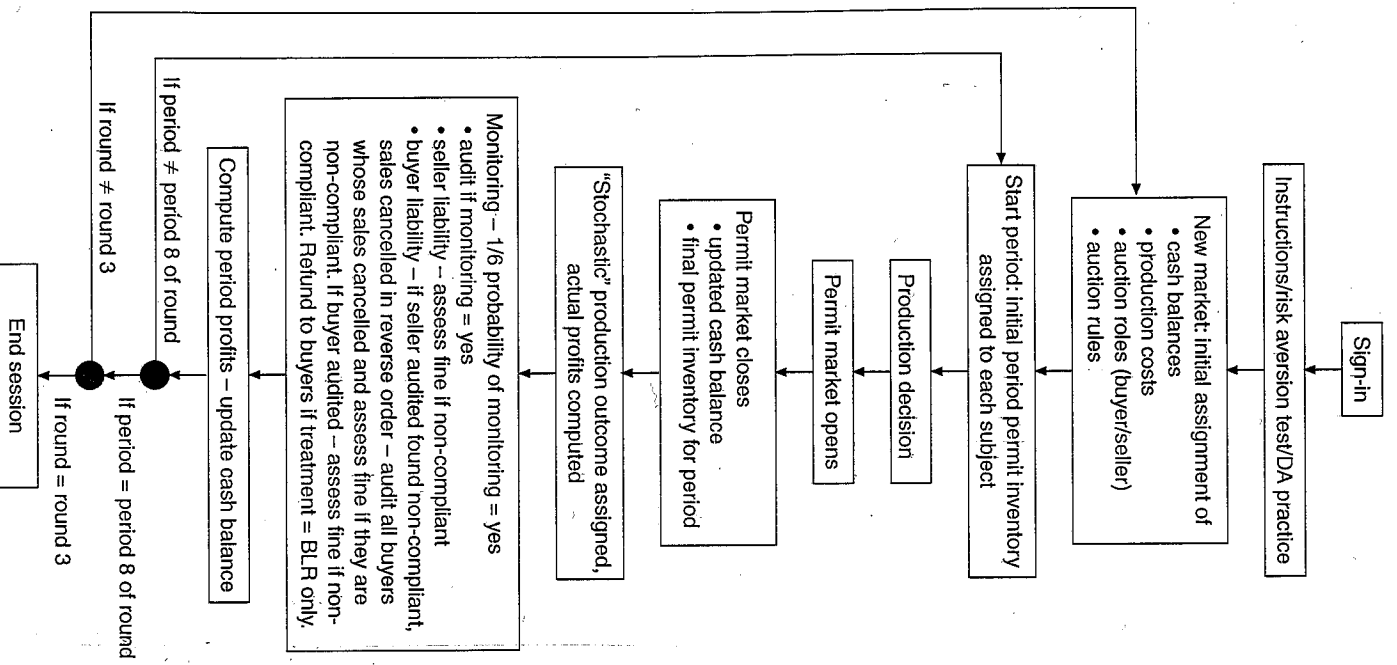


Figure 3.1 Session procedure.

*Prediction 2: Quantity of permits traded will be greater under buyer liability than under seller liability. Quantity traded will be unaffected by the presence of permit refunds, thus the following permit trade volume predictions arise:*  
 $Q_{BL} = Q_{BLR} > Q_{SL}$ .

In our environment, even though under buyer liability permit demand functions rotate downward due to increased risk (the horizontal intercept remains fixed), predicted trading volume increases under the assumption of risk neutrality. Sellers no longer value permits, creating a vertical supply curve at the total permit endowment level in the market. Given our assumption of risk neutrality, and using the permit and the cost parameters used in this experiment, quantity traded equals the number of permits endowed to sellers assuming buyer demand equals or exceeds supply.

Given the fact that the length of the round is finite and known, one might expect that a "lemons-market" outcome could occur here – that trade in permits would disappear since all buyers should expect all sellers to overproduce. In this experiment, however, given the probabilistic monitoring, demand for permits can still exist despite the fact that all buyers may expect all sellers to shirk. Although the increased risk of default could decrease buyer demand to the point where expected trading volume is less than that under seller liability, the market conditions created here result in the predicted volumes under seller liability (six) or both buyer liability treatments (12) when risk neutrality is assumed. Risk aversion among subjects would lower the predicted trading volume, although exact predictions depend on the subject's degree of risk aversion.

*Prediction 3: Buyer liability in permit markets distorts production outcomes, increasing production and emissions on the seller side of the market without necessarily reducing buyer's output and emissions, thus the following predictions regarding emissions arise:  $E_{BL} = E_{BLR} > E_{SL}$ .*

Buyer liability effectively relaxes the emission constraint faced by permit sellers and transfers it to buyers. Probabilistic monitoring and higher predicted permit inventories, however, increase the buyer's predicted production levels relative to those under seller liability by one unit in total. Without an effective emission constraint due to the liability rules imposed here, seller subjects increase production to their unconstrained profit maximizing levels, increasing their total production by seven units. Predicted aggregate market output increases by eight units under both buyer liability conditions. In general, whether the imposition of buyer liability results in buyer's production increasing or decreasing depends on the probability of monitoring. Seller output, however, always increases to unrestricted levels. Given the assumption of emissions proportionate to output, the resulting flow of total emissions increases and the stock of GHGs accumulates faster when buyer liability is used, which reduces the effectiveness of emission trading to achieve cost effective climate protection.

**Results**

We first present the key result, and then discuss the specific market factors that created this outcome. Since liability rules in climate negotiations are debated on two main criteria – the cost effectiveness (or market efficiency) and carbon emissions outcomes, we summarize our key finding over these criteria.

