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A Laboratory Experiment to Compare Two Market Institutions for Emissions Trading

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Abstract

We report results from an economic experiment where two markets institutions for controlling water pollution are compared. In the status quo institution, permit trades between point and nonpoint sources are subject to a trading ratio. In the alternative, nonpoint abatements are converted into permits with multiple attributes. The test bed captures important features of existing markets for water quality trading. First, pollution is stochastic, poorly observed and imperfectly controlled by nonpoints. Second, the market is characterized by oligopsony. The results indicate that the multi-attribute market generates a superior environmental outcome to the trading ratio market. Furthermore, the average cost of pollution control is lower in the multi-attribute market. Market power is found to be independent of the type of market institution, but sellers of permits learn to resist market power as they gain experience. This is at the cost of market efficiency since their resistance reduces the number of trades.

Keywords: Experimental Economics, Market Design, Oligopsony, Stochastic Pollution

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1 Introduction

Markets in tradable property rights are commonly regarded with approbation as efficient mechanisms for the attainment of specific policy targets at minimum social cost (or maximum social benefit) in the presence of pollution externalities. These rights are typically characterized as pollution licenses, emissions permits or abatement credits, which bestow upon the owner the right to discharge a specified quantity of pollutants (Hahn and Hester, 1989; Montgomery, 1972). In the last three decades, a sizeable experimental literature has developed around the testing and design of these markets as efficient economic instruments for pollution control. In much of this research, the polluters are point sources and the pollutants are airborne. By comparison, experimental analysis of tradable permit markets with nonpoint source participants is sparse. Yet, since tradable permit markets are the preferred economic instruments for nonpoint pollution control among policy makers today, additional research in this area is important.[1]

In this paper we report the results of an experiment that attempts to fill this lacuna in the literature. In the experiment, two market institutions for permit trading between point and nonpoint sources are compared. The first institution is based on the trading ratio, which is the number of units of nonpoint permits that must be purchased to allow a unit increase in point source pollution (Shortle, 1990). Since existing trading programs use the trading ratio, it may be considered the status quo institution. The second institution is based upon a probabilistic approach to pollution control. When pollution loads are stochastic, as is the case with nonpoint pollution, the latter institution generates market outcomes that are more cost-efficient *and* more likely to meet the environmental target (Ghosh and Shortle, 2009). The implication of this result is obvious and significant: policymakers will not get the maximum bang for their buck using tradable permit markets built around the trading ratio. Instead, using probabilistic markets might generate better returns.

[1]Evidence of this policy-level interest lies in the existence of numerous federal and state level initiatives to design, implement and support tradable permit markets with point and nonpoint participants (for a list of initiatives see Breetz et al., 2004).

However, the practical relevance of this theoretical result is limited given that it is contingent on assumptions that do not hold in existing tradable permit markets. One crucial assumption pertains to market structure. Ghosh and Shortle (2009) assume a competitive market, but most existing point-nonpoint trading programs, like those on the Kalamazoo and Rock rivers or in the Neuse River and Tar-Pamlico basins, are oligopsonies (Morgan and Wolverton, 2005). The point source permit-buyers, typically wastewater treatment plants and factories, are fewer and economically larger than the nonpoint source permit-sellers, typically farms.

We test whether the theoretical result on the superiority of the probabilistic market merits serious consideration from policymakers by comparing the two market institutions in an experimental testbed that deviates from the theoretical environment and exhibits the oligopsony found in real world tradable permit markets. Our research questions are first, whether oligopsony causes systematic deviations from the theoretical outcome and second, whether the deviations imply a reversal in the relative performances of the two market institutions. We also test whether the relative scale of oligopsony affects market outcomes by considering two scenarios. The first scenario is a sellers' market, where the sheer economic scale of the buyers ensures excess demand for permits above what the market can supply. The second scenario is a buyers' market, where sellers must compete, and some will not sell their permits at the competitive equilibrium.

If the probabilistic market is the superior institution under both types of oligopsony, then further testing of the two institutions is warranted. The testing could be in the form of more experiments or through pilot projects. If not, then one might infer that the results in Ghosh and Shortle (2009) are not robust and might not hold in real tradable permit markets.

The results indicate that the probabilistic market outperforms the TR market in the presence of oligopsony. It will generate superior environmental outcomes, by generating a greater quantity of trade in abatement projects with a favorable risk profile. The impacts of both markets on market power and overall market efficiency are not significantly different. The results support the argument for basing future tradable permit markets on the probabilistic institution when some market participants are nonpoint sources.

The paper is organized as follows. First, we provide some background on the nonpoint source pollution problem, discuss the literature and contextualize the policy support for markets as instruments to tackle this problem. Next we describe the experimental framework and testable hypotheses, which is followed by the results section. The paper concludes with a discussion where we draw inferences on policy design and suggest directions for future research.

2 Background and Previous Literature

Nonpoint sources of pollution such as agricultural runoff and urban storm water are major contributors to water quality impairment (USEPA, 2002). Nonpoint source pollution is diffuse, which precludes accurate and inexpensive metering and monitoring (Carpentier et al., 1998; Harrington et al., 1985). Also, agricultural loadings are inherently stochastic because they are affected by weather-related and other random factors (Shortle and Dunn, 1986). Because of these problems nonpoint source pollution cannot be efficiently controlled by the market institutions used to control point source pollution (Malik et al., 1993; Shortle and Horan, 2001).

The theoretical literature suggests two different approaches to controlling of nonpoint source pollution. One approach focuses on collective mechanisms of reward and punishment like ambient taxes and group contracts (e.g., Segerson, 1988; Cabe and Herriges, 1992). The other focuses on the amending the "textbook" model of tradable permit markets (see Tietenberg, 2000), originally designed to control point source pollution (e.g., Horan and Shortle, 2005; Hung and Shaw, 2005).

From the sizable experimental literature on collective non-market mechanisms one may draw three broad inferences. First, polluter heterogeneity negatively affects the performance of ambient instruments. In support of contentions by Shortle and Horan (2001) and Weersink et al. (1998) that ambient instruments are only appropriate when polluters are small and homogenous, Spraggon (2004) finds inefficiencies caused by freeriding by small polluters at the expense of large polluters. However, reverse auctions, when used in conjunction with group contracts, reduces freeriding (Taylor et al., 2004). Second, the evidence is mixed for ambient tax / subsidy instruments with some results indicating efficiency (Spraggon, 2002) and others indicating inefficiency through overabatement (Cochard et al., 2005), especially when subjects communicate (Vossler et al., 2006; Poe et al., 2004). And third, group fines are typically less efficient and less reliable (Cochard et al., 2005; Spraggon, 2002), but compliance is optimal under conditions of cheap talk (Vossler et al., 2006).

Despite academic interest, ambient instruments face political limitations (Shortle and Abler, 1994; Xepapadeas, 1999), which makes their implementation infeasible. The policy community has instead identified tradable permit markets as a feasible way of dealing with the institutional problems that attend nonpoint pollution control (Letson, 1992). Also, there is an expectation that these markets can result in cost savings in excess of US$ 1 billion when compared to command-and-control mechanisms (USEPA, 2001). The literature proposes a two-step adjustment to the "textbook" model of trading between point sources to account for the variability and non-measurability of nonpoint abatement. First, nonpoint abatement is defined by its mean. Second, the mean-based nonpoint permit is exchanged with point source permits subject to the trading ratio (TR). This ratio, when correctly calculated, accounts for the marginal damages and uncertainty of each nonpoint abatement and the transaction costs associated with each trade (Horan and Shortle, 2005; Malik et al., 1993). Correct calculation requires knowledge of the environmental damage function and the emissions demands of all polluters. As a practical matter, insufficient development of the science and information asymmetries hamper access to this knowledge. Hence the "true" TR is unknown, which impedes the performance of the market (Woodward, 2000). Ghosh and Shortle (2009) suggest that TR markets are only efficient under strong conditions on the relationship between the mean and the risk associated with an abatement. Validation of the existence of these conditions through data is imprecise at best. Anecdotal evidence suggests that existing TR markets are inefficient (Hoag and Hughes-Popp, 1997; Morgan and Wolverton, 2005).

The probabilistic market proposed by Ghosh and Shortle (2009) differs from the TR market in its treatment of the nonpoint source permit. The permit is defined as a multi-attribute good, where the attributes define the mean and covariance structure of the underlying pollution abatement. By expanding the definition of the permit (in the TR market the permit is defined only around the mean) information on pollution risk is supplied to the market. Buyers and sellers are then able to explicitly price risk when choosing their permit portfolios, unlike in TR markets where the regulator corrects for risk through intervention (by TR) in all trades. Market outcomes under this institution are superior to those under the TR. Following the convention used in Ghosh and Shortle (2009) we will refer to the probabilistic market institution as the Multi-Attribute Nonpoint Abatement or MANA market institution.

