Market Power in Tradable Emission Markets: A Laboratory Testbed for Emission Trading in Port Phillip Bay, Victoria*

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August 2002

Abstract

In theory, competitive emission permit markets minimise total abatement cost for any emission ceiling. Permit markets are often imperfectly competitive, however, if they are thin and dominated by large firms. The dominant firm(s) could exercise market power and increase other firms' costs of pollution control, while reducing their own emission control costs. This paper reports a testbed laboratory experiment to examine whether a dominant firm can exercise market power in a permit market organised using the double auction trading institution. Our parameters approximate the abatement costs of sources in a proposed tradable emissions market for the reduction of nitrogen in the Port Phillip Watershed in Victoria, Australia. We vary across treatments the initial (pre-trade) allocation of permits to sources, so that in one treatment the seller of permits is a monopolist and in another treatment the selling side of the market is duopolistic. We also vary the information that subjects have about the number and abatement costs of their competitors. We find that prices and seller profits are higher and efficiency is lower on average in the monopoly sessions compared to the duopoly sessions, but the differences are not substantial and are not statistically significant due to pronounced variation across sessions. Moreover, prices, profits and transaction volumes are usually much closer to the competitive equilibrium than the monopoly equilibrium.

JEL Classification: C91, Q25, Q28
Key Words: Market Power, Emission Permits, Experiments, Environmental Regulation

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1. Introduction

For almost four decades economists have argued that tradable emissions permits can allocate emissions control responsibility, under conditions of asymmetric information and heterogenous abatement costs, at least cost, for any given emissions ceiling (Dales, 1968; Montgomery, 1972; Tietenberg, 1985; and Baumol and Oates, 1988).

Policy makers have slowly begun employing trading schemes for environmental management, predominantly for point source pollution. One of the first and most ambitious schemes was the United States Federal SO_2 Trading Program, (Title IV 1990 Clean Air Act Amendments), which regulates sulfur dioxide emissions that cause acid rain from electricity utilities across the U.S. Another example is the Regional Clean Air Incentives Market, established by the South Coast Air Quality Management District in Southern California, which regulates nitrogen and sulfur oxide emissions from 400 industrial sources in the South Coast air basin. Examples of point source water quality trading schemes include the Cherry Creek Basin Trading Program for phosphorous in Colorado (USA), and the Hunter River Salinity Trading Scheme in Australia, which regulates saline water exports from point sources in the Hunter River New South Wales, Australia.

These programs have reported considerable cost savings. For example, Schmalensee et al. (1998) estimate that the U.S. Federal SO_2 Trading Program reduced abatement cost by 25-34 percent as compared to a scheme with the same allocations of allowances but no ability to transfer allowances.

Theoretical models of allowance trading often assume some level of competition (often perfect), such that no firm(s) can exercise power on the selling or buying side of the market. This may be appropriate for large markets like the U.S. SO_2 market, but other permit markets are often concentrated and therefore only imperfectly competitive. The dominant firm(s) could exercise market power and increase other firms' cost of pollution control, while reducing their own emission control costs (Hahn and Noll, 1982; Hahn, 1984; Newbery, 1990; Vickers and Yarrow, 1991). Some empirical studies, however, find that the extent of market power would need to be great (up to 90 percent of the potential trading volume) for a firm or group of colluding firms to manipulate control costs and even then, the savings from the permit market are not eroded to a significant extent (Maloney and Yandle, 1984).

Port Phillip Bay in southern Victoria, Australia is one such case where an emissions permit market would be dominated by one large firm. In 1996 the Port Phillip Bay Environmental study was conducted to investigate sustainable use and management of the Bay (CSIRO, 1996). This study identified nitrogen as the nutrient that limits algal growth in the Bay. It recommended that nitrogen emissions to the Bay should be reduced, with a specific target set for 2006. The Department of Natural Resources and Environment Victoria undertook a feasibility study into nitrogen emissions trading in Port Phillip Bay to reduce and maintain emissions from point sources (DNRE, 2002). One of the issues that needed to be explored was the likelihood of the dominant firm exercising market power. The testbed laboratory permit market reported in this paper was conducted to specifically test if the dominant firm could exercise power in this type of market.

In Port Phillip Bay there is one large emitter of nitrogen – a sewerage treatment plant managed by the Melbourne Water Corporation; three small sewerage treatment plants – City West Water Authority, Western Water Authority, Yarra Valley Water Authority; and two land based fish farms. The Melbourne Water Corporation's emissions account for approximately 94 percent of nitrogen emissions from point sources to the Bay. City West Water accounts for approximately 2 percent, Western Water 0.95 percent, Yarra Valley Water 1.9 percent and the two fish farms 0.4 percent each (Argent and Mitchell, 1998).

In order to testbed the permit market, abatement cost and scope for each firm in the Bay was estimated in consultation with the Melbourne Water Corporation, the Environmental Protection Authority Victoria, fish farmers and the Marine and Freshwater Research Institute Victoria (see Table 2 below). The firms differ in their cost and potential quantity of abatement. The Water Authorities have high fixed costs for the first unit of nitrogen abated. The Melbourne Water Corporation then faces low constant marginal costs and can abate a greater quantity of nitrogen than the other water authorities. The fish farms do not have up front abatement costs; however, the quantity of nitrogen they can abate is less than the water authorities. A primary focus of this laboratory study is how the potential for market power could differ depending on the initial endowment of permits. Hahn (1984) finds that the initial allocation could have an impact on both the post trade allocation of permits and the permit price in the presence of market power. This finding is contrary to the results for competitive markets, where both the price and the ultimate allocation of permits would be independent of the initial allocation. The intuition for this is the following: Whenever a single, price-setting firm receives an initial allocation that is either higher than or lower than its cost effective allocation, an incentive for trading would be created. When a price-setting firm receives an initial allocation containing fewer permits than its cost effective allocation, it would exercise market power on the buyer's side. Similarly, if it received more permits than needed given its relative abatement costs, it could exercise power on the seller's side of the market. The further the initial allocation diverges from the cost effective allocation, the greater is the potential for the price setter to exercise power over the market.

In the current application, if permits are endowed symmetrically so that all of the small sources receive an allocation that corresponds to the same fraction of their current estimated emissions, then under some conditions Melbourne Water would be the monopoly seller of permits in equilibrium. But an asymmetric allocation of permits could provide more permits to some smaller firms, and in some conditions this could lead to an additional source of permits in the market. The asymmetric allocation examined in the experiment would result in a second seller in equilibrium and therefore a duopoly market structure.

We find that prices and seller profits are higher and efficiency is lower on average in the monopoly sessions compared to the duopoly sessions, but the differences are not substantial and are not statistically significant due to pronounced variation across sessions. Moreover, prices, profits and transaction volumes are usually much closer to the competitive equilibrium than the monopoly equilibrium. This suggests for that at least for the double auction trading institution considered here, market power could have a smaller impact on the market performance than indicated by standard models of imperfect competition.

2. Related Experimental Literature

Previous experimental economics research has established that the ability of firms to exercise market power differs under alternative trading institutions. Smith (1981) used a series of experiments to show that a wide variety of market outcomes could occur in single seller markets, ranging between competitive and monopolistic depending on the trading institution. The double auction trading institution was seen to be most robust in generating competitive outcomes in market structures with potential for supercompetitive pricing.[1] This was attributed to the fact that

[1] In continuous double auction trading, both buyers and sellers can offer proposed buy and sell prices that are publicly displayed to all market participants, and they can also accept other's proposed terms of trade at any time.

within this institution, non-market power firms on the buying side can withhold demand, hence indirectly forcing the firm with market power to lower prices. This apparently unorganized, collective behavior among buyers can be described as a form of tacit collusion. The prices in these experiments were near competitive market prices, although traded quantities were typically reduced below competitive levels. Smith and Williams (1989) also replicated these results.

Ledyard and Szakaly-Moore (1994) adapted Smith's parameters to an emissions trading environment. In two of their three sessions they discovered a strong monopolist who was able to achieve earnings close to those predicted for a single price monopolist. Even in the last period of the experiment the strong monopolists were able to achieve about 25 percent of the potential monopoly price increase. Brown-Kruse, Elliot and Godby (1995) also detected market power in laboratory markets related to emissions trading. In their experiment, single buyers or single sellers of emission permits on one side of the market faced ten sellers (or ten buyers) of one permit each. The subject with market power had information about the cost schedules of the remaining participants. This is an important information difference relative to the previous market power experiments. In the last period of their sessions, monopolists achieved an average of 40 percent of the potential price gain and monopsonists 166 percent of the potential price reduction. Godby (1999) replicated many of these results. He aggregated the ten smaller agents in the Brown-Kruse et al. (1995) paper into five composite subjects with the capacity to use two permits each, while retaining a single buyer and a single seller with the capacity to use ten permits. The dominant firm was given information about the fringe firms' production and costs. In all the sessions, observed permit prices and transaction volumes were accurately described by the market power model. Godby (1999) argues that the extra information provided to the dominant firm could have served to harden the dominant firm's response to tacit collusion by small firms. An asymmetric information hypothesis (where the dominant firm knows the production and abatement costs of fringe firms but not vice versa) would then be useful in explaining why these experiments favor the market power model. Markets in the field often include large firms that could have informational advantages over smaller firms. Hence real world applications of double auction markets may be less resistant to monopoly pricing than Smith's early experiments suggest.