*Result 1: Instituting buyer liability in the laboratory markets decreased market efficiency and increased carbon emissions relative to levels observed under seller liability. As subjects gained experience, the inefficiency and emissions levels worsened under buyer liability, while in seller liability treatments they improved.*

Buyer liability leads to less economic efficiency and lower environmental protection. Figure 3.2 captures this finding by describing the average efficiency and emissions-via-production by treatment and round. Better outcomes – higher efficiency and lower emissions – occur in the lower left corner; worse outcomes – higher emissions and lower efficiency – are in the upper right. Efficiency here is the *ex ante* expected profit a subject would realize given their period production and permit holding choices relative to the expected profit possible had they made the predicted decisions. The measure defined here indicates the potential efficiency given subject choices (not realized), production and monitoring outcomes, and the monitoring and production choices of others over the last three periods of each round by treatment. The realized *ex ante* efficiency loss is computed as  $1 - ((\text{predicted } E_{tr} - \text{actual } E_{tr}) / \text{predicted } E_{tr})$  given subject's decisions recorded in

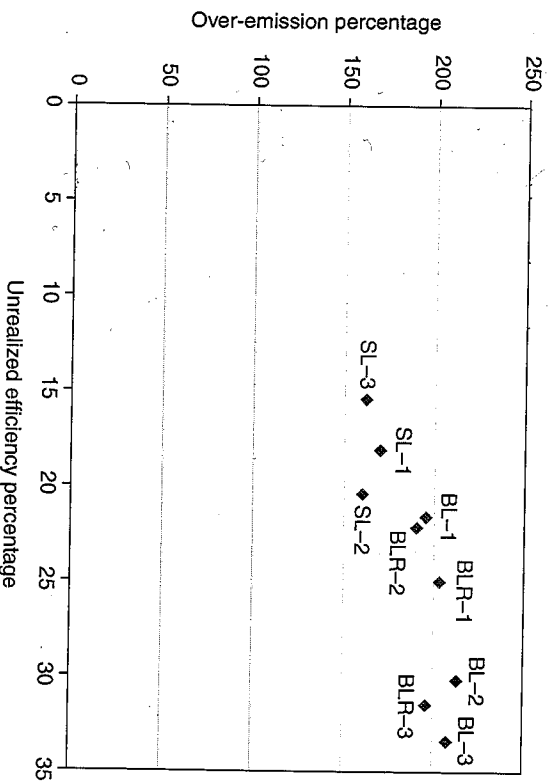


Figure 3.2 Efficiency and emission outcomes by treatment.

the last three periods of each round. Emission levels are the percentage deviation from the emission quota defined by the total number of permits available.

Figure 3.2 shows that the highest efficiency outcomes were always observed under seller liability: average efficiency in the last three periods of all seller liability treatments was 82.1 percent. Efficiency under buyer liability was significantly lower – 71.6 percent and 73.9 percent across all buyer liability without and with refund treatments. Efficiency increased with experience in the seller liability treatments, but worsened under buyer liability. Highest average efficiency and low emissions occurred under seller liability observed in round three (SL-3) of the experimental sessions, while lowest average efficiency and high emissions were observed in third round observations of the buyer liability treatments (BLR-3 and BL-3).

These results strongly support Prediction 3 – looking at Figure 3.2 there was little difference in average emissions levels across the buyer liability treatments, while average seller liability emissions levels were always lower than those under either buyer liability treatment regardless of experience. Emissions levels directly reflect production levels in our environment. Table 3.3 reports that differences in mean production outcomes by round are stable over time, and reflect the qualitative differences predicted between treatments. Using ANOVA analysis for descriptive purposes, mean production choices by sellers and buyers appear to be influenced by treatment ( $p = 0.00$  and  $p = 0.03$ ), experience ( $p = 0.00$  in both cases) and their interaction ( $p = 0.00$  in both cases).<sup>4</sup> Figure 3.3 presents a time

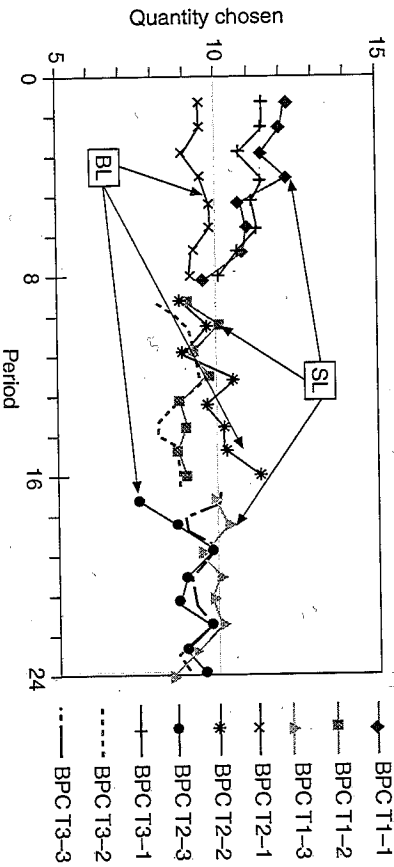


Figure 3.3 Mean aggregate buyer production by treatment.

- Notes
- BPC T1-1 = buyer production choice seller liability (SL), round 1.
  - BPC T1-2 = buyer production choice seller liability (SL), round 2.
  - BPC T1-3 = buyer production choice seller liability (SL), round 3.
  - BPC T2-1 = buyer production choice buyer liability (BL), round 1.
  - BPC T2-2 = buyer production choice buyer liability (BL), round 2.
  - BPC T2-3 = buyer production choice buyer liability (BL), round 3.
  - BPC T3-1 = buyer production choice buyer liability w/refund (BLR), round 1.
  - BPC T3-2 = Buyer Production Choice Buyer Liability w/Refund (BLR), Round 2.
  - BPC T3-3 = Buyer Production Choice Buyer Liability w/Refund (BLR), Round 3.

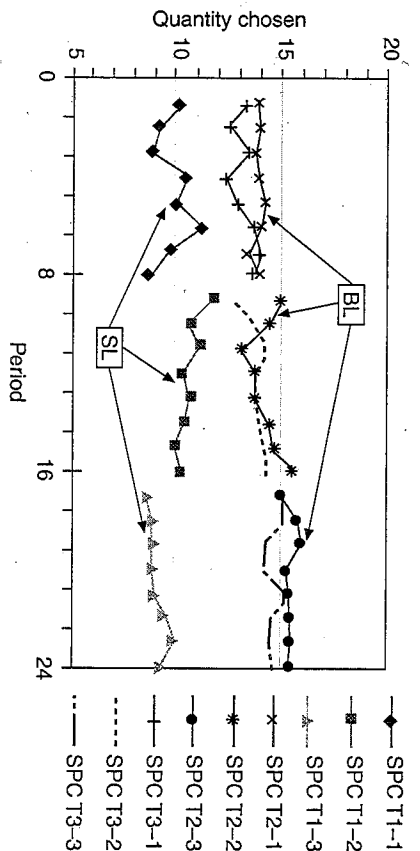


Figure 3.4 Mean aggregate seller production by treatment.