Experimental research on markets with nonpoint source polluters is sparse. Cason and Gangadharan (2006) use a test bed where pollution is variable but measurable and banking is allowed, and find that banking mitigates permit price variability at the expense of non-compliance and higher pollution levels. Their test differs from ours because they model pollution variability as discrete and as a consequence of shocks. The TR has not been studied experimentally.

Exploration of the impact of market power, because of size and information asymmetry, has been an area of research in the experimental literature on environmental markets. Most studies confirm the presence of market power in asymmetric markets – with few buyers and many sellers or vice versa – but to a lesser degree than indicated by the theory (Muller et al., 2002; Cason et al., 2003). A minority find no evidence of market power, with prices and trades converging to the competitive level (e.g., Carlèn, 2003). However, this research has been conducted in testbeds with only point sources. Our incorporation of market power into a point-nonpoint setting is a design innovation.

3 Experimental Framework

Our conceptualization of the experimental framework had four basic elements. First, we conceive the economic logic of the experiment, second, we devise the treatments that facilitate testing of the theory, third, we formulate hypotheses and their tests, and finally, we work through the experimental details, which include market structure, graphical layout, instructions and other session details. The elements are not independent, but our broad categorization eases the subsequent explanation of the model.

3.1 The Economic Rationale

The presence of nonpoint sources renders the pollution environment stochastic. In such an environment a safety-first approach to environmental decision making is appropriate (Qiu et al., 2001). The approach is equivalent to the use of significance levels for statistical decision making (Lichtenberg and Zilberman, 1988). This equivalence raises the likelihood that the safety-first approach will be amenable to scientists and policy makers in a wide variety of fields. Indeed, its core characteristic, which is a balancing of risk and cost, is also a characteristic of existing regulation on nonpoint source pollution control, notably the Total Maximum Daily Load program.

Under the safety-first approach the policy target is designed probabilistically. It requires that the target be met with a probability of x. In this paper, the variable of interest is aggregate pollution and probabilistic policy target is $\Pr(\text{Aggregate Pollution} \leq \text{Target}) \geq x$. From an economist's perspective, a policy instrument would be efficient only if it facilitated attainment of the probabilistic target at least cost. Ghosh and Shortle (2009) show that the market is an efficient instrument under certain easily implemented and enforced rules. These rules are based on the notion that market efficiency in the presence of risk is possible only if information on that risk is disseminated to all market participants. Accordingly, the stochastic nonpoint source permit is defined as a multi-attribute good, where the attributes contain pollution risk information. They call this market the

MANA market.

Ghosh and Shortle (2009) also show that current TR based markets only satisfy the safety-first environmental target at least cost in a single highly restrictive case. This is because the TR market incentivizes control of mean pollution but not its risk. The restrictive case requires that optimal control of mean pollution imply optimal control of risk. But this requires that pollution risk be a deterministic function of mean pollution for *all* polluters: a condition that is unlikely to hold true and is impossible to validate. Hence, Ghosh and Shortle (2009) infer that the MANA market will generate outcomes than the TR market.

The experimental test-bed for the comparison of the two market institutions is a simplified version of the theoretical environment in Ghosh and Shortle (2009). By simplifying the trading environment we control and and predict behavior with greater accuracy. This allows greater accuracy when measuring the phenomena of interest, and hence more accurate hypothesis testing. The first simplification is that nonpoint polluters only offer three abatement projects, unlike in the paper, where the abatement space is continuous. The second is that the nonpoint permit in the MANA market is defined only by its mean E and variance V. Its covariance with other permits is ignored. In effect we assume that pollution is independent across nonpoint sources. The final simplification is that all emissions constraints are linearized. As a consequence of the simplifications, the MANA and TR markets differ only in the way permits q are defined. However, expected outcomes in the simplified model are identical to those in Ghosh and Shortle (2009): under competitive conditions the MANA market generates superior environmental outcomes and at lower cost.[2]

Let the MANA and TR markets be indicated by $MANA$ and TR superscripts. In the MANA market the permits generated by an abatement project are $q^{MANA} = E - V$. Projects that are expected to supply high abatement with low variability are allotted the greatest number of permits. These projects will generate the highest revenue at any

[2]A formal version of the simplified model is available on request.

permit price. Sellers are incentivized to supply such projects, which are also optimal from the safety-first perspective. q^{MANA} may be interpreted as a measure of project quality: better quality projects have higher q^{MANA} values.

Reflecting current practice, in the TR market permits are defined in expected terms. A project with mean abatement E is allocated $q^{TR} = E/t$ permits where t is the project-specific trading ratio. TRs are chosen in a manner similar to that in existing trading programs. In half the parameter sets a uniform TR of 2:1 or 3:1 is used, reflecting arrangements in the Tar-Pamlico program, New York City Watershed Offsets Pilot Program and others. In the other half there is limited differentiation by nonpoint type and project, like in programs on the Kalamazoo, Charles and Rock rivers (for details see Breetz et al., 2004).[3]

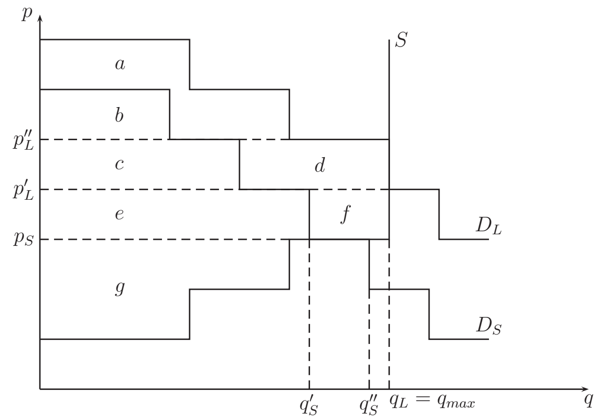
Our simplified model indicates that the MANA market will outperform the TR market in competitive conditions. Now consider the ramifications of oligopsony. If the oligopsonists are able to collude perfectly and maximize their joint profits then they, in effect, behave like a monopsonist. Market power is maximized and the monopsony outcome results. If they are unable to exert any market power, then the competitive outcome results. In general, the market outcome will lie between these two extremes. We are interested in how the economic size of the buyers affects the position of the market outcome between these extremes. Is the economic size positively correlated with market power or vice versa?

In Figure 1(a) we explore the competitive outcomes. D_L and D_S are aggregate demand curves for large and small buyers. S is the aggregate supply curve. It increases with price p until $p = p_S$, where permit supply is maximum q_{max}. Thereafter supply is perfectly inelastic. When buyers are large the competitive price tunnel is $[p'_L, p''_L]$ and $q_L = q_{max}$ permits are traded. The minimum consumers' surplus (CS) is $a + b$ and the maximum CS

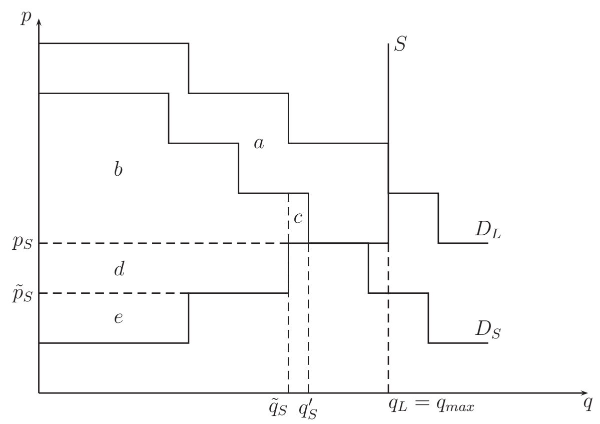
[3]The complex TRs found in the theory (see Hung and Shaw, 2005; Malik et al., 1993; Horan and Shortle, 2005) are not used for three reasons. First, the marginality conditions that define the optimal TR are meaningless in a discrete trading environment. Second, reflecting ground realities in existing markets, we assume that the environmental damage function is unknown. Third, the models in the cited papers assume a 1×1 trading environment and the transferability of those results to a more complex environment is unknown.

is $a+b+c+d$. The producers' surplus (PS) lies between $e+f+g$ and $c+d+e+f+g$. When buyers are small then the competitive price is p_S and permits traded lie in the interval $[q'_S, q''_S]$. The CS is $b+c+e$ and the PS is g. Total gains from trade are higher when buyers are large because the level of trade is higher. The gains from trade for nonpoint sellers are also higher because permit prices are higher. In a competitive market, sellers prefer larger buyers.