Muller et al. (2002) conduct experiments in which in different treatments they aggregate the five buyers into a single monopsonist or the five sellers into a single monopolist. They consider market power on either side in different sessions, and they adopt a crossover design that allows subjects to participate in both a market power and a competitive market environment in each session. In any one session, they switch between competition and market power and back again. The main result from this research is that market power outcomes are frequently observed. They also find that the double auction's apparent robustness to market power pricing outcomes is not as general a result as the previous experimental literature by Smith (1981) would suggest. However, widespread price discrimination implies that trading efficiency is not hampered, because market price in the double auction converges to (near) competitive equilibrium price over time. Income distribution effects emerge as the most important consequence of imperfect competition, since observed transaction quantity is less than the competitive equilibrium quantity. Soberg (2000) examines the impact of market power in emissions trading markets, when the trading institution is one sided (like the offer auction and the bid auction). He also finds that market power can be primarily interpreted as an income distribution issue and not an efficiency issue: Prices are near the competitive equilibrium, the monopolist is unable to extract monopoly rents, but the quantity traded is less than competitive equilibrium. Permit trading, whether under a single sided or double auction, yields an approximately cost effective allocation of emissions despite monopolization of the permit market.

3. Experimental Design

We report 24 sessions, each with five or six subjects who trade in a computerized double auction. We used the University of Zurich's *z-Tree* program (Fischbacher, 1999) to implement this double auction.

Each session had four buyers and one or two sellers. As shown in Table 1, half of the sessions had one monopoly seller and half had two duopoly sellers. The design is also balanced in terms of the number of sessions conducted at each site. Fewer sessions were conducted in the "More Information" condition because these follow-up sessions were added to determine if the information condition affects results; as shown in the next section, results do not differ by information condition.[2] This is consistent with Hizen and Saijo (2001), who only find relatively minor differences in price variance (but not price levels) when subjects receive more information about other subjects' marginal abatement costs.

Incentives to trade emissions permits arose from differences in abatement costs across market participants. Those with high abatement costs would seek to purchase permits to avoid paying the abatement costs, while those with low abatement costs would incur those costs and sell permits. In the Monopoly/Symmetric Endowment treatment, permits were allocated symmetrically to the five "small" firms, in amounts equal to 50 percent of their current emissions. Total current emissions for these firms are approximately 190 metric tonnes per

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[2] In the "Less Information" condition subjects only learned their own costs or values and did not receive any information about the costs and values of other subjects. In the "More Information" condition the large seller received an extra instruction sheet that gave the range of costs and values for the other subjects. The large seller might be expected to have access to this additional information for some of the other traders since some of the smaller firms were created when the large firm divested some assets.

annum, so permits for 95 tonnes were allocated. The large firm has already committed to an annual 500 tonne reduction in emissions, so it was provided enough permits to meet this previously negotiated reduced load.

Nitrogen load for the large firm - the Melbourne Water Corporation - was estimated in the Port Phillip Bay Integrated Model: Final Report (CSIRO, 1996). Loads for the three smaller Water Authorities - City West, Western Water and Yarra Valley - were taken from the FILTER model for the Bay developed by the Cooperative Research Center for Catchment Hydrology at the University of Melbourne (Argent and Mitchell, 1998). Nitrogen loads for the two fish farms were provided by the Environmental Protection Agency Victoria (personal communication, 8/3/2000). Estimated abatement costs for the Melbourne Water Corporation were provided by the Melbourne Water Corporation (personal communication, 6/09/2001). Estimated costs of abatement for the other Water Authorities were reported in Read-Sturgess (2001) and discussed with representatives from the Melbourne Water Corporation and the Department of Natural Resources and Environment. Abatement costs for the fish farms were taken from Muir et al. (1999) and Folke et al. (1994) and discussed with the Marine and Freshwater Research Institute Victoria.

Melbourne Water has the lowest estimated abatement costs, so we employ parameters in which this firm would be the largest seller of permits. In fact, in the Monopoly/Symmetric Endowment treatment, Melbourne Water would be a monopoly seller. The other subjects were assigned to buyer roles by the experiment software, with redemption values equal to their avoided abatement costs.

Rather than symmetrically endowing the small firms with permits that correspond to 50 percent of their current emission load, the 95 tonne permit endowment can be adjusted to create some (small degree of) competition on the selling side of the market. In the Duopoly/ Asymmetric Endowment treatment, a small firm with relatively low abatement costs was allocated permits representing 12 tonnes more than a 50 percent emission reduction, while a different small firm was allocated permits representing 12 tonnes less than a 50 percent emission reduction. [The disadvantaged firm received a monetary subsidy instead of permits to compensate.] Because of the extra permit endowment and its low abatement costs, this small firm provided a second source of permit supply and this led to a duopoly market structure. With this alternative endowment Melbourne Water was still a dominant permit supplier, however, selling 84 percent of the permits in the competitive equilibrium.

Table 2 and Figure 1 summarize the permit endowments, abatement costs, and supply and demand for the two treatments. The abatement costs shown in Table 2 are not monotonically increasing because significant fixed costs exist to implement certain levels of abatement. The demand and supply curves shown in Figure 1 are monotonically decreasing and increasing because the different "steps" on these curves are ordered and graphed in terms of the average abatement costs for the different amounts of emissions abatement. Each step on these curves is labeled with the firm number with that level of abatement cost (F1 through F6). To reduce the number of trades required each period, each contract was for a 4-tonne permit. In equilibrium the large firm sells 16 permits (representing 64 tonnes of emissions). In the Duopoly/Asymmetric Endowment treatment the extra seller adds 3 permits (representing 12 tonnes) to the market in equilibrium. The four buyers each purchase between 2 and 8 permits in equilibrium.

Table 3 summarizes the price, transaction volume and exchange surplus predictions of the competitive equilibrium (CE) model and the monopoly/optimal collusion model for the two endowment treatments. Both treatments share the same price predictions, but they have differing transaction cost and surplus predictions. We label the entire interval below the last step on the demand curve (512) and above the average cost of the dominant seller (391) as the competitive equilibrium price range, even though the unique competitive price is actually the lower end of this interval. This is because the dominant seller provides the excess supply at prices above 391, so it is unlikely to exert downward pressure on prices. All prices in this 391 to 512 range can maximize total exchange surplus.

All subjects were undergraduate students from Purdue University and the University of Melbourne. They were inexperienced in the sense that they had never participated in a previous double auction session that employed this design. Subjects were randomly assigned the various subject roles upon arrival at the laboratory. Instructions shown in Appendix A were read aloud while subjects followed along on their own copy. The instructions used neutral terminology throughout, as is the common practice in experimental economics. For example, the instructions simply refer to "units" that the subjects trade, not emissions permits. Subjects had costs and executed trades in experimental dollars, and transactions led to profits that were converted at the end of the session to local currency and paid in cash. The experimental dollars were converted at different rates for different subjects, since the experimental dollar earnings were quite different for the different subject types due to differences in abatement costs and permit endowments (see Table 2). Most subjects earned between US $10 and $35, with a mean of about US$19 based on an exchange rate of 2 Australian dollars = 1 U.S. dollar. Including the instruction time, sessions usually lasted between 60 and 90 minutes.

4. Results

The analysis focuses on four measures of market performance: transaction prices (Section 4.1), an alternative market power measure called the index of monopoly trading effectiveness (Section 4.2), transaction volume (Section 4.3) and overall efficiency (Section 4.4). Section 4.5 briefly presents results on transaction price variance.

4.1 Transaction Prices

Result 1: Transaction prices decline over time toward the competitive equilibrium (CE), and are greater on average in the Monopoly/Symmetric Endowment treatment than in the Duopoly/ Asymmetric Endowment treatment. The between session variability in prices is substantial, however, so the price difference across treatments is not statistically significant.

Support: Figure 2 presents the mean transaction prices for each period, averaged separately across the 12 sessions in each of the two treatments. The mean prices are greater in the Monopoly/Symmetric Endowment treatment in every period, and the declining trend (toward the CE prediction) is clearly evident for both time series. The relatively wide and overlapping interquartile range indicated on this figure suggests, however, that the price differences across these main treatments may not be statistically significant.