- Notes
- SPC T1-1 = seller production choice seller liability (SL), round 1.
  - SPC T1-2 = seller production choice seller liability (SL), round 2.
  - SPC T1-3 = seller production choice seller liability (SL), round 3.
  - SPC T2-1 = seller production choice buyer liability (BL), round 1.
  - SPC T2-2 = seller production choice buyer liability (BL), round 2.
  - SPC T2-3 = seller production choice buyer liability (BL), round 3.
  - SPC T3-1 = seller production choice buyer liability w/refund (BLR), round 1.
  - SPC T3-2 = seller production choice buyer liability w/refund (BLR), round 2.
  - SPC T3-3 = seller production choice buyer liability w/refund (BLR), round 3.

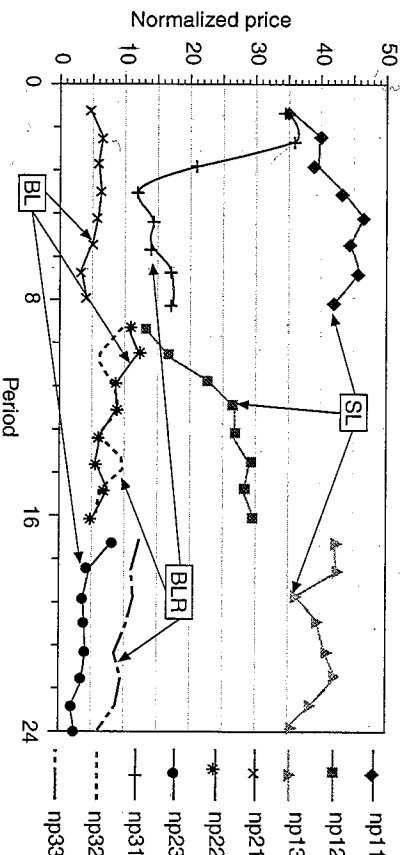


Figure 3.5 Mean permit prices by treatment.

- Notes
- Np11 = normalized price seller liability (SL), round 1.
  - Np12 = normalized price seller liability (SL), round 2.
  - Np13 = normalized price seller liability (SL), round 3.
  - Np21 = normalized price buyer liability (BL), round 1.
  - Np22 = normalized price buyer liability (BL), round 2.
  - Np23 = normalized price buyer liability (BL), round 3.
  - Np31 = normalized price buyer liability w/refund (BLR), round 1.
  - Np32 = normalized price buyer liability w/refund (BLR), round 2.
  - Np33 = normalized price buyer liability w/refund (BLR), round 3.

series of mean buyer production choices by treatment and round and indicates treatment effects occurred early in rounds. In rounds in which subjects were less experienced, buyers often overproduced. But as they gained experience both within and across rounds, average production (emission) levels chosen across all buyers converged toward the predicted levels (see Table 3.4). Figure 3.4, which presents a time series of mean seller production choices by treatment and round, shows a contrasting outcome. Considering seller's production (emission) choices (see Tables 3.3 and 3.5, and Figure 3.4), the effect of treatment seems apparent. On average, mean production (emission) choices by sellers increased by approximately four units under buyer liability relative to choices under seller liability conditions.

Table 3.3 summarizes the results on permit price, transaction and production volumes observed by round and treatment. Overall, the results support our benchmark predictions regarding permit prices and volume, which we summarize below.

*Result 2: Average permit prices deviate by treatment as predicted – prices were greater under seller liability relative to buyer liability; and buyer liability prices were only slightly lower than those observed under buyer liability with refund.*

The results in Figure 3.5 and Tables 3.3 and 3.6 support Prediction 1 – we see lower permit prices under buyer liability, especially after subjects gain experience with the markets.<sup>5</sup> Figure 3.5 reports average permit prices by treatment observed over time. Direct comparison of seller and buyer liability (with and without refund) price outcomes indicate mean prices are always higher under seller liability conditions in later periods, while comparison of the two buyer liability treatments both within and across sessions indicates that although variation in observed prices occurs, pricing behavior appears essentially similar. A Kruskal-Wallis test of mean prices by treatment indicates a significant effect due to treatment ( $p = 0.00$ ). Prices under the buyer liability treatments are also shown to differ significantly using a Mann-Whitney U-test across all three rounds, the last two or over the third round only ( $p = 0.00$ ).

We confirm these unconditional tests with a random effects regression:

$$P_{it} = \alpha + \beta'x_{it} + u_i + \varepsilon_{it}$$

where  $P_{it}$  is the price observation at time  $t$  of session  $i$  in the experiment;  $\alpha$  is an intercept,  $\beta$  is a vector of coefficients on the liability rule and order effects as defined in the matrix  $x_{it}$ .<sup>6</sup> We assume the random disturbance  $\varepsilon_{it}$  exhibits first order autocorrelation with previous disturbances, such that  $\varepsilon_{it} = \rho_i \varepsilon_{it-1} + \eta_{it}$ , where  $\rho_i$  is the autocorrelation coefficient in session  $i$ , and  $\eta_{it}$  is a classical disturbance term. We estimate:

$$P_{it} = a + b_1 BL + b_2 BLR + b_3 Rnd2 + b_4 Rnd3 + b_5 BL-Rnd2 + b_6 BL-Rnd3 + b_7 BLR-Rnd2 + b_8 BLR-Rnd3.$$