Figure 1: Outcomes under Oligopsony



(a) At the Competitive Limit



(b) At the Monopsonistic Limit

In Figure 1(b) we explore the monopsony outcomes. The demand and supply curves are identical to those in Figure 1(a). The difference between the competitive and monopsony outcomes is that prices are pushed down to the level that maximizes CS in the latter. When buyers are large, CS is maximized by restricting price to p_S, which is the competitive price in the market with small buyers. q_{max} permits are traded, CS is $a+b+c$ and PS is $d+e$. Monopsony does not cause a deadweight loss because high demand prevents a reduction in trade. Market power impacts the distribution of surplus, but not market efficiency. When buyers are small then price is $\tilde{p}_S$ and $\tilde{q}_S < q'_S$ permits are traded. CS is $b + d$, PS is e and there is a deadweight loss c, which exists because the buyers restrict trade below the socially optimal level – and the competitive level by design. Gains from trade and PS are higher when buyers are large, just as in the competitive outcome.

From an efficiency perspective, the policy maker will prefer markets where the buyers are large since such markets do not suffer deadweight losses. From the equity point of view, the picture is not clear. The comparative statics exercise does not supply inference on the market power exerted by the two buyer types. It does not indicate whether prices are closer to the competitive level when buyers are large or when they are small. We explore the interaction between size and market power in Section 3.3, where testable hypotheses are formulated.

3.2 Treatments

The experiment consists of two interacted treatments. The first treatment compares the MANA and TR market institutions through a within-subjects crossover design where the two market types are alternated over successive periods. A within-subjects design implies that each subject participates in both institutions. We alternate between markets to reduce ordering effects. The second treatment uses a between-subjects design to study the impact of buyer size on market power. A between-subjects design implies that subjects either participate in markets with small buyers or with large buyers, but not both. All possible treatment interactions are covered through a balanced 2x2 design, which implies equal numbers of observations on each treatment combination. Overall, we have eight sessions of data, split equally between large and small buyer markets. Each session has eight periods, which implies 64 market periods of data in all. The treatments are distributed across these periods as shown in Table 1.

The eight periods in a session are split equally between TR and MANA markets. Four parameter sets are used per session since each MANA market shares a parameter set with

Table 1: Distribution of Treatments across Periods

	TR Market	MANA Market	Total
Large Buyers	16	16	32
Small Buyers	16	16	32
Total	32	32	64

a TR market. The sessions with large buyers and small buyers have different parameter sets. Hence eight parameter sets are used in the experiment.

The method for calculating costs, revenues and profits is the same irrespective of the treatment type. Consider a seller S. Let q_S, $C(q_S)$ and π_S be its permit supply, cost and profit. Also consider a buyer B. Let $R(\cdot)$ and π_B be its revenue and profit. Let B_S be the set of sellers who contract with B. Then $\sum_{S\in B_S} q_S$ is the quantity of permits bought by B. The market price p is used to calculate profits for the round where

$$\pi_S = p \cdot q_S - C(q_S) \tag{1}$$

$$\pi_B = R\left(\sum_{S\in B_S} q_S\right) - p \cdot \sum_{S\in B_S} q_S \tag{2}$$

Calculation of market price p depends on the trading environment. We use a computerized uniform price call market trading system. A description of this trading system and its benefits are given in Appendix A.

Each nonpoint seller can produce three abatement projects, each supplying a known number of permits. Using this information an aggregate supply schedule, such as in Figure 1, is constructed. A point buyer's revenues increases as his ownership of permits increases, but at a decreasing rate. Using this information an aggregate demand schedule is constructed. From these schedules, competitive equilibrium prices p^C, monopsony prices p^{MO} and the number of trades n are calculated. Then, using equations (1) and (2) profits π are calculated. The parameterizations are not provided, but available on request. Table 2 summarizes the expected profits π, prices p and number of trades n at the competitive equilibrium for each parameter set. Table 3 summarizes the same results at the monopsony outcome. Both tables have identical column and row headings to facilitate easy comparison. The first column lists the parameter sets. The large and small buyer markets are labeled L and S respectively and the associated subscripts indicate the parameter sets. There are two seller types, S_1 and S_2 and one buyer type B. Profits in the L markets are scaled by the exchange rate between the markets ($E\$18$ in L market = $E\$8$ in S market) to facilitate comparison. The competitive equilibrium price p^C for the L market, as listed in Table 2, is the mid-point of the competitive price tunnel.

Table 2: Competitive Market Outcomes

Market	$\pi(S_1)$		$\pi(S_2)$		$\pi(B)$		p^C		n	
Size	MANA	TR	MANA	TR	MANA	TR	MANA	TR	MANA	TR
L_1	13.82	16.90	13.82	20.91	4.25	16.92	5.21	4.54	8	8
L_2	13.96	18.40	17.44	20.56	4.59	4.59	7.04	7.04	8	8
L_3	14.17	24.10	14.17	18.47	1.02	10.22	5.70	5.30	8	8
L_4	18.43	20.07	15.80	14.50	10.22	3.82	5.30	5.57	8	8
S_1	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	5–7	5–6
S_2	20.00	20.00	20.00	20.00	20.00	20.00	12.00	12.00	5–6	5–6
S_3	20.00	20.00	20.00	20.00	20.00	20.00	17.00	17.00	6–8	4–6
S_4	20.00	20.00	20.00	20.00	20.00	20.00	19.00	19.00	7–8	5–7

Table 3: Market Outcomes under Monopsony

Market	$\pi(S_1)$		$\pi(S_2)$		$\pi(B)$		p^{MO}		n	
Size	MANA	TR	MANA	TR	MANA	TR	MANA	TR	MANA	TR
L_1	0.00	0.00	0.00	0.63	59.54	91.28	1.76	1.16	8	8
L_2	0.00	1.96	0.00	0.00	67.39	78.59	3.56	2.93	8	8
L_3	0.00	2.56	0.00	0.00	57.69	90.24	2.87	2.22	8	8
L_4	0.00	2.67	0.00	0.00	78.69	67.62	2.67	2.67	8	8
S_1	20.00	12.00	10.00	20.00	38.00	32.00	18.00	18.00	4	4
S_2	12.00	20.00	20.00	11.00	34.00	34.00	10.00	9.00	4	4
S_3	12.50	20.00	20.00	12.00	33.00	36.00	14.50	15.00	4	4
S_4	20.00	14.00	12.50	20.00	29.00	28.00	17.50	18.00	4	4

Certain patterns manifest across sessions. As expected, seller profits are always higher at the competitive equilibrium and buyer profits are always higher at the monopsony outcome. However, there is a difference in the profit magnitude between the L and S markets. The difference between competitive and monopsony profits is greater in the L market than in the S market. This holds for buyers and sellers. Also, in the S market, there is a reduction in trade at the monopsony outcome when compared to the competitive outcome. This reduction causes an efficiency loss of 4 - 18%. There is no trade reduction in the L market and hence no efficiency loss.

3.3 Testable Hypotheses

Market efficiency a core consideration when gauging the relative performances of the MANA and TR markets. We also compare the efficiency of markets with economically large buyers to those with small buyers. Different conceptions of efficiency have been proposed and tested in the literature. For example, there is the concept of trading efficiency, where the researcher compares the welfare gains from trade to welfare gains at the social optimum. Gains from trade is the total surplus that accrues from trade and is defined as the difference between aggregate profit after trade and aggregate profit at autarky. We assess a market's trading efficiency by comparing realized gains from trade to gains from trade at the competitive equilibrium, which is the social optimum in our experiment. The proportional difference between the two is typically used as the measure of market efficiency by environmental experimentalists (see Cochard et al., 2005; Muller et al., 2002; Spraggon, 2002). Let π^{AU} be the profit under autarky and π^{C} be the competitive profit. Trading efficiency TE is

$$TE = \frac{\sum \pi - \sum \pi^{AU}}{\sum \pi^{C} - \sum \pi^{AU}} \tag{3}$$

$TE = 0$ when there are no gains from trade and $TE = 1$ when the market outcome is competitive and all gains from trade are realized.

We also propose the concept of environmental efficiency. The *raison d'etre* of a tradable permit market is the efficient attainment of the environmental policy target. Hence, one may measure an instrument's success by measuring the distance between the realized outcome and the optimal outcome. In a safety-first policy paradigm there is an optimum trade-off between the mean E and variance V of abatement. In this experiment the trade-off is embodied in the MANA market permit definition $q^{MANA} = E - V$. If $\tilde{q}_S^{MANA}$ is the permits sold by seller S at the optimum then $\sum_S \tilde{q}_S^{MANA}$ is the optimal level of nonpoint source abatement. The experimental market is environmentally efficient when it generates this optimal level of abatement. Our proposed performance measure for environmental efficiency is

$$EE = \frac{\sum q_S^{MANA}}{\sum \tilde{q}_S^{MANA}} \tag{4}$$

where EE is the proportion of optimum abatement realized. When $EE = 0$ the market is unable to generate any abatement and when $EE = 1$ it generates the optimal level. When $EE > 1$ the market causes over-abatement. The market's environmental efficiency increases as $EE \to 1$. EE is based on $P - MAR$, an efficiency measure proposed by Cason and Gangadharan (2005) to compare the efficiency of auctions at reducing nonpoint source pollution.