According to a nonparametric Wilcoxon signed-rank test conducted separately for each period, prices in both treatments are always significantly less than the monopoly prediction of 905 at the one-percent significance level (the only exception is period 1 in the Monopoly/ Symmetric Endowment treatment).[3] After period 3, prices in both treatments are not significantly different than the upper endpoint of the CE price interval (512). This Wilcoxon test rejects (at the five-percent significance level or better) the hypothesis that mean transaction prices equal the midpoint of the CE price interval (451.5) in periods 1 through 8 for the Monopoly/Symmetric

[3] These tests employ exactly one observation per session, so the data points are statistically independent, as required for this test.

Endowment treatment and in periods 1 through 6 in the Duopoly/Asymmetric Endowment treatment, but in later periods it does not reject the CE midpoint.

We first conducted a nonparametric Mann-Whitney test separately by period to determine whether prices are significantly greater in the Monopoly/Symmetric Endowment treatment than in the Duopoly/Asymmetric Endowment treatment. Each session contributes exactly one (and therefore statistically independent) observation to each test. This test indicates a significantly greater price in the Monopoly/Symmetric Endowment treatment (at the five-percent level; one-tailed test) only for period 1. Thereafter, prices are not significantly different across treatments.

An advantage of these univariate nonparametric tests is they only require that the data points be independent, and they do not make any assumption about the distribution of the data. But they often have lower power than parametric tests, and because they are univariate they cannot account for other factors that could affect prices—such as the different information provided to sellers in some treatments, and the experiment site. Figure 2 also suggests that it is important to account for the downward trend in prices. Table 4 therefore presents multivariate, random effects panel data models to address these shortcomings and augment the simple nonparametric tests just described.

The results relevant for transaction prices are shown in Model 1 and Model 2 on the left side of this table. (We discuss the other models in later subsections.) The dependent variable in Model 1 is the mean transaction price in each period, so it employs (24 sessions × 10 periods) – (1 missing period in session PU-Sym-II2) = 239 observations. The dependent variable in Model 2 is the individual transaction price (3327 total observations). In both of these models, the coefficient estimate for the Monopoly/Symmetric Endowment treatment dummy variable is positive, but it is not statistically significant.[4] The coefficients on the dummy variables for the extra information provided to sellers in the more information sessions and for sessions conducted at Purdue University are also not significant. The only significant explanatory variable in these models is 1/Period Number. The positive coefficient indicates that prices fall across periods, since 1/Period Number falls from 1 to 0.1 as sessions run from periods 1 through 10. Other specifications of this time trend (such as ln(Period Number) or simply the Period Number) provide similar qualitative results.

The 1/Period Number specification for the time trend permits a convenient interpretation for the intercept coefficient. Since 1/Period Number approaches zero as periods increase, the intercept term provides an estimate of the value to which the transaction price dependent variable approaches asymptotically. The coefficient estimates are only slightly above the upper endpoint of the CE price interval (512), and in neither Model 1 nor Model 2 is the intercept statistically different from either this upper endpoint or the midpoint of the CE price interval (451.5).

4.2 Index of Monopoly Trading Effectiveness

The index of monopoly trading effectiveness (IMTE) provides a convenient, unitless measure of the monopolists' and duopolists' ability to extract supercompetitive profit from the market (Isaac et al., 1984). Define π as the sellers' realized total profits, π_c as the theoretical total seller profits at the CE, and π_m as the theoretical total profits at the (uniform) monopoly/collusive price.[5] The IMTE is defined as:

$$\text{IMTE} = (\pi - \pi_c)/(\pi_m - \pi_c).$$

[4] The substantial variation across sessions that is accounted for by the random effects error structure seems to be responsible for the lack of precision in the monopoly treatment dummy variable estimate for these and all the other models in Table 4. When these models are estimated without random effects, the monopoly dummy variable is usually highly significant.

[5] We use the upper endpoint rather than midpoint of the CE interval to define π_c, so that any profits above π_c are definitely inconsistent with the competitive equilibrium.

IMTE > 0 when sellers earn profits above the CE level, and IMTE = 1 if sellers earn profits equal to the monopoly/collusive level. In principle IMTE can exceed 1 if sellers successfully price discriminate. IMTE can be negative if sellers earn profits in the range of the CE; for example, if prices are constant at the lower endpoint of the CE interval (391), then in the Duopoly/Asymmetric Endowment treatment $\pi = 435 < \pi_c = 2739$, so that IMTE = -0.935.

Result 2: The index of monopoly trading effectiveness (IMTE) varies considerably across periods and across sessions. On average IMTE is greater in the Monopoly/Symmetric Endowment treatment than in Duopoly/Asymmetric Endowment treatment, but this difference is not statistically significant.

Support: Figure 3 presents the mean IMTE for each period, separately averaged across the 12 sessions in each of the two treatments. The mean IMTE is greater in the Monopoly/Symmetric Endowment treatment in every period except period 7, and the interquartile range varies from less than –1 (period 1 for Duopoly) to almost 0.9 (period 3 for both the duopoly and monopoly treatments). Both averages tend to decline over time.

According to a nonparametric Wilcoxon signed-rank test conducted separately for each period, the IMTE in both treatments is always significantly less than the monopoly/collusion prediction of 1 at the five-percent (and usually one-percent) significance level. According to this same test, the IMTE in both treatments is not significantly different from the (upper) CE level of 0 in any period. A nonparametric Mann-Whitney test conducted separately by period indicates that the IMTE is significantly greater in the Monopoly/Symmetric Endowment treatment than in the Duopoly/Asymmetric Endowment treatment only for period 1. Thereafter, the IMTE is not significantly different across treatments.

These nonparametric results are confirmed by the panel regression Model 3 in Table 4 that controls for other potential influences on IMTE. The Monopoly/Symmetric Endowment treatment dummy variable is positive but not significantly different from zero. The time trend is also not significant, and the intercept (a measure of the asymptotic IMTE) is not significantly different from zero.[6]

4.3 Transaction Volume

Result 3: The transaction volume increases on average across periods toward the CE prediction. After normalizing by the difference CE predictions in the two treatments, transaction volume is not significantly different in the Monopoly/Symmetric Endowment and Duopoly/Asymmetric Endowment treatments.

Support: Recall from the experimental design that 19 units trade in the CE of the Duopoly/ Asymmetric Endowment treatment, whereas 16 units trade in the CE of the Monopoly/ Symmetric Endowment treatment (Table 3). We therefore expect (and observe) greater transaction volume in the Duopoly/Asymmetric Endowment treatment. But if we normalize the transaction volume by subtracting these different CE predictions, according to a Mann-Whitney test conducted separately by period the normalized transaction volume is significantly different between the monopoly and duopoly treatments only for period 9.

Model 4 of Table 4 indicates that other features of the experimental design do not affect the transaction volume, in a model that employs this normalized volume as the dependent variable. None of the coefficients except the time trend are significantly different from zero. The

[6] Model 3 is the only case in which qualitative conclusions regarding the time trend differ between specifications. While 1/Period Number is not significantly different from zero in Table 4, alternative specifications that employ ln(Period Number) or Period Number to account for the time trend have negative and significant coefficients for these variables.

large and negative estimate for 1/Period Number indicates that average volume begins in period 1 well below the CE predictions, but rises over time.

4.4 Trading Efficiency

Trading efficiency is defined as the fraction of the maximum available gains from trade that are realized by subjects. It cannot exceed 1, and the monopoly/collusive price prediction makes specific predictions for the efficiency level: 0.829 in the Monopoly/Symmetric Endowment treatment and 0.789 in the Duopoly/Asymmetric Endowment treatment.

Result 4: Trading efficiency rises until period 4 in both treatments, and it often significantly exceeds the collusive prediction in the Duopoly/Asymmetric Endowment treatment. Although higher on average in the Monopoly/Symmetric Endowment treatment, efficiency is not significantly different in the two treatments.

Support: Figure 4 presents the mean efficiency and interquartile range for each period, separately averaged across the 12 sessions in each of the two treatments. By period 4 both means reach or exceed the monopoly/collusive predicted efficiency of 79 to 83 percent, but thereafter they increase very little. Wilcoxon tests indicate that mean efficiency is not significantly different from the monopoly prediction of 0.829 in the Monopoly/Symmetric Endowment treatment in any period. But contrast, Wilcoxon tests indicate that mean efficiency exceeds the monopoly/collusive prediction of 0.789 (at the five-percent level or better) in the Duopoly/ Asymmetric Endowment treatment in periods 3, 4, 6, 7, 9 and 10. Mann-Whitney tests never reject the hypothesis that mean efficiency is different in the two treatments, however.