Table 3.3 Experiment results by treatment

	Mean permit price	Aggregate permit holdings		Aggregate production choice		
		Sellers	Buyers	Sellers	Buyers	Total
<i>Treatment: SL</i>						
Prediction:	33–40	6	6	8	8	16
Mean obs. (std. dev.)						
Round 1	42.39 (15.34)	6.41 (2.33)	5.59 (2.33)	9.84 (1.92)	11.25 (1.93)	21.09 (2.88)
Round 2	24.84 (9.35)	6.16 (1.39)	5.84 (1.39)	10.69 (1.89)	9.19 (1.42)	19.88 (1.98)
Round 3	40.82 (18.05)	6.72 (1.71)	5.28 (1.71)	9.47 (1.48)	9.88 (1.36)	19.34 (2.12)
<i>Treatment: BL</i>						
Prediction:	0–2	0	12	15	9	24
Mean obs. (std. dev.)						
Round 1	5.63 (4.10)	5.16 (2.57)	6.84 (2.57)	13.91 (1.33)	9.44 (1.61)	23.34 (1.65)
Round 2	8.72 (8.58)	4.97 (1.96)	7.03 (1.96)	14.38 (2.32)	9.97 (1.75)	24.34 (2.47)
Round 3	4.26 (4.42)	4.75 (3.20)	7.25 (3.20)	15.50 (0.88)	9.00 (1.95)	24.50 (2.33)
<i>Treatment: BLR</i>						
Prediction:	0–3	0	12	15	9	24
Mean obs. (std. dev.)						
Round 1	21.07 (33.64)	5.31 (2.07)	6.69 (2.07)	13.38 (1.60)	11.03 (1.69)	24.41 (2.69)
Round 2	7.76 (7.95)	6.97 (1.60)	5.03 (1.60)	13.84 (2.22)	8.75 (1.50)	22.59 (2.53)
Round 3	9.98 (8.95)	4.06 (1.93)	7.94 (1.93)	14.69 (1.26)	9.38 (2.17)	24.06 (2.97)

Note

Predictions assume risk-neutral traders, and that in the case of both buyer liability treatments, that the buyers assume a probability of  $p = 1$  that sellers will overproduce.

Table 3.4 Buyer mean production choices (periods 6-8)

Round	Session	Statistic	1	2	3	
11003	SL-BL-SL	Mean price	3.08	2.583333	2.75	
		Std. dev.	0.14	0.144338	0.25	
		Frequency	3	3	3	
	11004	SL-BL-SL	Mean price	2.08	2.416667	2.083333
			Std. dev.	0.52	0.144338	0.381881
			Frequency	3	3	3
	11010	SL-BLR-SL	Mean price	2.67	2.5	2.333333
			Std. dev.	0.29	0.25	0.144338
			Frequency	3	3	3
	11011	SL-BLR-SL	Mean price	2.58	2	2.333333
			Std. dev.	0.14	0	0.381881
			Frequency	3	3	3
11012	BLR-SL-BLR	Mean price	3	2.42	1.67	
		Std. dev.	0	0.14	0.14	
		Frequency	3	3	3	
11015	BLR-SL-BLR	Mean price	2.25	1.83	1.83	
		Std. dev.	0.5	0.14	0.38	
		Frequency	3	3	3	
11017	BL-SL-BL	Mean price	2.75	2.67	2.92	
		Std. dev.	0.25	0.14	0.14	
		Frequency	3	3	3	
11018	BL-SL-BL	Mean price	2.33	2	2.25	
		Std. dev.	0.14	0	0	
		Frequency	3	3	3	
11022	BLR-BL-BLR	Mean price	2.67	3.08	2.92	
		Std. dev.	0.14	0.14	0.29	
		Frequency	3	3	3	
11023	BLR-BL-BLR	Mean price	2.75	2.5	2.75	
		Std. dev.	0.25	0.25	0	
		Frequency	3	3	3	
11025	BL-BLR-BL	Mean price	2.08	2.33	2.33	
		Std. dev.	0.14	0.14	0.29	
		Frequency	3	3	3	
11026	BL-BLR-BL	Mean price	2.25	1.67	1.92	
		Std. dev.	0	0.29	0.14	
		Frequency	3	3	3	
Total		Mean price	2.54	2.33	2.34	
		Std. dev.	0.39	0.41	0.45963	
		Frequency	36	36	36	

Here  $a$  is the estimated average price in markets using seller liability rules in round 1; the coefficients  $b_1$  and  $b_2$  are the estimated average price deviations from those observed under seller liability in round 1 induced when buyer liability and buyer liability with refund rules are used;  $b_3$  and  $b_4$  are estimated order effects and indicate the average deviation in prices observed in rounds 2 or 3;

Table 3.5 Seller mean production choices (periods 6-8)

Round	Session	Statistic	1	2	3
11003	SL-BL-SL	Mean price	2.75	3.08	2.33
		Std. dev.	0.25	0.38	0.14
		Frequency	3	3	3
11004	SL-BL-SL	Mean price	2.42	4.00	2.08
		Std. dev.	0.29	0.00	0.29
		Frequency	3	3	3
11010	SL-BLR-SL	Mean price	2.92	3.75	2.92
		Std. dev.	0.80	0.00	0.29
		Frequency	3	3	3
11011	SL-BLR-SL	Mean price	1.83	2.92	2.58
		Std. dev.	0.29	0.14	0.14
		Frequency	3	3	3
11012	BLR-SL-BLR	Mean price	4.00	2.92	3.50
		Std. dev.	0.00	0.38	0.25
		Frequency	3	3	3
11015	BLR-SL-BLR	Mean price	3.17	3.00	3.25
		Std. dev.	0.29	0.25	0.00
		Frequency	3	3	3
11017	BL-SL-BL	Mean price	3.17	2.00	4.00
		Std. dev.	0.29	0.43	0.00
		Frequency	3	3	3
11018	BL-SL-BL	Mean price	3.83	2.33	3.75
		Std. dev.	0.14	0.38	0.00
		Frequency	3	3	3
11022	BLR-BL-BLR	Mean price	3.42	3.83	3.83
		Std. dev.	0.14	0.14	0.14
		Frequency	3	3	3
11023	BLR-BL-BLR	Mean price	3.25	4.00	4.00
		Std. dev.	0.00	0.00	0.00
		Frequency	3	3	3
11025	BL-BLR-BL	Mean price	3.58	4.00	4.00
		Std. dev.	0.14	0.00	0.00
		Frequency	3	3	3
11026	BL-BLR-BL	Mean price	3.25	3.50	3.75
		Std. dev.	0.00	0.00	0.00
		Frequency	3	3	3

and the estimated coefficients  $b_5$ - $b_8$  indicate the average interaction effects of buyer liability and market order.