Transaction volume or the number of trades n is another indicator of market efficiency. Experimental markets are transactionally efficient when $n = n^C$, the number of trades at the competitive equilibrium. We define the transaction efficiency loss TL of a market as $TL = n^C - n$. $TL = 0$ when the market is transactionally efficient and it increases as inefficiency increases. Expected transaction volumes n under each market type at the competitive equilibrium and under monopsony are listed in Tables 2 and 3.

We use the three proposed efficiency measures to test Hypothesis 1 below. Since trading profits are higher for large buyers than for small buyers, we expect higher trade volumes in the large buyer market. This higher trade volume will ensure high trading, environmental and transactional efficiency. In other words, we expect that $TE_L > TE_S$, $EE_L > EE_S$ and $TL_L < TL_S$ where L and S indicate the large buyer and small buyer markets respectively.

Hypothesis 1. *The market will be more efficient when buyers are large*

The MANA and TR markets differ in the manner in which abatement projects are appraised and permits allocated. Since $q_S^{MANA} = E - V$ and $q_S^{TR} = E/t$ more permits are allocated to high quality projects with high mean and low variability in the MANA market. As a consequence, the cost per permit or average cost of producing these high quality projects is lower in the MANA market. At any price, these high quality projects are more profitable in the MANA market. Hence, sellers are incentivized to trade in high quality abatement projects in the MANA market. Trade in such projects is more likely to facilitate attainment of the environmental target. This leads to the expectation that $EE^{MANA} > EE^{TR}$ and the next hypothesis, stated below.

Hypothesis 2. *The Environmental Efficiency of the MANA market is higher.*

High quality projects are allotted more permits and have a lower average cost per MANA permit, $AC^{MANA} = C(q_S^{MANA})/q_S^{MANA}$, in the MANA market. Projects with high E are allotted more permits and have a lower average cost per TR permit, $AC^{TR} = C(q_S^{TR})/q_S^{TR}$, in the TR market. When the two sets of projects are not identical then projects that are most cost effective in one market are less cost effective in the other. Cost effective projects are also more profitable for sellers and hence, high quality (high E) projects are supplied in the MANA (TR) market. Also note that AC^{MANA} measures a project's cost effectiveness from the policy maker's point of view.

On the other side of the market, buyers prefer projects with more permits. Hence, they prefer high quality projects in the MANA market and high E projects in the TR market. The logic is as follows: Buyers purchase permits from multiple sellers until they own the profit maximizing quantity $q_B^* = \sum_{S \in B_S^*} q_S$ where B_S^* is a project portfolio supplying q_B^*. The greater the number of trades, the greater the uncertainty over whether the buyer will manage to buy q_B^* permits in a round. The buyer's preference will be for fewer trades, which implies more bids for high permit projects.

Higher quality projects will be offered and demanded in the MANA market and higher E projects in the TR market. By definition, the high quality projects will have lower V than the high E projects. The following related hypotheses are formulated on project characteristics in the two markets.

Hypothesis 3. *First, projects traded in the MANA market will be of a higher quality than projects traded in the TR market. Second, aggregate variability of abatements generated by the MANA market will be lower. Third, aggregate expected value of permits traded in* *the TR market will be higher. Finally, projects traded in the MANA market will be more cost-effective from the policy maker's point of view*

Market power may be defined as the ability to profitably deviate prices from the competitive equilibrium (Mas-Colell et al., 1995, pg. 383). Do the large or the small buyers exert more market power? On one hand, there may be greater price competition among large buyers since permits in the L market are scarcer. Since large buyers demand more permits relative to supply, they may compete by offering higher bid prices relative to small buyers. On the other hand, large buyers also have a stronger incentive to collude. Supercompetitive profits from collusion and enforcement of market power are higher for large buyers (see Tables 2 and 3). If buyers react to the profit incentive and depress prices large buyers will capture a greater share of the gains from trade.

Permit price movements are one manifestation of market power. Under competition, bids will be higher and the permit price will be closer to the competitive outcome. Conversely, under collusion, bids are kept low and the permit price will be closer to the monopsony outcome. Through comparison of permit prices in the two markets inferences on the relative exercise of market power may be drawn. We devise a unitless index of market power based on permit prices, called the Price Index of Monopsony Trading Effectiveness, I^p. It is based on the Index of Monopoly Trading Effectiveness devised by Isaac et al. (1984).

$$I^p = \frac{p - p^{MO}}{p^C - p^{MO}} \tag{5}$$

In (5), p^{MO} is the monopsony price and p^C is the competitive price. When buyers collude perfectly then $p = p^{MO}$ and $I^p = 0$. When buyers behave competitively then $p = p^C$ and $I^p = 1$. Buyers exert market power when $0 \leq I^p < 1$, increasing as $I^p \to 0$. Sellers exert market power when $I^p > 1$. This outcome is not expected. We use I^p to test the validity of Hypothesis 4, stated below.

Hypothesis 4. *Permit prices will be closer to the competitive equilibrium price in the large buyer treatment*

Under Hypothesis 4 $I_L^p > I_S^p$. If the evidence supports Hypothesis 4 then we infer that large buyers behave more competitively than small buyers. They disregard their stronger profit incentives. We will also use the data to test the opposite statement, i.e. test if $I_S^p > I_L^p$ and that large buyers are better at collusion.

Buyers exerting market power capture a greater proportion of the gains from trade than buyers behaving competitively. As a corollary, sellers will fare worse. Hence market power can be measured by comparing realized profits to competitive profits. We devise two unitless metrics of market power, based on buyers' and sellers' profits. The former is the Buyers' Index of Monopsony Trading Effectiveness I^B (6) and the other is the Sellers' Index of Monopsony Trading Effectiveness I^S (7).

$$I^B = \frac{\sum_B \pi_B - \sum_B \pi_B^C}{\sum_B \pi_B^{MO} - \sum_B \pi_B^C} \tag{6}$$

$$I^S = \frac{\sum_S \pi_S - \sum_S \pi_S^{MO}}{\sum_S \pi_S^C - \sum_S \pi_S^{MO}} \tag{7}$$

B in (6) indexes the buyers and S in (7) indexes the sellers. $\sum_B \pi_B$ and $\sum_S \pi_S$ are the aggregate buyers' and sellers' profits respectively, as realized in a market period. MO and C superscripts are appended to indicate the monopsony and competitive outcomes. In (6) $I^B = 0$ when buyers compete and $\sum_B \pi_B = \sum_B \pi_B^C$, and $I^B = 1$ when buyers collude perfectly and $\sum_B \pi_B = \sum_B \pi_B^{MO}$. When $0 < I^B \leq 1$ we infer that buyers collude to exert market power, which increases as $I^B \to 1$. I^B is negative either when price exceeds the competitive price level, or when trading volumes fall below competitive levels but prices remain near the competitive level. The latter scenario implies trading inefficiency. In (7) $I^S = 0$ when buyers collude perfectly and generate the monopsony outcome. $I^S = 1$ when seller earnings equal the competitive equilibrium level. The sellers exert market power when $I^S > 1$ and buyers exert market power when $0 \leq I^S < 1$, increasing as $I^S \to 0$. We use I^p and I^S to test Hypothesis 5, given below. Like the first, it is designed to facilitate understanding of how market power interacts with buyer size. Under Hypothesis 5, $I_S^B < I_L^B$ and $I_S^S > I_L^S$. Validation of the hypothesis implies that small buyers exert more market power than large buyers. The large buyers are unable to coordinate their strategies under permit scarcity.

Hypothesis 5. *Small buyers will capture a greater proportion of the gains from trade*

3.4 Experimental Details

Eight experimental sessions were conducted between between November 17, 2008 and April 22, 2009 at the Laboratory for Economic Management and Auctions at the Pennsylvania State University. All subjects were graduate and undergraduate students at Penn State. Instructions and the visual environment made use of neutral terminology to remove the effect of subjective environmental biases on decision making. For example permits were called "fips" and abatement creating technologies were referred to as "projects." In each session ten subjects traded permits in a computerized uniform price call market trading system. The experimental market was programmed and conducted with the z-Tree software (Fischbacher, 2007).