Model 5 in Table 4 presents the panel regression results for efficiency, employing a Tobit model due to the restriction that efficiency cannot exceed 1. Only the time trend is significant, consistent with the early periods' increase in efficiency indicated in Figure 4.

4.5 Price Variance

Result 5: Within period price variance declines over time but remains substantial even in late periods. Price variance is significantly greater in the Monopoly/Symmetric Endowment treatment than the Duopoly/Asymmetric Endowment treatment.

Support: Model 6 in Table 4 presents the panel regression results for the standard deviation of transaction prices, using a Tobit model since this dependent variable is non-negative. (Similar results obtain for transaction price variance.) Variability is significantly greater in the Monopoly/Symmetric Endowment treatment, and (curiously) it is also lower in the sessions conducted at Purdue. The positive coefficient on the 1/Period Number variable indicates that variance also decreases across periods. Note that any equilibrium model that does not predict price dispersion (such as the CE and monopoly/collusive benchmarks we have been using here) implies a price variance of zero. But the intercept of Model 6 is quite significantly different from zero. In other words, transaction prices do not converge to a uniform level within periods for the length of sessions that we have conducted. In fact, transaction price variance does not exactly equal zero in any of the 239 session-periods in our dataset.

5. Conclusion

The testbed laboratory permit market reported in this study was conducted to inform policy makers about how effectively a dominant firm in an emissions permit market could exercise market power, when trading was organised using the continuous double auction trading institution. The laboratory market approximates the economic and environmental conditions present in the Port Phillip Watershed, Victoria Australia.

A primary focus of the experiment was to determine how the potential for market power could differ depending on the initial allocation of permits. In the Monopoly/Asymmetric Endowment treatment, all small firms were allocated permits equal to 50 percent of their current emissions. In the Duopoly/Symmetric Endowment treatment one small firm with low abatement costs was allocated permits greater than 50 percent of its current emissions, so that this small low cost firm could become an active seller and introduce some competition into the selling side of the market. Another small firm was allocated permits less than 50 percent of its current emissions and received a monetary subsidy instead of permits to compensate. This is akin, for example, to an environmental agency subsidizing the first few units of abatement for the disadvantaged firm in order to create more competition in the market. It is no different from allocating permits free of charge for those units of emissions.

A secondary focus of this laboratory study was to examine how information can influence the ability of the dominant firm to exercise market power. In the 'Less Information' treatment all firms know only their own abatement costs and do not have any information about the abatement costs of other firms. In the 'More Information' treatment the dominant firm (the Melbourne Water Corporation) receives information on the distribution of abatement costs of other firms. When the dominant firm holds information about the abatement costs of other firms it may strengthen this firm's resolve to withstand the tacit collusion (withholding of permit demand) by the smaller firms.

The 'large' firm(s) were able to raise transaction prices more in the Monopoly/Symmetric Endowment treatment than in the Duopoly/Asymmetric Endowment treatment. The difference was not statistically significant, however, due to substantial price variance across experimental sessions, indicating that the market did not adjust to a unique equilibrium price. It is not uncommon to observe variance in prices in market power experiments as the ability to influence outcomes depends on one or two subjects in each experiment. Transaction prices did decline towards the competitive equilibrium (CE) prediction range and were significantly different from the predicted monopoly and collusive price in both treatments. The Index of Monopoly Trading Effectiveness, a measure of firms' ability to extract supercompetitive profits, also declined across periods, and was significantly less in both treatments than the predicted monopoly and collusive price level. Transaction volume starts below the CE level but increases towards the CE in later trading periods.

Trading efficiency in both treatments quickly rises higher than the monopoly and collusive price equilibrium level, but after trading period 4 it increases very little. Nonparametric tests indicate that mean efficiency is not significantly different from the monopoly equilibrium prediction in the Monopoly/Asymmetric Endowment treatment, but the same tests indicate that mean trading efficiency significantly exceeds the monopoly and collusive equilibrium in many periods of the Duopoly/Asymmetric Endowment treatment.

Overall, the results suggest that a monopoly supplier of permits may not be able to dominate a potential tradable emissions permit market in Port Phillip Bay, at least when trade is organised with double auction trading rules. Prices, however, could vary considerably—perhaps due to the large fixed capital abatement costs that the water authorities face. Although in most sessions the prices adjusted towards competitive equilibrium over time, this finding might be sensitive to the sophistication of the dominant firm traders. Nevertheless, at least in this laboratory testbed the initial allocation of permits does not significantly impact market performance, so policy makers may not need to vary initial allocation to introduce some competition into the market.

It is important, of course, to assess the robustness of these conclusions. For example, the results may be influenced by the strong competitive tendencies of the double auction institution. It would be useful to compare a posted offer auction or bilateral bargaining trading institution with these double auction results to evaluate whether dominant sellers can better exercise market power in these alternative institutions. If so, this would suggest that policy should focus on encouraging (or sponsoring) competitive trading institutions rather than endowing permits to enhance competition.

Table 1: Summary of 24 Laboratory Sessions

Session Name	Endowment Treatment	Location	Information Condition*
UM-Asym-II2	Duopoly/Asymmetric	Univ. of Melbourne	Less
UM-Asym-II3	Duopoly/Asymmetric	Univ. of Melbourne	Less
UM-Asym-II4	Duopoly/Asymmetric	Univ. of Melbourne	Less
UM-Asym-II5	Duopoly/Asymmetric	Univ. of Melbourne	Less
PU-Asym-II1	Duopoly/Asymmetric	Purdue University	Less
PU-Asym-II2	Duopoly/Asymmetric	Purdue University	Less
PU-Asym-II3	Duopoly/Asymmetric	Purdue University	Less
PU-Asym-II4	Duopoly/Asymmetric	Purdue University	Less
UM-Asym-MI1	Duopoly/Asymmetric	Univ. of Melbourne	More
UM-Asym-MI2	Duopoly/Asymmetric	Univ. of Melbourne	More
PU-Asym-MI1	Duopoly/Asymmetric	Purdue University	More
PU-Asym-MI2	Duopoly/Asymmetric	Purdue University	More
UM-Sym-II1	Monopoly/Symmetric	Univ. of Melbourne	Less
UM-Sym-II2	Monopoly/Symmetric	Univ. of Melbourne	Less
UM-Sym-II3	Monopoly/Symmetric	Univ. of Melbourne	Less
UM-Sym-II4	Monopoly/Symmetric	Univ. of Melbourne	Less
PU-Sym-II1	Monopoly/Symmetric	Purdue University	Less
PU-Sym-II2	Monopoly/Symmetric	Purdue University	Less
PU-Sym-II3	Monopoly/Symmetric	Purdue University	Less
PU-Sym-II4	Monopoly/Symmetric	Purdue University	Less
UM-Sym-MI1	Monopoly/Symmetric	Univ. of Melbourne	More
UM-Sym-MI2	Monopoly/Symmetric	Univ. of Melbourne	More
PU-Sym-MI1	Monopoly/Symmetric	Purdue University	More
PU-Sym-MI2	Monopoly/Symmetric	Purdue University	More

*In the "Less Information" condition subjects only learned their own costs or values. In the "More Information" condition the large seller also learned the ranges for the costs and values of the other subjects.

Table 2: Permit Endowments and Abatement Costs for Each Firm

	Large Firm 1	Small Firm 2		Small Firm 3		Small Firm 4	Small Firm 5	Small Firm 6
Treatment→	Both	Symmetric	Asymmetric	Symmetric	Asymmetric	Both	Both	Both
Permit Endowment	800	8	11	4	1	8	2	2
Role	seller	inactive	seller	buyer	buyer	buyer	buyer	buyer
Unit 1 Abate Cost	1016		246	370	370	1200	1026	1074
Unit 2 Abate Cost	349		246	370	370	872	681	729
Unit 3 Abate Cost	349		246	370	370	872		
Unit 4 Abate Cost	349			941	370	1647		
Unit 5 Abate Cost	349				370	564		
Unit 6 Abate Cost	349				370	1730		
Unit 7 Abate Cost	349				1370	669		
Unit 8 Abate Cost	349					1141		
Units 9+ Abate Cost	349							

Note: Each permit unit and endowment quantity refers to a 4-tonne permit.