Table 3.7 reports the regression results, and indicates liability treatment has a significant impact on closing prices, and that these differences do not require previous experience in markets to be realized. On average, prices under buyer liability fall by about 30 lab-dollars relative to prices observed under seller liability, while prices under buyer liability with refund fall by between 20 and 24 lab-dollars. Further, no significant difference emerges in how experience

Table 3.6 Session mean price results (periods 6-8)

Round	Statistic	1	2	3
11003	Mean price	45.36	18.07	57.33
SL-BL-SL	Std. dev.	2.33	2.91	3.30
	Frequency	3	3	3
11004	Mean price	43.07	2.89	34.87
SL-BL-SL	Std. dev.	0.92	0.91	2.44
	Frequency	3	3	3
11010	Mean price	35.53	15.43	37.33
SL-BLR-SL	Std. dev.	2.58	1.13	1.61
	Frequency	3	3	3
11011	Mean price	51.63	8.65	15.42
SL-BLR-SL	Std. dev.	3.59	5.40	0.81
	Frequency	3	3	3
11012	Mean price	7.45	29.46	11.26
BLR-SL-BLR	Std. dev.	1.95	2.30	2.52
	Frequency	3	3	3
11015	Mean price	6.17	36.06	18.14
BLR-SL-BLR	Std. dev.	0.73	0.82	7.91
	Frequency	3	3	3
11017	Mean price	7.54	32.87	2.09
BL-SL-BL	Std. dev.	0.62	1.05	0.19
	Frequency	3	3	3
11018	Mean price	2.94	21.57937	6.33
BL-SL-BL	Std. dev.	0.13	1.38	0.19
	Frequency	3	3	3
11022	Mean price	12.94	1.73	2.36
BLR-BL-BLR	Std. dev.	3.54	0.91	0.57
	Frequency	3	3	3
11023	Mean price	42.30	1.09	2.92
BLR-BL-BLR	Std. dev.	3.38	0.44	0.29
	Frequency	3	3	3
11025	Mean price	5.41	3.35	2.69
BL-BLR-BL	Std. dev.	2.57	0.79	0.73
	Frequency	3	3	3
11026	Mean price	3.30	0.63	-2.13
BL-BLR-BL	Std. dev.	1.70	0.11	0.75
	Frequency	3	3	2

influences outcomes under alternative liability treatments.<sup>7</sup> Our results do suggest, however, that early negative price and risk experiences under buyer liability initially depress closing prices under seller liability, as supported by the time paths of prices in periods 9-16 (see Figure 3.5).

*Result 3: Permit trading volume increases under buyer liability. Predicted differences in volume between liability treatments, however, are not observed in all sessions.*

Table 3.7 Estimated regression results (*p*-values in parentheses)

Estimated coefficient	Dependent variable ( <i>P<sub>it</sub></i> )	
	Closing prices all periods <sup>1</sup>	Closing prices periods 4-8 <sup>2</sup>
Constant ( <i>a</i> )	38,609 (0.000)	39,681 (0.000)
BL ( <i>b<sub>1</sub></i> )	-30,815 (0.000)	-29,640 (0.000)
BLR ( <i>b<sub>2</sub></i> )	-19,887 (0.000)	-24,049 (0.000)
Rnd2 ( <i>b<sub>3</sub></i> )	-11,918 (0.000)	-9,678 (0.001)
Rnd3 ( <i>b<sub>4</sub></i> )	-1,168 (0.639)	-4,515 (0.221)
BL-Rnd2 ( <i>b<sub>5</sub></i> )	5,195 (0.124)	1,629 (0.695)
BL-Rnd3 ( <i>b<sub>6</sub></i> )	-0,814 (0.794)	1,047 (0.799)
BLR-Rnd2 ( <i>b<sub>7</sub></i> )	1,025 (0.813)	6,912 (0.187)
BLR-Rnd3 ( <i>b<sub>8</sub></i> )	-7,825 (0.088)	-1,780 (0.739)
Number of observations	287	179

## Notes

*p*-values in parentheses - bolded values indicate significance at the 5 percent level.

1 Estimates for all periods are the GLS coefficients, allowing for heteroskedasticity between sessions (cross sections) and assuming an ARI process present in the data.

2 Estimates for all periods are the OLS coefficients, allowing for heteroskedasticity between sessions (cross sections) and assuming an ARI process present in the data. Using these coefficients is recommended when the number of time periods is small relative to the number of panels (see Beck and Katz, 1995).

Table 3.3 shows differences in permit trading occurred across treatments, and volume differences under buyer liability increased with experience. By the third round, the average buyer holds two more permits relative to holdings under seller liability. A Kruskal-Wallis test confirms a significant difference between average buyer's permit holdings over the last three periods of the each round ( $p = 0.00$ ) by treatment. A Mann-Whitney U-test also verifies that no significant difference exists in buyers' permit inventories after trade between buyer liability treatments ( $p = 0.47$ ), supporting our benchmark prediction. While these results indicate trading volume (and therefore buyer inventories) increases under buyer liability, the increase is less than expected.

Figure 3.6 shows the average permit trading volumes by round and treatment. By periods 4-8, buyer liability outcomes diverge toward a volume appreciably greater than seller liability, and this divergence increases with experience. What is unclear in the figure is that significant deviation occurs in trading volume under buyer liability across sessions. In about half the sessions, volume converges toward predicted levels, whereas in the other half, trading is thin. A zero trading outcome would be consistent with a "lemons-market": buyer liability creates an incentive for sellers to cheat and if they are monitored permit purchases could be lost. With such risk, trade could collapse to zero. But since risk of monitoring is low, this is not a predicted outcome. Although in the early periods of a round, markets were thin, trade rarely failed to occur. In later rounds, volume increased but remained below predicted volumes.<sup>8</sup> Overall, the causes of the inferior emission and efficiency outcomes under buyer liability seem apparent - they arise due to the predicted distortions in observed permit

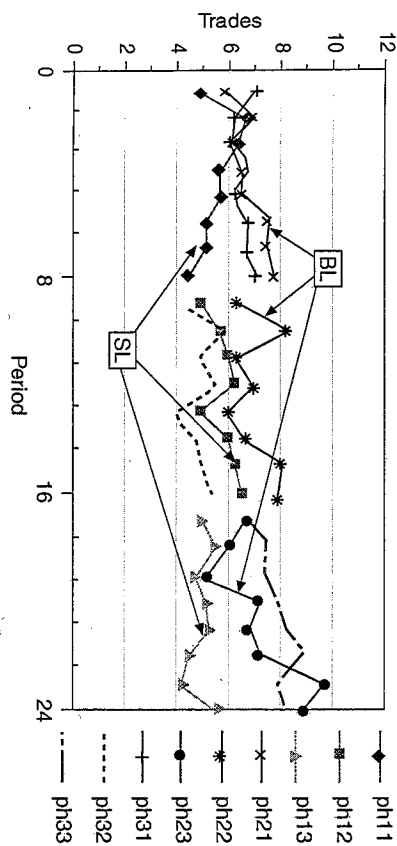


Figure 3.6 Mean trades by treatment.