We assume that point sources only buy permits and nonpoint sources only sell permits. In existing markets nonpoint sources have no incentive to buy permits because they do not face mandatory emissions caps. Rather, the expectation is that emissions markets will control nonpoint emission *without* direct regulation, through financial incentives provided by point sources (USEPA, 2003). We do not allow trades between point sources because such trades will obscure point-nonpoint interactions, which are the phenomena of interest.

Two subjects are cast as point sources buying permits and the remaining eight are cast as nonpoint sources selling permits when the experimental session begins. Subjects keep their job roles for the duration of the session. The description and distribution of roles reflects the oligopsony and incentive structure in current point-nonpoint markets. The market consists of three types of subjects: two seller types and one buyer type. Subjects within a type are homogeneous.

Sellers are divided into two groups of four and are homogeneous within groups but heterogeneous across groups. Each seller type has access to three technologies that supply stochastic abatements. The seller is aware of the permits supplied by each technology and its implementation cost. In any round she may offer only one of the three projects to the market. By imposing this rule we abstract from interactions between technologies and their impact on cost and permit generation. Also, the rule is useful as a mechanism for increasing seller participation because it increases the likelihood that individual sellers are able to trade successfully. Cason and Gangadharan (2005) made a similar observation in the context of permit auctions.

Buyers are homogeneous. Each buyer faces an emissions cap, which he meets by permit purchase and own abatement. He buys permits by contracting with a seller to implement a given project. His permit stock increases by the quantity of permits supplied by the project. Buying permits increases revenue because it allows expansion of production. This revenue is characterized in the experiment as "redemption value." Typically the more permits supplied by a project the higher its redemption value. We assume that the marginal benefits from permit purchase are decreasing. In every round a buyer can make multiple bids for projects. Since marginal benefits decrease in permits bought, redemption values associated with later bids are less than those associated with earlier bids: a project with a redemption value of \$70 when the market opens might only have a redemption value of \$50 conditional on ownership of two other projects.

Each experimental session consists of eight periods. Each period consists of a minimum of three and maximum of eight rounds. Periods end either when the permit price has converged or if eight rounds have passed. We assume convergence when prices remains unchanged across two periods. The rounds-within-periods format is common to market experiments (e.g., Bossaerts et al., 2002), although most market experiments on emissions trading use periods with a single round (e.g., Cason and Plott, 1996; Franciosi et al., 1993; Muller et al., 2002). We find the rounds-within-periods approach more suited to our experimental framework, where the markets in each period are structurally identical but have different parameterizations. Because of changing parameterizations many traders are unable to find realistic prices in early rounds. However, their experience with a given parameterization increases proportionately to the number of rounds, and trade volume is typically higher in the later rounds.

The call market in our experiment works as follows. When the market opens in the first round the seller knows the cost and permits supplied by her three abatement projects. She uses this information to make a single offer, consisting of project name and price. The buyer knows the earned revenues and permits associated with the six projects potentially on offer. He uses this information to make multiple bids. After the market closes bids and offers are ranked by project. Bids are ranked in descending order (highest price first) and offers in ascending order. Bids and offers of equal rank and that have bid price exceeding offer price are paired by project. These are considered the successful bids and offers for the round. Unit bid and offer prices are calculated for these successes and then compiled into demand and supply schedules. The point or interval where schedules intersect determines the uniform market price p per permit.

In the next round when the market opens the seller is informed of her offer status and the project profitability at current prices. The buyer is informed of of his bid(s) status and the redemption value earned from successful bids. Subjects are also informed of the market price and all other bids and offers made in the previous round. While the market is open the buyer makes new bids while the seller amends, resubmits or deletes her old offer, or makes a new offer. When the market closes bids and offers are again ranked and a new market price determined. The process continues until the period ends. Termination criteria are either that eight rounds have passed or that the market price remains unchanged over two consecutive periods.

Including instructions, sessions took about two hours to complete. Earnings were denominated in experimental dollars, which were converted into US dollars at E$18 to US$1 in the L market type and E$8 to US$1 in the S market type. Earnings ranged from US$10 to US$83 with a mean of about US$21. Experiment instructions are available on request.

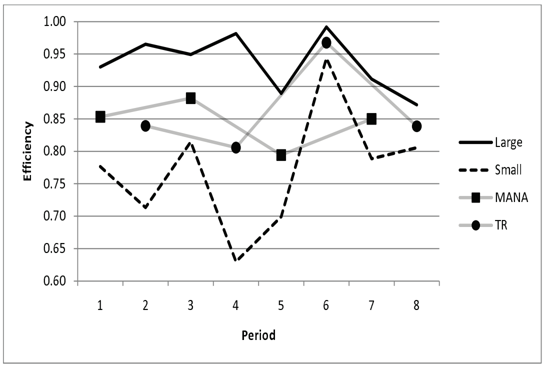
4 Results and Discussion

The trading efficiency TE of the experimental market under each treatment is shown in Figure 2(a). The solid and dotted black lines indicates TE in the large buyer market and small buyer markets respectively. The grey line with square data points indicates TE in the MANA market and the grey line with circular data points indicates TE in the TR market. We will use an identical graphical scheme to denote the behavior of other variables in each treatment. As mentioned earlier, we alternated between the MANA and TR markets during each session. Practically, this means that all observations for periods one, three, five and seven correspond to the MANA market and all others correspond to the TR market.

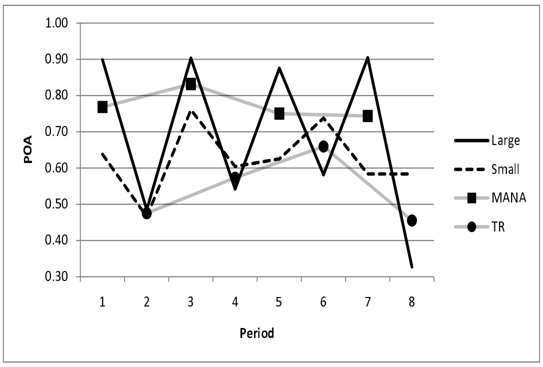
In the following discussion, we continue to use L and S subscripts to denote variable values in the large buyer and small buyer markets respectively. We also use $MANA$ and TR superscripts to indicate variable values in the MANA and TR markets. As Figure 2(a) shows, overall trading efficiency is higher in the large buyer market, with $0.86 \leq TE_L \leq 0.99$, than in the small buyer market where $0.63 \leq TE_S \leq 0.94$. Overall trading efficiency in the TR and MANA markets seem similar with $0.80 \leq TE^{MANA} \leq 0.88$ and $0.80 \leq TE^{TR} \leq 0.96$.

We estimate a random effects panel data model to quantify the relationships between TE per period and the treatments. Given eight periods and sessions, there are 64 observations. The results are presented as model 1 in Table 4. The estimates are corrected for serial correlation and heteroscedasticity through application of the Newey and West (1987) procedure. The independent variables are dummies for treatment effects and a time trend specified as 1/Period Number. As noted by Cason and Gangadharan (2003) the 1/Period time trend specification allows the intercept to be interpreted as asymptotic trading efficiency. Dum_{Inst} corresponds to the market institution treatment, equalling 0 for the status quo TR market and 1 for the MANA market. Dum_{Size} corresponds to the buyer size treatment, equalling 1 under the L treatment and 0 otherwise. Hence, when $Dum_{Inst} = 0$ and $Dum_{Size} = 0$ then the intercept is interpreted as asymptotic TE in the

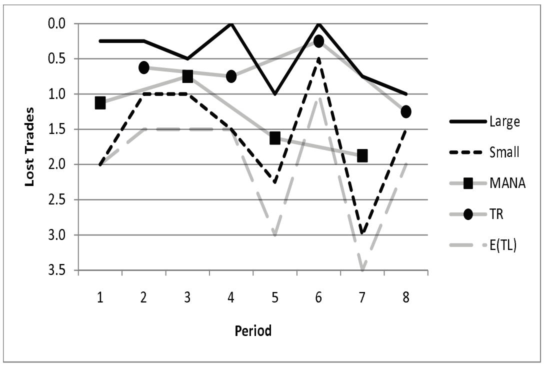
Figure 2: Efficiency Indices



(a) Trading Efficiency, TE



(b) Environmental Efficiency, EE



(c) Transaction Efficiency Loss, TL

TR market with small buyers. When $Dum_{Inst} = 1$ and $Dum_{Size} = 0$ then the sum of the intercept and the Dum_{Inst} coefficient is interpreted as asymptotic TE in the MANA market with small buyers. The asymptotic TE in the MANA and TR markets under the L treatment is analogously calculated. Hence, model 1 indicates that $TE_S^{MANA} = 0.76$, $TE_S^{TR} = 0.78$, $TE_L^{MANA} = 0.92$, and $TE_L^{TR} = 0.94$.