Table 3: Model Predictions

	Symmetric / Monopoly		Asymmetric / Duopoly	
	Competitive Equilibrium	Monopoly/Collusive Equilibrium	Competitive Equilibrium	Monopoly/Collusive Equilibrium
Price	391 to 512	905	391 to 512	905
Transaction Quantity	16	10	19	10
Seller Surplus	1941	4893	2739	5202
Buyer Surplus	6064	1745	6067	1745
Total Surplus	8005	6638	8806	6947
Efficiency	100%	82.9%	100%	78.9%

Note: Seller and buyer surplus figures for the Competitive Equilibrium columns are for the upper endpoint of the indicated price interval (Price=512)

Table 4: Panel Regression Models of Market Performance

Dependent Variable →	Mean Transaction Price in Period (Model 1)	Individual Transaction Prices (Model 2)	Index of Monopoly Trading Effectiveness (Model 3)	Transaction Volume – CE Volume Prediction (Model 4)	Market Efficiency (Model 5)	Standard Deviation of Transaction Prices (Model 6)
Intercept	515.7** (57.9)	533.5** (56.3)	0.048 (0.190)	-1.52 (1.08)	0.943** (0.073)	82.7** (12.6)
Dummy Variable=1 for Monopoly Treatment	72.7 (61.5)	60.2 (60.2)	0.217 (0.201)	-0.16 (1.14)	-0.083 (0.081)	27.9* (12.1)
Dummy Variable=1 if seller receives extra info.	27.1 (65.3)	7.0 (63.8)	-0.078 (0.213)	-1.15 (1.21)	-0.067 (0.078)	3.0 (12.2)
Dummy Variable=1 if site is Purdue	-33.6 (61.5)	-41.6 (60.2)	-0.318 (0.201)	-0.36 (1.14)	-0.049 (0.082)	-24.0* (11.8)
1/Period Number	168.4** (22.5)	123.0** (10.1)	0.040 (0.100)	-4.84** (0.66)	-0.379** (0.029)	118.3** (7.5)
R-squared	0.112	0.033	0.091	0.123	(Tobit)	(Tobit)
Number of Observations	239	3327	239	239	239	239

Notes: Standard errors in parentheses. ** denotes a coefficient that is significantly different from zero at 1-percent; * denotes a coefficient that is significantly different from zero at 5-percent; † denotes a coefficient that is significantly different from zero at 10-percent (all two-tailed tests). All models are estimated with a random effects error structure, with the session as the random effect.

Figure 1, Panel A:
Permit Supply and Demand for Monopoly/Symmetric Endowment Treatment

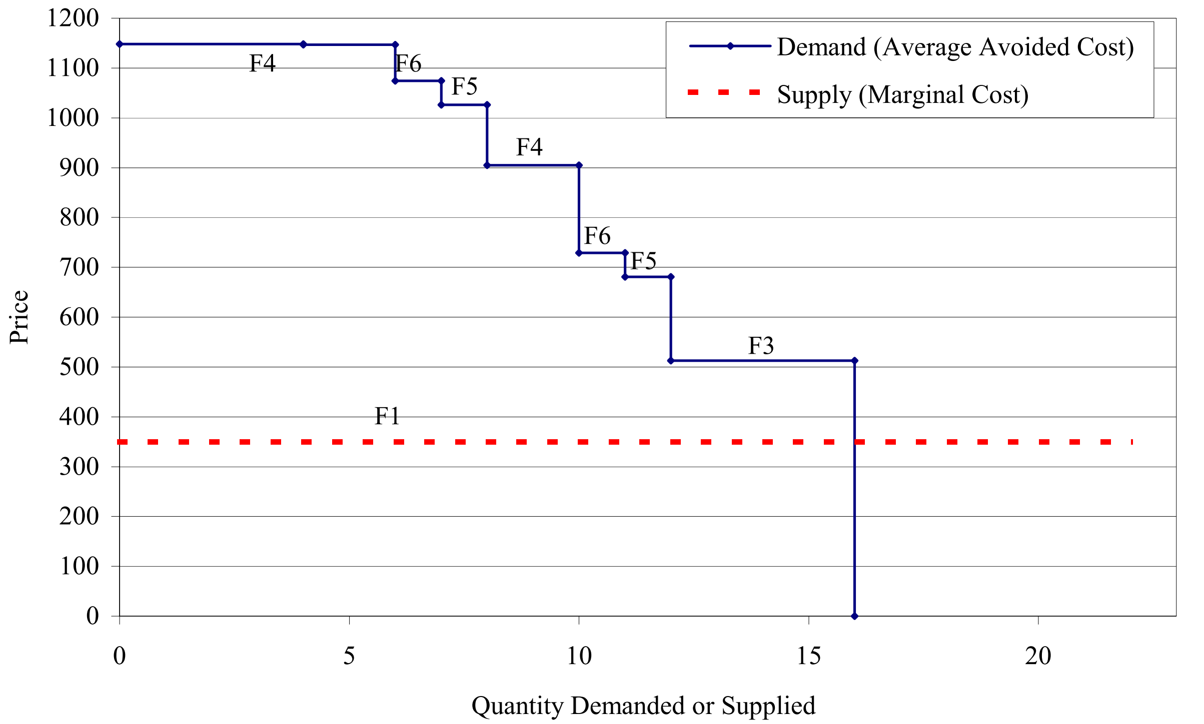


Figure 1, Panel B:
Permit Supply and Demand for Duopoly/Asymmetric Endowment Treatment

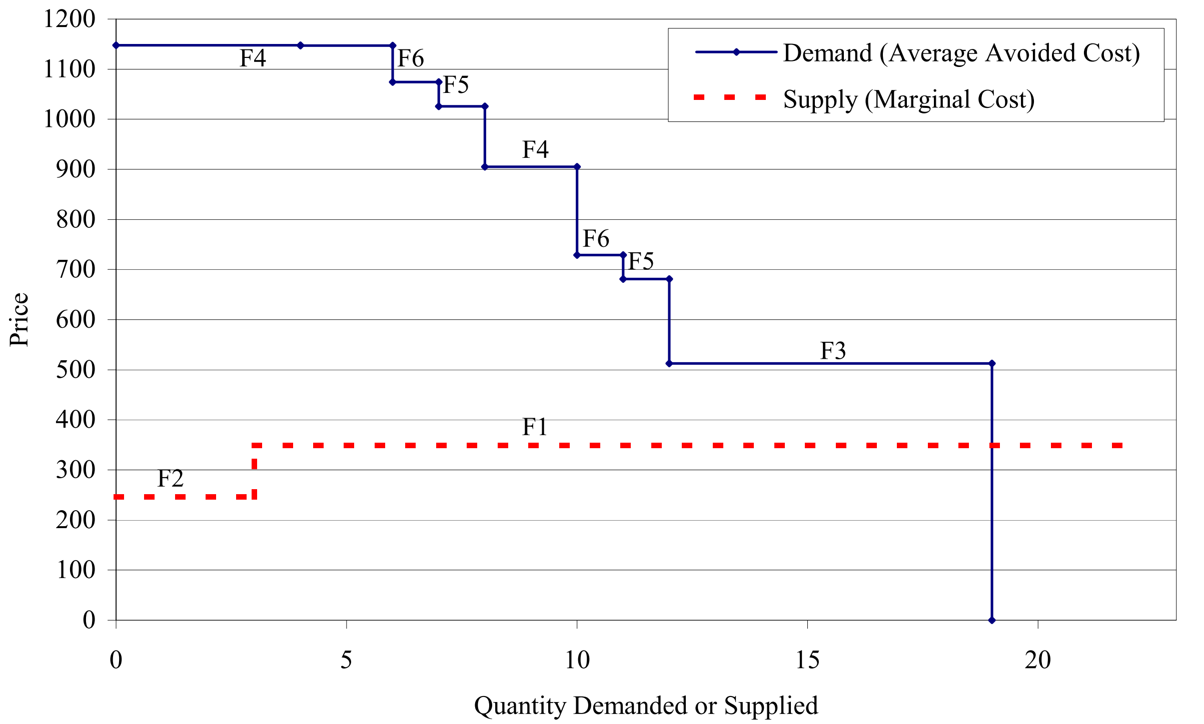


Figure 2: Mean Prices and Interquartile Range Across the 12 Sessions for in Each Treatment (24 Sessions Total)