Notes

- ph11 = Permit holding seller liability (SL), round 1.
- ph12 = Permit holding seller liability (SL), round 2.
- ph13 = Permit holding seller liability (SL), round 3.
- ph21 = Permit holding buyer liability (BL), round 1.
- ph22 = Permit holding buyer liability (BL), round 2.
- ph23 = Permit holding buyer liability (BL), round 3.
- ph31 = Permit holding buyer liability w/refund (BLR), round 1.
- ph32 = Permit holding buyer liability w/refund (BLR), round 2.
- ph33 = Permit holding buyer liability w/refund (BLR), round 3.

prices and trading volumes. These distortions result in allocative inefficiencies and production pattern distortions that reduce permit market cost effectiveness, and increase emissions.

**Robustness tests – high enforcement and random endings**

Less climate protection at greater cost under buyer liability is a strong result. Consider the robustness of this outcome given two changes in the permit market: an increase in the monitoring probability to two-thirds (0.667) from one-sixth (0.167), and removal of fixed-ending point effects caused by using a known number of periods within each round by introducing a random ending point (i.e. an infinite horizon) after the eighth round. These conditions create an environment more likely to produce “good seller” reputations in the permit market so buyer liability stands a better chance of success.

*Increased monitoring probability*

Table 3.8 summarizes the revised predictions and results in the high monitoring environment. Under seller liability with a higher enforcement, eight permit trades are predicted with permit market prices predicted to lie within an interval of 27–71. This wide interval occurs due to the wide discrepancy between buyer and seller valuations at this quantity due to the characteristics of the expected

Table 3.8 Experiment results by treatment: additional sessions

	Mean permit price	Aggregate permit holdings		Aggregate production choice		
		Sellers	Buyers	Sellers	Buyers	Total
<i>High enforcement, fixed length sessions</i>						
<i>Treatment: SL</i>						
Prediction:	27–71	4	8	4	8	12
Mean obs. (std. dev.)						
Round 1	81.57 (16.81)	6.50 (1.32)	5.50 (1.32)	6.00 (2.16)	7.06 (1.24)	13.06 (2.98)
Round 2	61.59 (8.64)	8.25 (1.65)	3.75 (1.65)	7.19 (2.46)	3.88 (1.54)	11.06 (2.88)
Round 3	69.22 (7.85)	5.81 (1.11)	6.19 (1.11)	5.94 (1.06)	5.94 (0.93)	11.875 (1.31)
<i>Treatment: BL</i>						
Prediction:	0	12	0	15	0	15
Mean obs. (std. dev.)						
Round 1	50.51 (17.68)	8.13 (2.06)	3.88 (2.06)	9.25 (3.09)	3.94 (1.44)	13.19 (3.31)
Round 2	38.94 (16.57)	4.75 (1.12)	7.25 (1.12)	8.44 (2.16)	6.31 (1.54)	14.75 (2.38)
Round 3	38.43 (8.96)	7.50 (1.15)	4.50 (1.15)	10.63 (3.01)	2.81 (1.05)	13.44 (3.03)
<i>Low enforcement, random length sessions</i>						
<i>Treatment: SL</i>						
Prediction:*	33–40	6	6	8	8	16
Mean obs. (std. dev.)						
Round 1	28.48 (8.61)	7.42 (2.86)	4.58 (2.86)	12.25 (1.83)	9.21 (1.22)	21.46 (2.19)
<i>Treatment: BL</i>						
Prediction:*	0–3	0	12	15	9	24
Mean obs. (std. dev.)						
Round 2	9.73 (6.20)	6.80 (2.14)	5.20 (2.14)	12.92 (1.35)	8.16 (1.93)	21.08 (2.71)

Note

\* Predictions in random length sessions are those for fixed length sessions, and not necessarily the only possible prediction.

profit maximization. Although this interval allows for prices that are lower than those predicted with lower monitoring odds, one could expect that since the probability of being monitored and caught producing without a permit has increased, permits would be more valuable and sell at a higher price than observed when monitoring occurred only one-sixth of the time. The center of this interval occurs at 49, approximately 10 lab-dollars higher than expected previously. Relative to the lower enforcement setting, increasing the monitoring probability increases permit prices and permit trades, while reducing market output. In seller liability sessions, no subjects are predicted to produce without a permit; sellers are predicted to reduce output to a level commensurate with their predicted permit holdings.

Under buyer liability, increased monitoring probability should significantly affect predicted market outcomes. Buyers should presume that sellers will always overproduce given they face no sanctions. Buyers now should not value permits, and one should observe a complete market failure – valueless permits should not be exchanged. Facing no risk of a fine, we predict sellers will produce at their unconstrained profit maximizing levels, increasing total market output 25 percent beyond the emission cap imposed. Buyers are predicted to produce nothing.

*Result 4: Higher enforcement reduces output and increases emission compliance under seller liability, as predicted. Contrary to prediction, however, permit trade occurred under buyer liability as sellers reduced their production to support trade. Buyer liability with high enforcement made the problems observed in low enforcement sessions more costly due to naive and strategic behavior – “good sellers” exploit their reputations, while still promoting over-emissions, albeit at reduced levels.*

Tables 3.8 and 3.9 present the summary statistics on how high enforcement altered market performance as measured by permit price, permit holdings, production, and the overproduction-to-total sales ratio.<sup>9</sup> As predicted, seller liability resulted in almost perfect compliance with the emission target. For seller liability, Table 3.8 shows that trading led to higher mean permit prices relative to the low enforcement sessions, as predicted. The price increase is more extreme than expected – mean price (81.57) is 10 lab-dollars greater than predicted (although in the later rounds, mean prices fall to within the predicted range). We observe little change in permit trade volume relative to the low-enforcement sessions. Aggregate output decisions are not substantially different from aggregate permit holdings, supporting the prediction that higher enforcement reduces output and increases emission compliance. High monitoring reduced mean-production outcomes by about eight units (nearly 40 percent) from low monitoring. As predicted, aggregate output choices are, by the second round, compliant with the emission target in the market.

