# Directed search, coordination failure and seller profits: an experimental comparison of posted pricing with single and multiple prices


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**Abstract**

We use a human–subjects experiment to examine market outcomes in two related settings involving posted pricing by firms and and directed search by consumers. Sellers simultaneously post asking prices for a single indivisible good; buyers observe the prices and simultaneously choose which firm to visit. In the *one–price* model, each firm posts a single asking price. In the *two–price* model, each posts a menu of prices: a "single–buyer" price (applicable when exactly one buyer visits), and a "multi–buyer" price (applicable when multiple buyers visit). While the multi–buyer price allows sellers the possibility of taking advantage of local market power, our experimental results – based on a 2x2 (2 buyers, 2 sellers) market – suggest that multi–buyer prices can actually be *lower* than either single–buyer prices or prices in the one–price treatment. We also find that allowing a separate multi–buyer price has no apparent effect on seller profits, and leads to a small increase in frictions. Finally, observed price dispersion is higher in the two–price treatment than in the one–price treatment. A follow–up experiment, using asymmetric 3x2 and 2x3 markets, shows that our main results are robust to giving either buyers or sellers market power.



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# 1 Introduction

The concept of search has been a versatile one in economics. Theoretical models incorporating some type of search have been used to explain such disparate phenomena as the emergence of money as a medium of exchange (Kiyotaki and Wright, 1989; 1993), price dispersion in goods markets (Salop and Stiglitz, 1977; Burdett and Judd, 1983), unemployment and job vacancies (Pissarides, 1985) and discrimination by consumers or firms (Borjas and Bronars, 1989; Black, 1995). Much of the early work on search in markets (e.g., consumers and producers, or workers and firms) assumed that search is *undirected*: an agent of one type is equally likely to meet any of the agents of the other type. This approach has been innovative, not least in highlighting the notion that people trade with each other as much as against budget constraints. However, it has faced criticisms along lines summarised by Howitt (2005): "[i]n contrast to what happens in search models, exchanges in actual market economies are organized by specialist traders, who mitigate search costs by providing facilities that are easy to locate. Thus, when people wish to buy shoes they go to a shoe store; when hungry they go to a grocer; when desiring to sell their labor services they go to firms known to offer employment" (p. 405).

Such criticisms argue in favour of *directed* instead of undirected search for realistic modelling. In a seminal paper, Burdett, Shi and Wright (2001) analysed a stylised market with directed search. In the simple version of their setup, there are two buyers who each want to buy one unit of an indivisible good, and two sellers who each want to sell one unit of that good. Sellers set prices, and then each buyer chooses which seller to visit (this last feature is what distinguishes directed from undirected search). Even though buyers are costlessly informed of the price (and location) of each seller, there is a chance of frictions due to coordination failure: both buyers might show up at the same seller's location, in which case one customer is unable to purchase the good, and since no buyer showed up at the location of the other seller, that seller is unable to sell.[1]

Coles and Eeckhout (2003) argue that while price posting is widely used in trading mechanisms, these models typically restrict sellers to commit to a single price, regardless of how many buyers show up to purchase the good. Coles and Eeckhout extend Burdett, Shi and Wright's (2001) model by allowing sellers to post prices contingent on demand, such as advertising a higher price should more than one buyer desire the good. In the two–buyer, two–seller case, each seller posts a price pair $(p, \hat{p})$, where $p$ is the "single–buyer" price charged if only one buyer shows up and thus buys the good, while $\hat{p}$ is the "multi–buyer" price charged if multiple buyers visit at the same time. They suggest that such a pricing mechanism "admits an auction scenario" (p. 266), letting the seller – in essence – compel multiple buyers to compete amongst themselves for the good, leading to an increase in seller profit. However, Coles and Eeckhout show that while their model implies a unique single–buyer price $p$ (equal to the price chosen in BSW's model), the multi–buyer price $\hat{p}$ can lie anywhere between the seller's minimum acceptable price and the buyer's maximum acceptable price. Thus, seller profits can be lower than as well as higher than under a single price.[2]

This multiplicity of equilibria means that little can be said, based on the theory itself, regarding systematic qualitative differences between Burdett, Shi and Wright's one–price model and CE's two–price model. We attempt to resolve some of this indeterminacy by means of a laboratory experiment in which human subjects interact – in the role of buyers or sellers – in environments based on these two models. We have three main results. (1) Allowing distinct single–buyer and multi–buyer prices does not alleviate the coordination problem arising from directed search, as observed market efficiency is actually lower in the two–price ("CE") treatment compared to

[1] This is a coordination failure in the sense that the buyer who was unable to buy could alternatively have visited the seller who was unable to sell, making them both strictly better off without affecting the payoffs of the other buyer and seller: a Pareto improvement.

[2] Indeed, Coles and Eeckhout (2003) remark that while setting high multi–buyer prices would seem to be profitable, "in many environments such opportunistic behavior is not observed" (p. 266).

the one–price ("BSW") treatment (though the difference is not always statistically significant). (2) Contrary to CE's original conjecture, but consistent with their theoretical conclusions, firms are (on average) either unable or unwilling to use the multi–buyer price to increase their profits, since multi–buyer prices tend to be either significantly below or insignificantly different from single–buyer prices in the CE treatment or prices in the BSW treatment. (3) Price dispersion is higher in the CE treatment than in the BSW treatment (though again, the difference is not always significant), suggesting that the multiplicity of equilibria in the CE model may be as severe a problem empirically as it is theoretically. These results are observed both in our original experiment based on a 2x2 (i.e., 2 buyers and 2 sellers) market, which we describe in Sections 2 and 3, and in a follow–up experiment based on the asymmetric 2x3 and 3x2 cases, which we describe in Section 4.