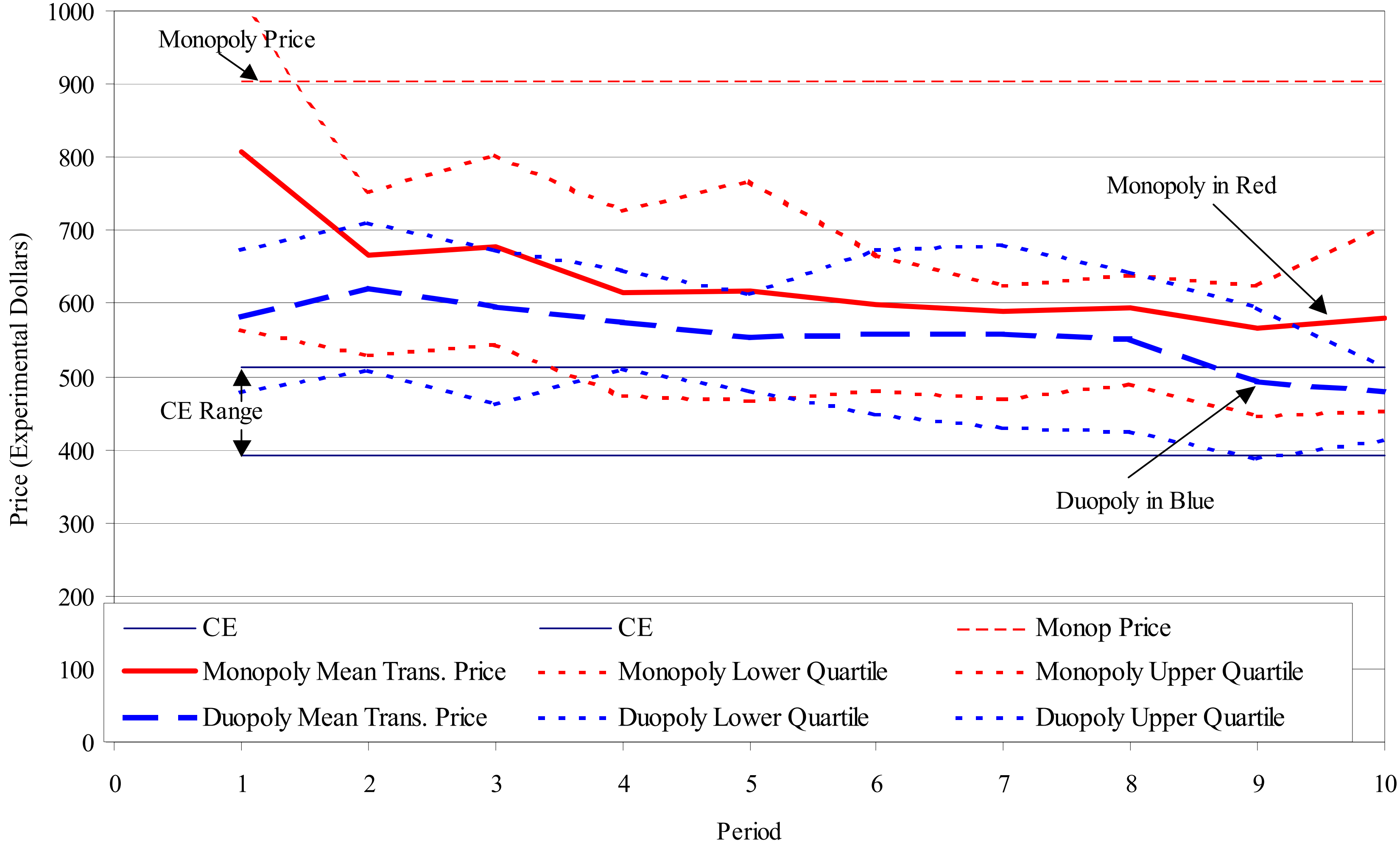


Figure 3: Mean Index of Monopoly Trading Effectiveness (IMTE) and Interquartile Range Across the 12 Sessions for in Each Treatment (24 Sessions Total)

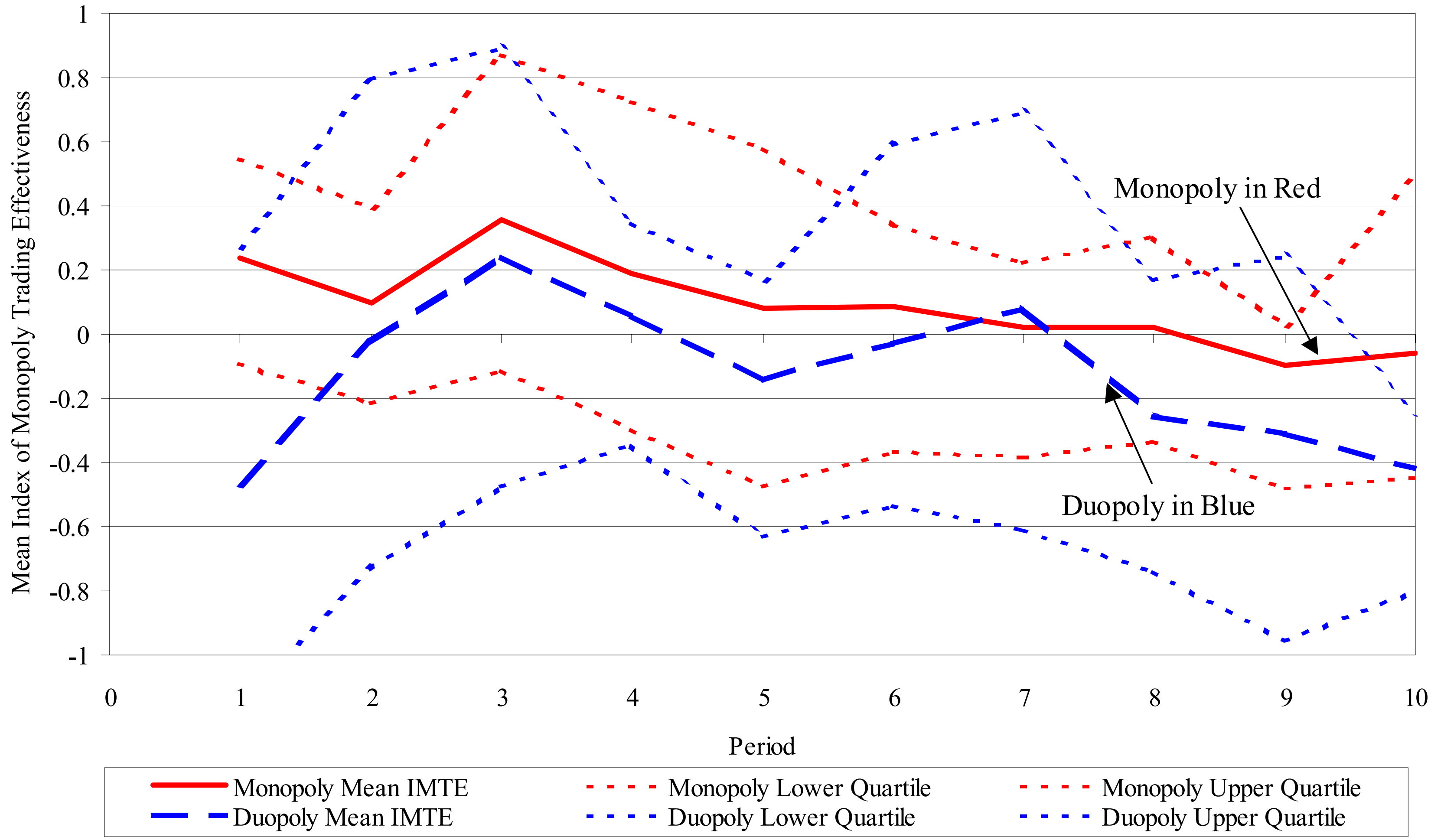
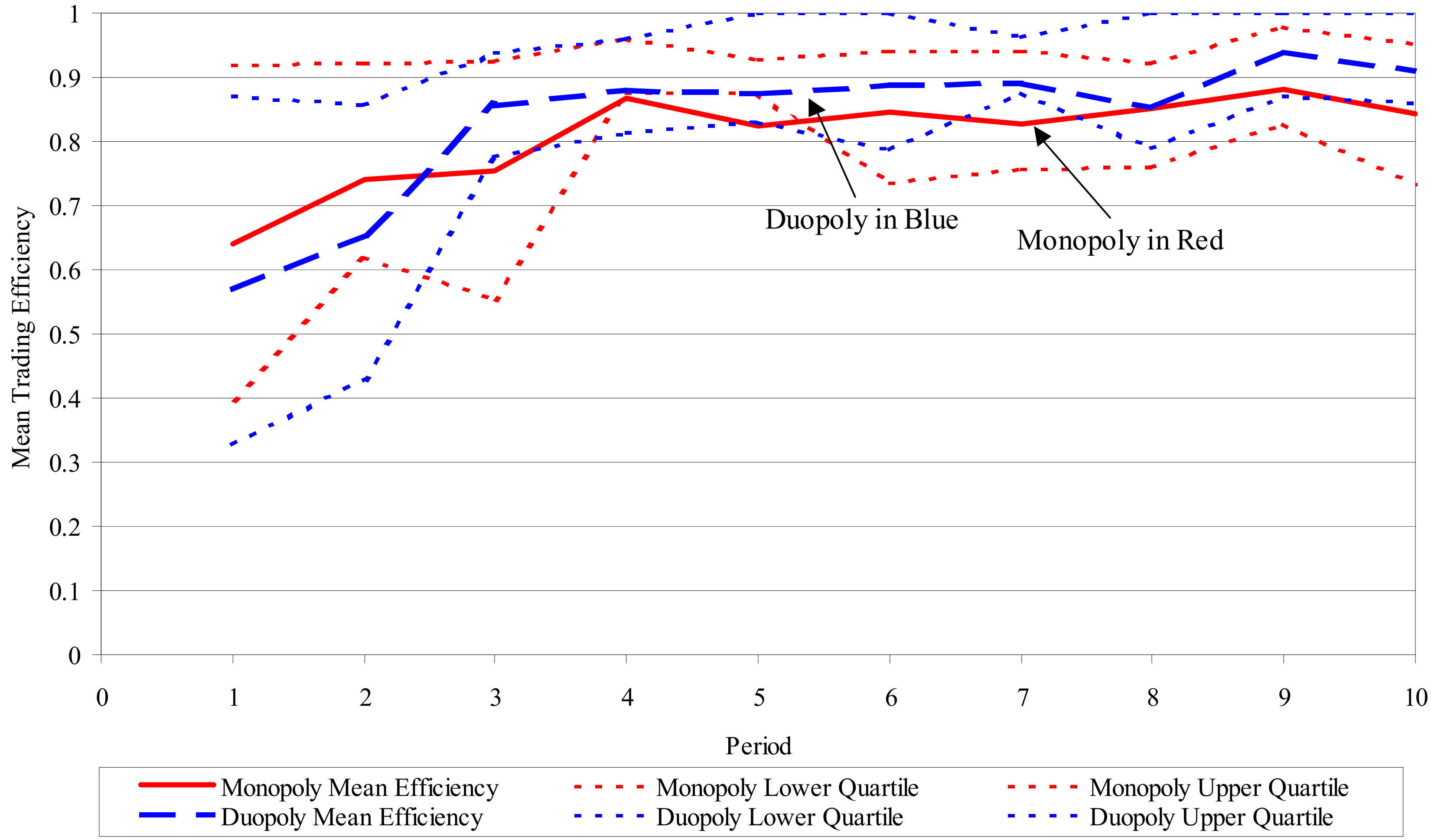