Contrary to predictions, however, the permit market did not completely collapse under buyer liability. Permit trades still occur at prices similar to the low

Table 3.9 Overproduction-to-total sales ratio

Treatment	Round		
	1	2	3
<i>Low monitoring probability fixed length sessions</i>			
Seller liability	0.62 (0.53)	0.76 (0.38)	0.51 (0.26)
Buyer liability	1.27 (0.21)	1.38 (0.39)	1.64 (0.54)
Buyer liability w/refund	1.21 (0.23)	1.29 (0.65)	1.34 (0.16)
<i>High monitoring probability sessions</i>			
Seller liability	-1.12 (0.40)	-0.31 (0.54)	-0.003 (0.22)
Buyer liability	0.33 (0.83)	0.49 (0.35)	0.76 (0.64)
<i>Random end-point sessions</i>			
Seller liability	1.04 (0.53)	N/A	N/A
Buyer liability	N/A	1.13 (0.27)	N/A

enforcement case. The extent of market failure is shown in Figure 3.7, which redraws Figure 3.2 adding the additional sessions. Trades occurred because sellers reduced their output to cover permit sales and because not all permits sold were “bad” (i.e. buyers were not fined) – seller output averaged 40 percent less than predicted. Market efficiency now decreased because production was lower and some permit trades went “bad” and buyers were fined. Market inefficiency resulted from myopic or naive market decisions, especially by buyers who had greater costs through realized fines and lower subject earnings. Increased enforcement made the market more unforgiving – subjects endured high penalties for poor production decisions and sudden strategic switches in seller behavior. This strategic effect held when “otherwise-good” sellers turned on their buyers and began overproducing in the later periods of the rounds. Since buyers did not refrain from trading under these circumstances, efficiency losses arose from the penalties they incurred. In buyer liability sessions under high enforcement, seller overproduction occurred in all rounds, and increased over time (see Table 3.9). In the first round, these values indicate on average two-thirds of permit sales did not risk being returned if a seller was monitored. Increasing enforcement resulted in overproduction ratios 75 percent lower than those in the low enforcement sessions. Similarly, in the last round, although overproduction/total sales values and the risk of returning permits rose over time, on average, almost 25 percent of the permits sold were backed by output reductions. Compared to the low monitoring sessions, this overproduction ratio was less than 50 percent of the value observed under buyer liability (0.76 versus 1.64), and 44 percent lower than observed under buyer liability with refund (0.76 versus 1.34). Buyer liability in a market with high enforcement made the problems observed in low enforcement sessions more costly, while still promoting over-emissions, albeit at reduced levels.

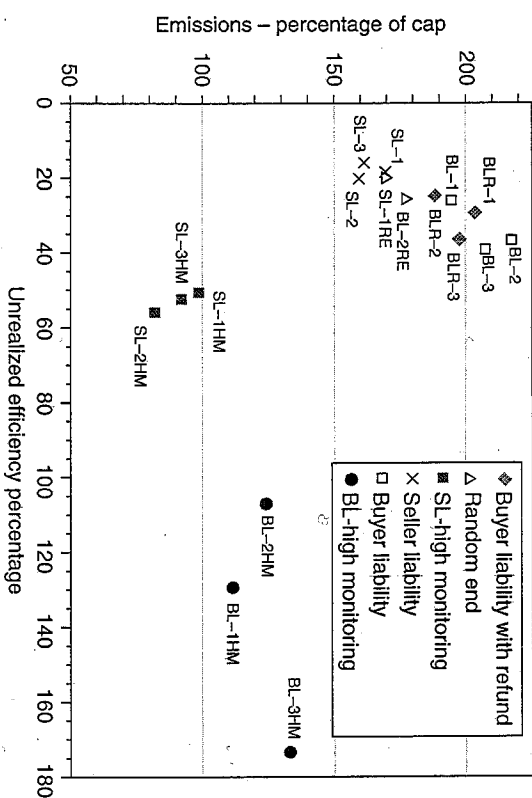


Figure 3.7 Efficiency and emission outcomes by treatment.

### Random ending points

Our markets were hostile to reputation effects since our rounds were short and of known length. This design reflects current climate policy – the original Kyoto timetable from 2008–2012 is fixed and short. Compliance periods beyond 2008–2012 have yet to be negotiated. This contrasts with other emission markets where buyer liability has been promoted that do not end at a fixed date. It is assumed participants in these markets would assume market conditions are permanent or at least that the end of the market is unpredictable. To capture this belief within our experiment and to avoid the end-period strategic effects that arose in the high enforcement sessions, we replaced the fixed and known end point to each round used previously with a random end point. This allowed us to explore whether “good seller” reputations might emerge in the laboratory, and whether such outcomes could alter our key results.

We focus on the low monitoring probability treatments. All conditions of the original sessions were maintained with two exceptions: (1) in buyer liability, we used a random ending point; in seller liability, we did not tell subjects when the period would end; and (2) we used an AB experiment design. Seller liability always occurred for the first eight periods (A), with buyer liability rules for the rest of the sessions (B) (see Table 3.1 for sessions 020604–020615). The AB design ensured sessions would not be too long, since the random ending point could cause the buyer liability rounds to go on for some time. Although using an AB design theoretically confounds the effect of experience and treatment on interpretation of observed results, we expected the effects of time and treatment would be easily identified by comparison to previous ABA sessions. If they

were not, it was expected that the effect of changing the fixed to random ending point would have significant impacts on market outcomes if the new sessions had the predicted effect. After the eighth period in buyer liability markets, we used a random number generator to draw a number between one and 100 at the end of each period.<sup>10</sup> Subjects knew the period ended if the number drawn was 20 or less – a one-fifth chance – otherwise another period would take place.

We use the same predictions as in the low enforcement probability sessions under seller liability as a benchmark. Under buyer liability, our predictions are those computed for the fixed length rounds. If a reputation effect emerged, market outcomes will differ from predictions, suggesting the random end point changed behavior and market outcomes.