The Dum_{Size} coefficient is significant, which indicates that TE is significantly higher when buyers are large. The Dum_{Inst} coefficient is negative, but not significant, indicating that TE is similar in the TR and MANA markets. The time trend has no effect on TE.

Environmental efficiency EE under each treatment is shown in Figure 2(b). Model 2 contains the results of the random effects panel data regression between EE per period and the treatments. In Figure 2(b) EE^{MANA} hovers around the 80% mark while EE^{TR} ranges from 45-65%. EE seems significantly higher in the MANA market. This is corroborated by the regression results, which indicates that EE in the MANA market is

Table 4: Panel Regression Models for Efficiency Tests

Dependent Variable	TE in Period (Model 1)		EE in Period (Model 2)		TL in Period (Model 3)	
Intercept	0.78**	(0.04)	0.51**	(0.04)	1.44**	(0.32)
Dum_{Inst}	-0.02	(0.03)	0.24**	(0.03)	0.72**	(0.23)
Dum_{Size}	0.16**	(0.03)	0.06*	(0.03)	-1.12**	(0.25)
1/Period	0.00	(0.07)	-0.02	(0.07)	-0.61	(0.42)
R-Squared	0.30		0.38		0.36	
Number of Obs.	64		64		64	

Standard errors are in parentheses. ** and * indicate that coefficients are significantly different from zero at the 1% and 10% levels. The session acts as the random effect, corrected for through the Newey and West (1987) procedure.

24% higher than in the TR market. A policy maker may expect abatement to be 24% higher in the MANA market than in the TR market. The graphical indicators on L versus S market efficiency are not as clear. We see that EE_L in is higher than EE_S under the MANA treatment, but lower under the TR treatment. The difference under the MANA treatment is greater than under the TR treatment, which indicates, that overall EE_L may be slightly higher than EE_S. This result is corroborated by Model 2, which indicates a 6% difference. However, the results are only significant at the 10% level. EE is lowest under the small buyer and TR treatments with $EE_S^{TR} = 51\%$. It is highest under the large buyer and MANA treatments with $EE_L^{MANA} = 81\%$.

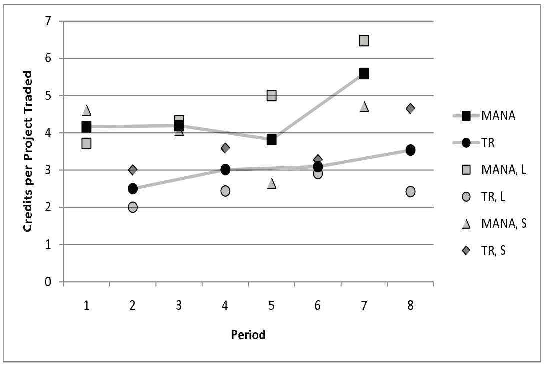
As Tables 2 and 3 show, the market with large buyers is calibrated such that it will not lose transaction efficiency because of monopsony: $E(TL)_L = 0$. By contrast, the expected loss in transaction efficiency under the S treatment is 1-3.5 units per period as marked by the dotted grey $E(TL)_S$ line in Figure 2(c). In the experiment, TL_L is in the 0-1 range while TL_S ranges from $0.5 - 3.0$ units, as seen in Figure 2(c). The results of the regression of TL on treatments effects and time are given in Model 3 in Table 4. They support the graphical evidence that the loss in transaction efficiency is significantly greater when buyers are small. On average, the transaction loss under the small buyer treatment is one trade more than under the large buyer treatment. The difference between EE_L and EE_S may be because of TL, since the shortfall in trade below the competitive outcome is significantly higher under monopsony when buyers are small. This expectation is borne out by the results.

Figure 2(c) and Model 3 also indicate a significant difference in n between the two market institutions. On average, TL in the MANA market is three quarters of a unit higher than in the TR market. The difference might be explained by looking at the $E(TL)_S$ line in Figure 2(c). Note that $E(TL)_S$ is lower in the odd-numbered periods, which correspond to the MANA market type, which implies that $E(TL)_S^{MANA} > E(TL)_S^{TR}$ under monopsony. Even though $E(TL)_L^{MANA} = E(TL)_L^{TR}$, lower expected trade volume in MANA markets with small buyers might be sufficient to ensure that overall efficiency losses are higher in under the MANA market. This is a parameterization issue. The markets were structured such that there are fewer transactions in the MANA market under monopsony. When the experimental results also show fewer transactions in the MANA market, it merely indicates that the results conform to expectations. It should not be construed as indicating that transactional inefficiency is higher in the MANA market for any reason other than parameterization.

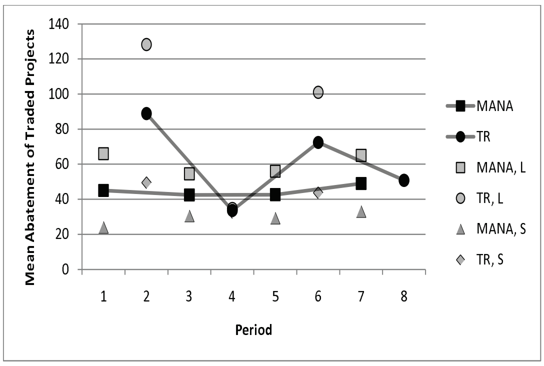
Overall, the results show that under each measure the market with large buyers is significantly more efficient than the market with small buyers. Whether considering trading efficiency, environmental efficiency or transactional efficiency, oligopsonistic tradable permit markets perform better the greater the economic size of the buyers. This is especially true in the case of trading and transactional efficiency. These results support Hypothesis 1. The results come about because when buyers are large, even when exerting market power, they are not tempted to reduce the number of transactions below the social optimum. The results also indicate that the environmental efficiency of the MANA market is significantly greater than that of the TR market, which supports Hypothesis 2. The MANA market will generate superior environmental outcomes, even in the presence of monopsony.

We now analyze qualitative differences in the abatement projects traded in under MANA, TR, S and L treatments. The quality of the abatement projects is measured by the number of permits allocated to the project in the $MANA$ market, q^{MANA}. Figure 3(a) shows the differences in project quality across the four market types. The grey line with square (round) data points denotes the MANA (TR) market. The grey squares and circles indicate permits traded by large buyers in the MANA and TR markets. The grey triangles and diamonds indicate permits traded by small buyers in the MANA and TR markets. We use the same graphical scheme in Figures 3(b), 3(c) and 3(d). Projects traded in the MANA market supply an unambiguously greater number of permits than the projects traded in the TR market. This is true irrespective of whether the large or small buyers are trading. The graphics are supported by the results of Model 4, which reports results of a regression of q^{MANA} on the treatments and time. Dum_{Inst} is positive and significant, indicating that projects traded in the MANA market supply 1.5 more permits on average. Asymptotically, a project in the TR market supplies 3.36 permits and one in the MANA market supplies 4.92 permits. Buyer size does not significantly affect project quality. There is also a significant time trend. The projects traded in later periods contain more permits.

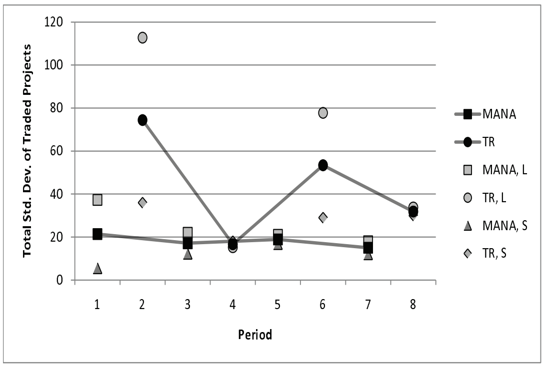
Figure 3: Quality and Cost Effectiveness of Traded Projects



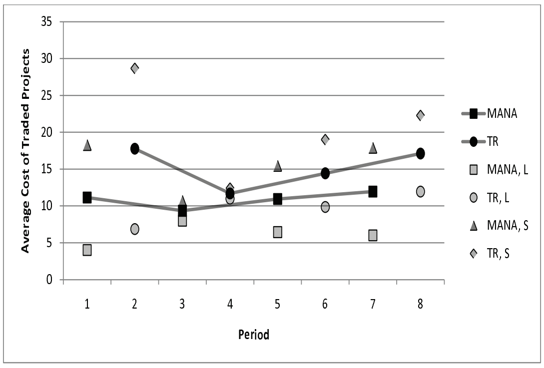
(a) Permits per Trade, q^{MANA}



(b) Mean Abatement per Period, $\sum E$



(c) Standard Deviation of Traded Abatements per Period, $\sum SD$



(d) Unit Cost of Traded Abatements, $\sum C(q^{MANA})/q^{MANA}$

The two characteristics of nonpoint abatement that are of interest to a policy maker following the safety-first approach are its expectation and variance. As stated in Hypothesis 3, it is expected that projects traded in the TR market will have higher mean abatement, but will also be less reliable and characterized by higher variability. These expectations are borne out by the experimental results, as shown in Figures 3(b) and 3(c), where the TR line market lies above the MANA line. The mean and variance of traded abatement is especially high in the TR market with small buyers. The expectations are also borne out by Models 5 and 6, which report the regression results with respect to E and SD. Mean abatement in the MANA market is almost 19 units lower than in the TR market in the aggregate. However, the standard deviation is also 29 units lower in the aggregate, which is why project quality is higher in the MANA market.