Figure 4: Mean Trading Efficiency and Interquartile Range Across the 12 Sessions for in Each Treatment (24 Sessions Total)



Appendix A:

Instructions (Duopoly/Asymmetric Endowment Treatment, More Information)

General

This is an experiment in the economics of decision making. The instructions are simple and if you follow them carefully and make good decisions you will earn money that will be paid to you privately in cash. All earnings on your computer screens are in Experimental Dollars. These Experimental Dollars will be converted to real Dollars at the end of the experiment, at a rate of _______ Experimental Dollars = 1 real Dollar. Everyone starts with 2000 Experimental Dollars (which is worth _______ real Dollars), and your additional earnings are added to this starting amount.

We are going to conduct a set of markets in which you will be a participant in a sequence of market trading periods. Attached to these instructions you will find a sheet labeled Personal Record Sheet, which will help you keep track of your earnings based on the decisions you might make. You are not to reveal this information to anyone. It is your own private information.

During each market period you will be free to buy or sell units as you choose. Buyers earn money from redeeming any purchased units at a known amount from the experimenter. Sellers earn money from selling units that cost a known amount. You will be either a buyer or a seller in today's experiment, and you will remain in this role throughout the experiment. This experiment has two sellers and four buyers.

Buyers

Redemption is like a resale to the experimenter at a set price. If you are a buyer, your computer screen includes Redemption Values written on the left side—one value for each unit you might buy. See Figure 1 (the values on this example screen are completely different from the actual values used in the experiment). If you buy a unit during the trading period you will receive this Redemption Value at the end of the trading period. The profits from each redeemed unit (which are yours to keep) are computed by taking the difference between the redemption value and the price paid for the unit. That is,

[your earnings = (redemption value) – (purchase price)]

Suppose, for example, that your redemption value for your first unit bought is 49, and your redemption value for your second unit bought is 49. If you buy the first unit at a price of 41 and the second unit at a price of 44, your earnings are:

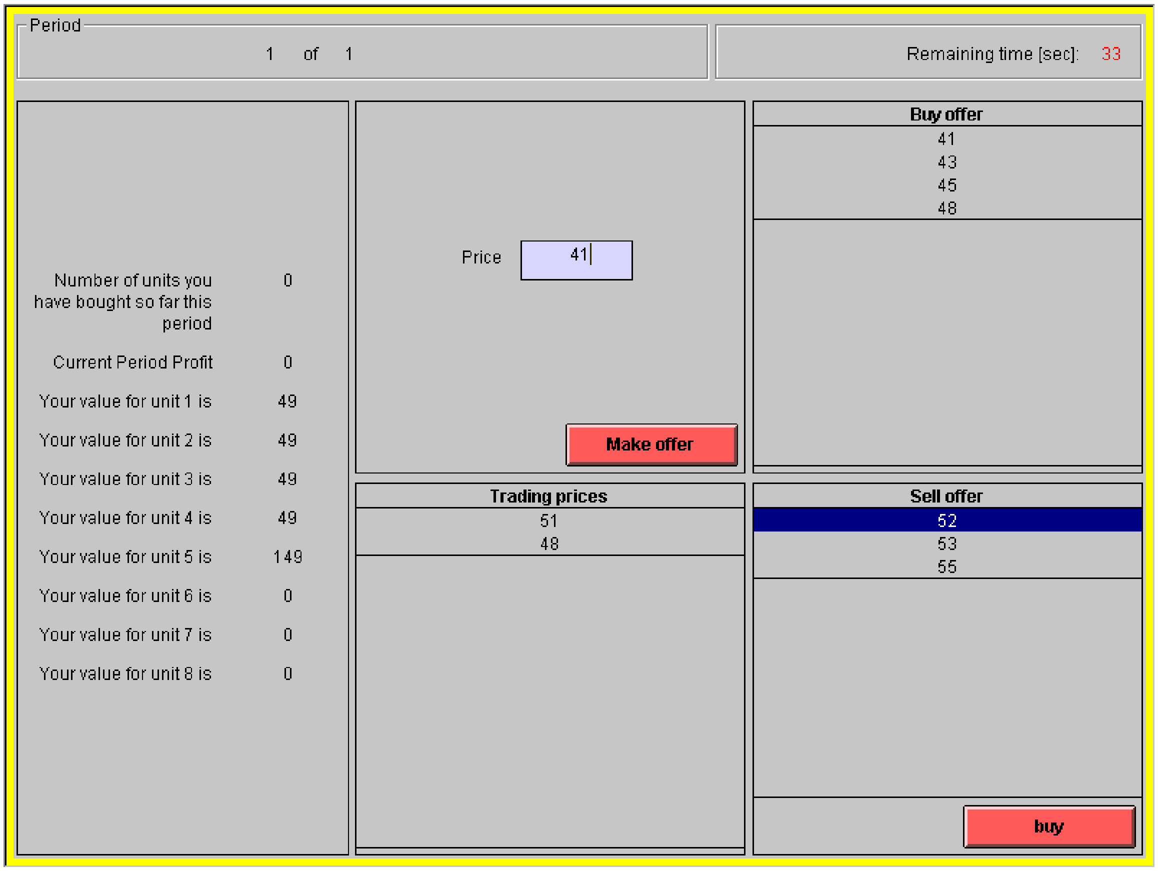


Figure 1: Example Market Trading Screen for Buyers

Earnings from first unit = 49 – 41 = 8

Earnings from second unit = 49 – 44 = 5

Total earnings = 8 + 5 = 13

Your total earnings will be updated immediately after a purchase on the left side of your computer screen, above your redemption values, and are labeled *Current Period Profit*. Please pay careful attention to the number of units you have bought so far this period, since that information is useful when assessing the redemption value of the next unit you buy.

Notice that if you pay more for a unit than its redemption value then you suffer a loss in earnings on that unit. If you do not buy any units in a period then your earnings are zero for that period. Your redemption values may be different from the values of other buyers. Note that some buyers may need to buy some lower-value units before they can purchase higher-value units. (For example, on the Figure 1 example screen units 1 through 4 have a lower value of 49, while the 5th unit bought has a higher value of 149.) Some buyers will have a redemption value of 0 for some units, and it is never profitable to buy those units. Remember, keep an eye on the number of units you have purchased so that you don't accidentally buy a unit that has a zero redemption value.

Sellers

Sellers incur a per-unit cost when they sell a unit. If you are a seller, your computer screen displays your costs on the left side—one cost value for each unit you might sell. See Figure 2 (the costs on this example screen are completely different from the actual costs used in the experiment).