*Result 5: A random ending point had little effect in seller liability sessions – outcomes were similar to those observed with a fixed end point. Under buyer liability, the results of with random ending point are not inconsistent with a weak reputation effect – we observed fewer permit trades and lower production levels. Overall, the random ending point sessions were broadly consistent with the levels of over-emission and efficiency loss by treatment observed earlier.*

Again Tables 3.8 and 3.9 summarize the results. Although we see minor differences across the random and fixed ending treatments, our basic results still hold. Under seller liability, an uncertain ending point had an almost identical outcome to that observed when end points were known. Under buyer liability, emissions increased and market efficiency fell, as reported in Result 1. Buyer liability also lowers permit prices relative to seller liability, supporting Result 2. Output patterns reflect earlier behavior – sellers produced the highest proportion of total output. Total output level observed, however, is approximately three units less than previous sessions and total seller output levels are as much as two units less on average. The patterns of permit trade and output decreases observed are broadly consistent with the hypothesis that the inclusion of a random ending point in buyer liability rounds reduced the incidence of “cheating”, at least in later periods of a round; lowering the production levels in the market. Table 3.9 shows the overproduction: total sales ratios observed over all periods reinforce this conclusion, as they are 20 percent lower than those observed in the second round of previous buyer liability sessions.

### Conclusions

Successful global climate protection policy depends in part on the cost effectiveness of greenhouse gas emission trading. We present evidence that emission trading under a buyer liability rule could lead to less climate protection at greater costs given relatively weak international enforcement for environmental shirking. Promoting a *caveat emptor* liability rule backfired in our experiment on both economic and environmental criteria. Holding the subjects that represented high-emission buyer nations responsible for climate shirking rather than holding the

relatively poorer low-emission seller nation subjects responsible resulted in average emission levels exceeding those observed under seller liability by nearly 34 to 40 percent. The imposition of an escrow-like refund system did not alter this result, and neither did the introduction of tighter enforcement or conditions that could create stronger seller reputations. Our findings support the notion that buyer liability in global emission trading might lead to less climate protection at greater cost.

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### Notes

- 1 Specific emission targets for developing countries were not set in the protocol.
- 2 Also see Cason's (1995) test bed experiments on efficiency of the acid deposition auctions run by the US Environmental Protection Agency.
- 3 In policy documents, proponents of buyer liability often suggest reputation effects will result in market outcomes equivalent to or approaching those expected under seller liability. In general, however, multiple equilibria exist in games with reputation, and which of these are reasonable outcomes to expect will be critically dependent on the characteristics of the market setting and the prior distribution of player types assumed. Results of reputation games in a number of settings are reviewed in Fudenberg and Tirole (1991). In the predictions presented here, since each round consisted of eight periods, backward induction suggests that in buyer liability rounds, buyers should expect sellers to overproduce since permits have no other use value to sellers. Using this assumption and the conditions described in Table 3.2, we find the values reported in Table 3.3. We do not attempt to develop alternative reputation-effect predictions that might be possible in this environment. Instead, we suggest that outcomes varying from the risk neutral predictions presented could indicate shortcomings in the method of computing predictions we use.
- 4 This test is performed on mean outcomes by round, but is inappropriate if one expects that the independence assumption required is violated across rounds.
- 5 Experimental predictions are computed assuming equilibrium market outcomes, but early periods appear to have convergence processes at work thus resultant mean values across periods vary in the predicted direction by treatment, if not by the predicted magnitude. This occurs in the summary data (see Table 3.3), and is present to a lesser degree when permit price outcomes are averaged over the last three periods of each round to allow for convergence (see Table 3.6). Treatment outcomes across rounds differ in the directions predicted, and Table 3.6 shows mean session outcomes are closest to the values predicted.
- 6 Since experimental sessions used separate subject groups, a random-effects model is employed in which the fixed and constant subject or session effect on price observations is described by  $u_i$ , while  $e_{it}$  is a random disturbance term.
- 7 There are no significant interaction effects of order of presentation and liability treatment as estimated by coefficients  $b_5$ - $b_8$ . The decreased significance of  $b_8$  across the last five periods relative to all periods where it is significant at the 10 percent level

may suggest that initially refunds may cause subjects to increase their permit valuations in the first round; however experience appears to result in closing price outcomes that are not significantly different across rounds in this treatment.

8 Volume differences are consistent with subject-pool differences in risk aversion, which could explain the lower than predicted average trading volumes observed under buyer liability treatments in some sessions. It could suggest the assumption of risk neutrality to generate the experimental predictions may be an excessive abstraction in this environment.

9 Overproduction is the difference between a firm's output and its permits. For the overproduction-to-total sales ratios, a positive value means sellers overproduced relative to predictions; a negative value means they underproduced; a value over unity says sellers did not back permits sold with an output reduction.

10 We used an Excel spreadsheet to generate random numbers between one and 100.

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## 4 A test bed experiment for water and salinity rights trading in irrigation regions of the Murray Darling Basin, Australia

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### Introduction

The Murray Darling Basin covers more than 1,000,000 square kilometers, or one-seventh of the Australian continent, and is the catchment for the Murray and Darling rivers. The river system extends from Queensland, and includes three-quarters of New South Wales and half of Victoria, through South Australia and drains out of a single exit of Lake Alexandriana to the sea. The Basin supports almost three-quarters of Australia's irrigated agricultural production, an important export for Australia. While naturally saline, human activity has significantly changed the Basin's natural water balance systems. The removal of (deep-rooted) native vegetation and the replacement with (shallow rooted) European style annual crops and pastures has resulted in excess rain and irrigation water entering the groundwater systems. As groundwaters rise, the gradient between these saline groundwater mounds and the rivers decrease. In some regions groundwater salinity can reach 50,000 EC, i.e. electroconductivity, which is a measure of salt concentration: 600 EC is thought to be suitable for potable water.<sup>1</sup> Saline water contained in the soils then percolates into the rivers, increasing water salinity. While estimates vary, costs reported by the Murray Darling Basin Commission place annual costs due to human-induced salt impacts at \$130 million in agricultural costs, \$100 million in infrastructure and \$40 million in environmental costs across the Basin.<sup>2</sup>

In response to increasing salinity costs, and informed by improved scientific information on salinity impacts, in November 2000 the Commonwealth of Australian Governments, agreed to the National Action Plan for Salinity and Water Quality (the NAP).<sup>3</sup> This plan is the Australian government's vehicle to deliver on-ground change, across this complex Basin, which includes the coordination of institutions and resources across four states and one territory.

The government agreements supporting the NAP specifically include the facilitation of new market-based incentives, including trading mechanisms