There is also a significant buyer size effect. In the aggregate, projects with higher mean and higher variability are traded in the large buyer market. However, this does not have an impact on project quality since, as Model 4 shows, buyer size does not affect project quality. The difference between the aggregate expected value of traded permits in the large and small buyer markets is significant but does not have inferential value because it arises from underlying parameter differences. In the large buyer markets the range of expected abatement supplied by a project is $4 \leq E_L \leq 18$, while in the S market the range is $4 \leq E_S \leq 12$. Parameterization also explains the significant difference in project variance between the large and small buyer treatments. There is no parameterization effect when comparing expected abatement in the MANA and TR markets because parameters in MANA-TR market pairs are identical. The time trend is relatively small, but significant in Models 5 and 6. It indicates that projects traded in later sessions have higher means and variances. This is also a consequence of parameterization. It does not have inferential value.

The final metric of abatement quality is the average cost of projects traded per MANA market permit supplied. The market that supplies projects with lower average costs is more cost-efficient. The *raison d'etre* of an emissions trading market is its perceived cost efficiency. Hence markets with higher cost efficiency may be considered as the 'better' market. As stated in Hypothesis 3 the MANA market is expected to be more cost efficient. Figure 3(d) bears out this expectation with the TR line always lying above the

Table 5: Panel Regression Models for Abatement Quality Statistics

Dependent Variable	q^{MANA} per Trade (Model 4)		E in Period (Model 5)		SD in Period (Model 6)		AC in Period (Model 7)	
Intercept	3.36**	(0.34)	41.77**	(4.63)	27.75**	(4.92)	20.07**	(0.99)
Dum_{Inst}	1.56**	(0.29)	-18.63**	(5.48)	-29.12**	(5.79)	-4.53**	(1.00)
Dum_{Size}	-0.16	(0.20)	32.84**	(5.05)	22.28**	(4.79)	-10.06**	(0.93)
1/Period	-0.95*	(0.37)	12.46*	(6.91)	19.86**	(7.00)	0.79	(1.62)
R-Squared	0.41		0.46		0.45		0.71	
Number of Obs.	64		64		64		64	

Standard errors are in parentheses. ** and * indicate that coefficients are significantly different from zero at the 1% and 10% levels. The session acts as the random effect, corrected for through the Newey and West (1987) procedure.

MANA line. However, the vertical distance between the two lines is not large, and it is possible that the cost difference may not be significant. This possibility is put to rest by the results in Model 7, where the results of the regression of AC^{MANA} on treatments and time are reported. Dum_{Inst} is significant and indicates that AC^{MANA} of projects traded in the MANA market is about 4.5 experimental dollars lower than those traded on the TR market. Dum_{Size} is also significant, but this result is a consequence of the parametrization of E and V in the large and small buyer markets. The time trend is not significant.

Overall, the results in Figure 3 and in Models 4-7 support Hypothesis 3. They indicate that projects traded in the MANA market tend to have higher quality – in the sense of embodying a more judicious mix of mean pollution reduction and pollution risk reduction – than the projects traded in the TR market. In the mean, the TR market supplies more abatement. However, the projects traded in the TR market are environmentally riskier. In aggregate this leads to poor project quality. As a consequence the safety-first environmental target is more likely to be violated in the TR market. Finally, projects traded in the MANA market are more cost efficient, and hence more profitable for nonpoint sources. These results hold independently of the impacts of market power.

Our analysis now shifts to an examination of the experimental results on the presence of market power. In Section 3.3 we defined three measures of market power, I^p, I^B and I^S. I^p is based on permit prices and its values across periods and treatments is shown in

Figure 4(a). From the definition of I^p we know that prices are perfectly competitive when $I^p = 1$ and that perfect monopsony is exerted when $I^p = 0$. The I^p_{MANA} and I^p_{TR} lines lie close together and intersect, indicating that the market institution does not impact the exercise of market power. The results of the regression of I^p on treatment and time effects (see Model 8 in Table 6) support this graphical evidence.

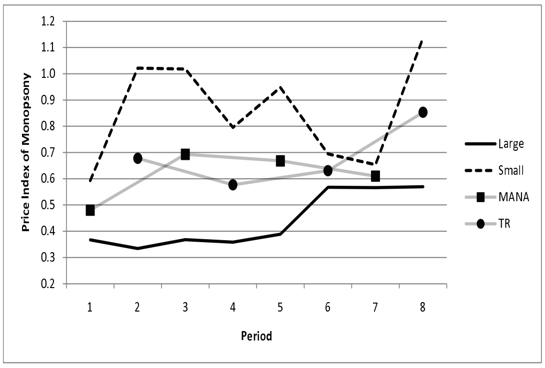
The I^p_L line, however, is always below the I^p_S line, which indicates that prices are closer to the competitive outcome when buyers are small. Model 8 indicates that this result is significant. I^p_L is 42% less than I^p_S and this difference is significant at the 1% level. A t-test also indicates that I^p_S is not significantly different from 1, which indicates that prices in the small buyer treatment are not significantly different from competitive prices. Small buyers are not able to deviate prices from the competitive outcome. These results strongly refute Hypothesis 4. We infer that large buyers respond to the strong signal for collusion, which is embodied in their high supercompetitive profits. As a result, they collude tacitly and depress prices significantly below competitive levels.

However, Figure 4(a) indicates that they are not quite able to depress prices to monopsony levels. Prices in the large buyer market remain about 30-60% above monopsony level. Their collusion is not optimum. Also note that prices are higher during later periods, perhaps signifying learning effects among sellers. It is feasible that over time, sellers learn to counter attempts by large buyers to exert market power. The inverse time coefficient in Model 8 is negative, but not significant, which lends some support for this assertion.

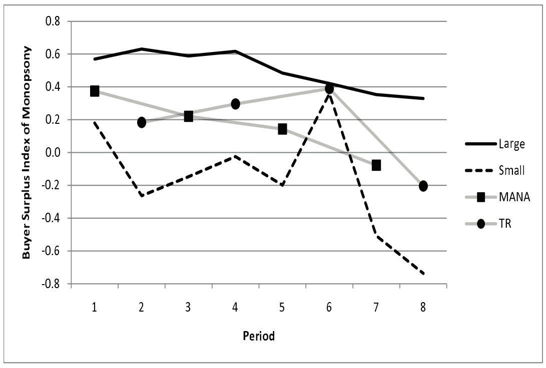
The second measure of monopsony is the Buyers' Index of Monopsony Trading Effectiveness I^B. $I^B \to 0$ when buyers' surplus reaches competitive equilibrium levels and $I^B \to 1$ when it reaches monopsony levels. Figure 4(b) indicates that I^B does not vary significantly by market institution. This result is supported by the regression results in Model 9 in Table 6. In this model I^B is regressed against the treatment and period effects. Hence, we may infer that the buyers' use of market power is not affected by the type of market institution.

The size of the buyer, on the other hand, does seem to impact market power. I^B_L is

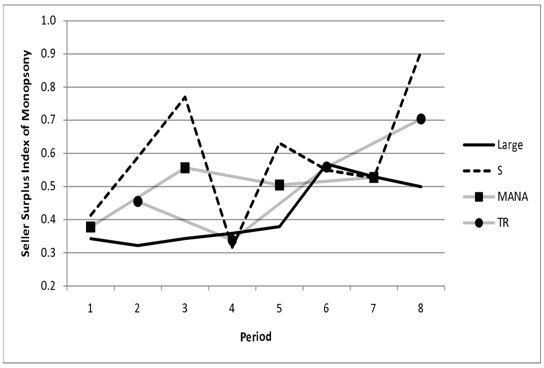
Figure 4: Indices of Monopsony Trading Effectiveness



(a) Price-Based Index, I^p



(b) Buyers' Surplus Index, I^B



(c) Sellers' Surplus Index, I^S

always higher than I^B_S in Figure 4(b), indicating that large buyers are able to capture a significantly larger proportion of the available gains from trade than small buyers. The results in Model 9 also show strong support for this notion. Large buyers capture 67% more of the gains from trade than the small buyers. The intercept is significantly negative at the 10% level. Given the non-significance of Dum_{Inst}, this indicates that the gains from trade captured by small buyers is lower than the competitive level. This seemingly anomalous result is explained by the coexistence of two factors. The first is the high losses in transaction efficiency in the small buyer market and the second is that prices in the small buyer market are similar to competitive prices. When prices are competitive, then buyers make competitive profits by buying enough permits that in the aggregate, competitive levels of trade result. If, on the other hand, they trade less, then their profits fall below competitive levels. This dip in profits is a consequence of market inefficiency rather than because of sellers exercising market power.