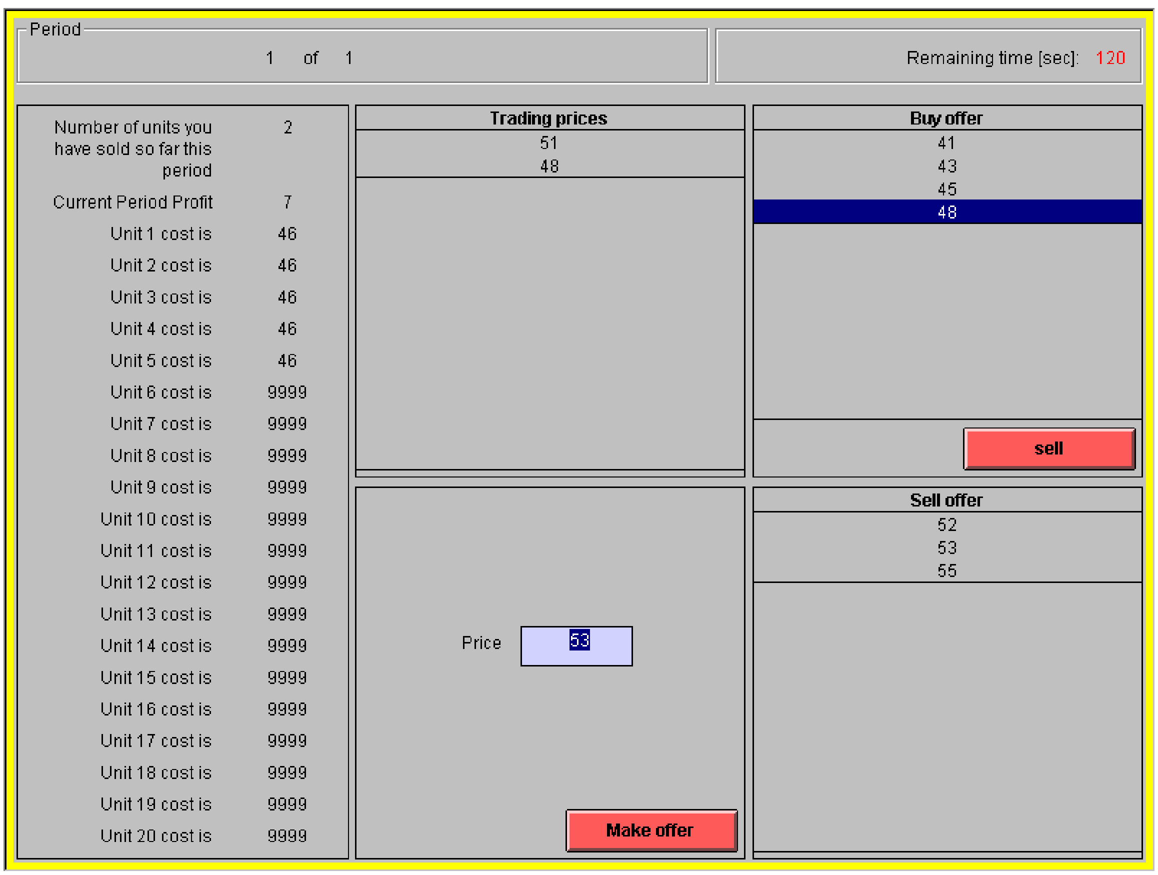


Figure 2: Example Market Trading Screen for Sellers

The profits from sales (which are yours to keep) are computed by taking the difference between the sale price of the unit and the cost of the unit. That is,

[your earnings = (sale price of unit) – (cost of unit)].

Suppose, for example, that the cost for your first unit is 46, and the cost of your second unit is 46. If you sell the first unit at a price of 54 and the second unit at a price of 52, your earnings are:

Earnings from first unit = 54 – 46 = 8

Earnings from second unit = 52 – 46 = 6

Total earnings = 8 + 6 = 14

Your total earnings will be updated immediately after a sale on the left side of your computer screen, above your costs, and are labeled *Current Period Profit*. Please pay careful attention to the number of units you have sold so far this period, since that information is useful when assessing the cost of the next unit you sell.

Notice that if a unit costs more than the amount for which you sell it then you suffer a loss in earnings on that unit. If you do not sell any units in a period then your earnings are zero for that period. Importantly, You do not incur the cost of a unit unless you sell that unit. Your costs may be different from the costs of other sellers. Note that some sellers may need to sell some higher-cost units before they can sell lower-cost units. Some sellers will have a cost of 9999 for some units, and it is never profitable to sell those units. Remember, keep an eye on the number of units you have sold so that you don't accidentally sell a unit that has a cost of 9999.

How to Buy and Sell

Each trading period will be open for trading for 4 minutes. At any time during the period, any buyer is free to make an offer to buy a unit at a price they choose; likewise, any seller is free to make an offer to sell a unit at a price they choose. Also at any time during the period, any buyer is free to buy at the best offer price specified by the sellers, and any seller is free to sell at the best offer price specified by the buyers.

You will enter offer prices and accept prices to execute transactions using your computer. Figure 1 shows the market trading screen seen by buyers. The time left in the period is shown on the upper right of the trading screen. Buyers submit offer prices using the "Price" box in the upper center of the screen, and then clicking on the “Make Offer” button. This offer price is immediately displayed on all traders’ computers on the upper right part of the screen, labelled “Buy Offer.” Once this offer price has been submitted, it is binding in the sense that any seller can accept this price offer. Such an acceptance results in an immediate trade at that price. The previous trading prices in the current period are displayed in the “Trading Prices” list in the center of your computer screen.

If there are already Buy Offers displayed in the current period, then new buy offers submitted by any buyer must provide better trading terms to the sellers. Sellers prefer higher prices, so any new buy offers must be higher than the current highest buy offer. Your computer will give you an error message if you try to offer a lower price than the best price currently available.

Buyers observe the Sell Offers made by sellers on the lower right part of their computer screen. They accept the best (that is, lowest offer price) by simply clicking the “Buy” button on the lowest right corner of their computer screen. This results in an immediate trade at that price.

Figure 2 shows the market trading screen as seen by sellers. Sellers submit offer prices using the “Price” box in the lower center of the screen, and then clicking on the “Make Offer” button. This offer price is immediately displayed on all traders’ computers on the lower right part of the screen, labelled “Sell Offer.” Once this offer price has been submitted, it is binding in the sense that any buyer can accept this price offer. Such an acceptance results in an immediate trade at that price.

If there are already Sell Offers displayed in the current period, then new sell offers submitted by any seller must provide better trading terms to the buyers. Buyers prefer lower prices, so any new sell offers must be lower than the current lowest sell offer. Your computer will give you an error message if you try to offer a higher price than the best price currently available.

Sellers observe the Buy Offers made by buyers on the upper right part of their computer screen. They accept the best (that is, highest offer price) by simply clicking the “Sell” button on the right side of their computer screen. This results in an immediate trade at that price.

Recording Rules

Your end of period earnings equal the sum of all profits (positive and negative) on the units that you trade. This total will be updated continuously on the left side of your computer screen, and it will be displayed briefly on a screen at the end of a trading period. At the end of a trading period you should write down these earnings in column (2) of your Personal Record Sheet. Keep track of your cumulative profits in column (3), by adding the column (2) period profit to the previous period's cumulative profit. At the end of the experiment you will divide your cumulative profit by the conversion rate to determine your total earnings in real Dollars.

Summary

- Seller earnings on a sold item = sale price of item – cost of item
- Buyer earnings on a purchased item = redemption value of item – price paid for item
- At any time during the 4-minute trading period, buyers submit offers to buy or accept sellers' offers to sell an item. Sellers submit offers to sell or accept buyers' offers to buy an item.
- New offers to buy must be higher than existing offers to buy, and new offers to sell must be lower than existing offers to sell.
- Profits should be recorded on Record Sheets at the end of each period.

Are there any questions now before we begin the experiment? Before we begin trading for real money, we will conduct one 5-minute trial period using completely different redemption values and costs than what we will use in the real experiment. This trial period is for you to get comfortable with the trading software, and it does not affect your experiment earnings.

Extra instructions distributed only to the large firm:

Instructions Specific to Subject 1:

The buyers have different values for the units. Buyer 1's values range from 370 experimental dollars to 1370 experimental dollars; Buyer 2's values range from 564 experimental dollars to 1730 experimental dollars; Buyer 3's values range from 681 experimental dollars to 1026 experimental dollars; and Buyer 4's values range from 729 experimental dollars to 1074 experimental dollars.

The other seller in the market has costs of 246 experimental dollars.

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