The time trend is also significant at 10%, which implies a reduction in I^B and a more

Table 6: Panel Regression Models for Monopsony Statistics Tests

Dependent Variable	I^p in Period (Model 8)		I^B in Period (Model 9)		I^S in Period (Model 10)	
Intercept	0.95**	(0.09)	-0.27*	(0.14)	0.66**	(0.11)
Dum_{Inst}	-0.04	(0.07)	-0.06	(0.11)	0.01	(0.07)
Dum_{Size}	-0.42**	(0.09)	0.67**	(0.12)	-0.17*	(0.09)
1/Period	-0.21	(0.16)	0.40*	(0.22)	-0.23	(0.15)
R-Squared	0.32		0.38		0.09	
Number of Obs.	64		64		64	

Standard errors are in parentheses. ** and * indicate that coefficients are significantly different from zero at the 1% and 10% levels. The session acts as the random effect, corrected for through the Newey and West (1987) procedure.

equitable sharing of gains from trade as subjects gain experience. Sellers improve at resisting the downward pressure on price exerted by buyers and thereby reduce buyers' surplus. Given inefficiency in the small buyers market, the significant time trend implies that buyers' gains from trade in this market fall further below competitive levels.

The final measure of market power considered is the Sellers' Surplus based Index of Monopoly Effectiveness (7). At the monopsony outcome $I^S = 0$ and at the competitive equilibrium outcome $I^S = 1$. As shown in Figure 4(c), I^S does not vary significantly across the MANA and TR markets, implying that it is not significantly affected by the institution effect. This result is corroborated by the regression results in Model 10 in Table 6, where Dum_{Inst} is not significant. In this model I^S is regressed against treatment and time effects.

Similar to the results on the other monopsony measures however, Figure 4(c) and Model 10 indicate that buyer size does have a significant impact on market power. I_S^S lies above I_L^S and Dum_{Size} is a significant regressor, but only at the 10% level. Sellers' surplus capture is significantly less when buyers are large. When buyers are small then surplus capture by sellers is 66% of the competitive level. By contrast, when buyers are large then surplus capture is only 49%. Note that when buyers are small then surplus capture by buyers *and* sellers are lower than competitive levels. This is further indication of transaction efficiency losses. If the market were efficient then less-than-competitive surplus capture on one side of the market is counterbalanced by more-than-competitive surplus capture on the other side.

The coefficient on the time trend is negative, implying an increase in buyers' market power as the experiment progresses, but the impact is not significant. This supports the time trend results on I^B and supplies more evidence in support of the notion that sellers learn to resist market power as the experimental session progresses.

The results in Models 9 and 10 indicate that large buyers capture a significantly larger proportion of the gains from trade than small buyers. Hence, the experimental evidence refutes Hypothesis 5. As a corollary, we infer that large buyers are better at collusion than small buyers. Also, note that buyer profits are more responsive to buyer size than seller profits. When buyers are large their profits increase by 67%, but seller profits only decrease by 17%. This result is explained by market asymmetry. Consider a buyer trading with four sellers, each selling one permit. If the market price falls by one unit, seller profits fall by one unit, but buyer profits rise by four units. Hence, given the relative scarcity of buyers, *ceteris paribus* buyer profits will always increase at a faster rate than seller profits fall.

5 Conclusion

The experimental results are broadly as follows. First, better quality and more cost-efficient abatement projects are traded in the MANA market. Second, environmental outcomes are better in the MANA market. Third, market efficiency is higher when buyers are large, as compared to when they are small because levels of trade do not fall below the competitive level. Fourth, large buyers exert more market power than small buyers and thereby capture a greater proportion of the gains from trade. Finally, there are no significant differences in how the MANA and TR market institutions affect market efficiency and market power.

The experimental results support Hypothesis 3, which states that abatement quality will be higher in the $MANA$ market than in the TR market. First, we find that mean abatement quality, as measured by q^{MANA}, is significantly higher in the $MANA$ market. Projects with a higher mean are traded in the TR market, which is good. However, these projects also have high variance, because of which, projects traded in the MANA market are of higher quality, all things considered. The final result on abatement quality is that q^{MANA} permits are more cost effectively obtained in the MANA market. Overall, the results also support Hypothesis 2 and show that environmental outcomes are better in the MANA market. Since the *raison d'etre* of emissions trading is to create quality abatements cost effectively, the experimental results strongly support the MANA market at the expense of the TR market.

Permit prices were significantly higher in the small buyer markets, which indicates that large buyers were better able to push prices downward towards monopsony levels in a refutation of Hypothesis 4. Lower permit prices were instrumental in ensuring that large buyers got a significantly greater proportion of the gains from trade than the small buyers; a result that refutes Hypothesis 5.

Markets were parameterized such that profit differentials existed between monopsony and competitive equilibrium outcomes. This differential was larger in the large buyer markets. We may think of the profit differential as a "signal" to cooperate and generate the profitable monopsony outcome instead of compete and reach the competitive equilibrium outcome. Extending the analogy, the signal to cooperate is stronger in the large buyer market: the incentive to collaborate would be bigger for the large buyers given the greater profit differential. It is reasonable to assume that buyer awareness of the need to collaborate would be directly proportional to signal strength. And to assume that buyers who want to collaborate are likelier to do so, thereby increasing their profits. Patterns in permit price and capture of the gains from trade support this chain of reasoning. It seems that large buyers did indeed cooperation tacitly, pushing prices down and generating higher profits than the smaller buyers. We infer that signal strength significantly affected the degree of cooperation between buyers.

The experimental evidence shows that the large buyer market was more efficient than the small buyer market. Efficiency was measured by TE, which compared realized gains from trade to optimum gains from trade, and TL, which compared the realized number of transactions to the optimum number of transactions. These results corroborate Hypothesis 1.

With reference to our primary research question on the relative performances of the MANA and TR markets in the presence of oligopsony, the experimental results show that the MANA market is significantly better than the TR market at reducing pollution since high quality projects are traded in the former market. Neither institution significantly affects the exercise of market power by buyers. Market efficiency, as measured by gains from trade, is similar under the two institution. Hence, the results support the use of the MANA institution in real world markets for controlling nonpoint source pollution. More realistically, the results show that the MANA market might merit serious consideration from policy makers as a replacement for the TR market. Especially since the real world experience with TR markets has not been positive.

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Appendix

A The Uniform Price Call Market Trading System

The call market resembles the Walrasian tâtonnement process and is often used to efficiently organize securities trading (Kehr et al., 2001). Consider a market for a single security – in our market the security is the nonpoint pollution permit. In a known time interval, potential buyers place sealed bids and potential sellers place sealed offers or asks. At their most basic, the bids (asks) consist of the units of the security demanded (supplied) and a price. The bid (ask) price is the maximum (minimum) that the buyer (seller) is willing to pay (accept) for the units demanded (supplied). After the interval lapses the market closes or is "called." The bids and asks are collected and organized. Trades are then executed in all cases where bids exceed asks at a price that is determined by a pre-specified mechanism.

In the case of a uniform price call market, the price is chosen as follows. Once the market is called the auctioneer organizes all bids and asks to construct demand and supply schedules. The price at which these schedules intersect is determined as the uniform unit price. All trades are then executed at this price. All bids (offers) on the demand (supply) schedule to the left of the intersection are traded: bids exceed asks in all such cases.

The call market environment is preferred to a continuous double auction environment for many reasons. First, a call market is more efficient than a double auction when trading volumes are low (Economides and Schwartz, 1995), which is a problem in existing point-nonpoint markets (Morgan and Wolverton, 2005). Second, it eliminates buy-ask spreads and so removes a significant portion of the price variability that exists in double auctions (Economides and Schwartz, 1995). Third, its discrete nature implies lower administrative costs than in the continuous double auction environment (Cason and Plott, 1996).

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