## 2 Theory

Here, we discuss the one–price and two–price models in greater detail. The models described in this section are isomorphic to those of Burdett, Shi and Wright (2001) and Coles and Eeckhout (2003), respectively. The minor changes we make are in order to parallel the experiment we discuss in Section 3, and do not affect the theoretical analysis in any non–trivial way.

There are two buyers and two sellers. Sellers are able to produce up to one unit of a homogeneous, indivisible good at an avoidable cost of 10; buyers derive a value of 20 from consuming up to one unit of the same good.[3] Sellers begin by simultaneously posting prices. There are two possibilities: in the *one–price* game (corresponding to Burdett, Shi and Wright's model, and which we will call the "BSW game"), each seller posts a single price, regardless of how many buyers visit; in the *two–price* game (corresponding to Coles and Eeckhout's model, and which we will call the "CE game"), each seller posts a price schedule made up of a "single–buyer price" that applies when exactly one buyer visits, and a "multi–buyer" price for when multiple buyers visit. Buyers observe all prices, then simultaneously choose which seller to visit. If the buyers visit different sellers, both are able to buy, and both sellers are able to sell (in the CE game, at the single–buyer price). If both buyers visit the same seller, then a randomly chosen buyer is able to buy (in the CE game, at the multi–buyer price) from that seller, while the other buyer and seller cannot trade.

Burdett, Shi and Wright (2001) show that in the one–price game, a large number of subgame perfect equilibria exists. However, only one satisfies the additional conditions of symmetry (in the strategies of identical buyers) and robustness (to small–probability trembles by sellers) and doesn't place extreme demands on buyers' ability to coordinate; in this equilibrium, both sellers post a price of 15 (halfway between seller cost and buyer value), and buyers mix, visiting either seller with equal probability.[4] Coles and Eeckhout (2003) similarly show that in the two–price game, sellers choose a single–buyer price of 15 in all subgame perfect equilibria satisfying certain additional conditions (symmetry for firms, pure strategies for firms, and symmetry for buyers). There is a continuum of such

[3] The sellers' cost is avoidable in the sense that if there is no willing buyer, the cost is not incurred. This can be motivated by assuming that the firm can quickly produce to order, or alternatively that the good is durable with negligible storage costs (so would eventually be sold).

[4] In general, for a market with $m$ buyers and $n$ sellers, and with buyer value and seller cost normalised to 1 and 0, Burdett, Shi and Wright (2001, p. 1068) show that the equilibrium price is

$$\frac{m - m\left(1 + \frac{n}{m-1}\right)\left(1 - \frac{1}{m}\right)^n}{m - \left(m + \frac{n}{m-1}\right)\left(1 - \frac{1}{m}\right)^n}.$$

Setting $m = n = 2$, and re–scaling so that value and cost are 20 and 10, yields a price of 15. Loertscher (2010) shows that the equilibrium selected by Burdett, Shi and Wright's selection criteria is also the only one that satisfies a law–of–demand condition.

equilibria, all with both firms choosing the same multi–buyer price in (10, 20], and buyers again visiting either seller with equal probability; this continuum includes the one–price case where firms set both prices equal to 15, along with the "auction" case where firms set a multi–buyer price of 20, capturing all of the surplus if visited by more than one buyer.

So, there is little theoretically to distinguish the two models. If we accept the equilibrium selection arguments of Burdett, Shi and Wright (2001) and Coles and Eeckhout (2003), then in both models, firms choose a single–buyer price of 15.[5] Since buyers choose either seller with equal likelihood, the probability of a given agent being able to trade is 0.75 in both models. We will define market efficiency to be the number of units exchanged divided by the maximum possible number of units that can be exchanged (this is reasonable, since all exchanges create a fixed surplus of 10); this also has an expected value of 0.75. The distribution of surplus between buyers and sellers can differ in the two models, due to the indeterminacy of the multi–buyer prices; however, there exist equilibria of the CE game corresponding to almost any possible distribution of gains from trade – in particular, either buyers or sellers can capture the majority of the surplus – as compared to the BSW game, where both sides are predicted to share the surplus equally.

# 3 The experiment

Because of the difficulty in obtaining clear–cut theoretical predictions for differences between the one–price and two–price models, we conduct a laboratory experiment in order to determine empirically whether any such differences arise. Lab experiments are a useful complement to theoretical analysis for (at least) two reasons. First, in cases where multiple equilibria exist (as for multi–buyer prices in the CE game, and for single–buyer prices in both games if Burdett, Shi and Wright's and Coles and Eeckhout's selection criteria are not imposed), observed behaviour from an experiment can shed light on which of the equilibria are most likely to occur. Second, even if choices in an experiment are not fully consistent with equilibrium behaviour, weaker implications of equilibrium can still be examined (e.g., descriptive statistics for aggregate behaviour, or comparative statics as parameters are changed).

In our experiment, the main treatment variable is whether sellers are able to charge different prices depending on whether one or multiple buyers visit them. In our "CE" treatment, sellers can do so (though they are able to set both prices to be equal if they wish); in our "BSW" treatment, they are constrained to post a single price. Our analysis of the data will be organised according to the BSW and CE models' theoretical predictions, though as noted in the previous paragraph, it is not necessary for subjects to play according to equilibrium for our results to be of interest.

## 3.1 Experimental design and procedures

There were a total of thirteen experimental sessions, with 128 subjects in all. Each session lasted for forty rounds, split into two halves. Some subjects played twenty rounds of the BSW game, followed by twenty rounds of the CE game, while for others, the order of games was reversed (see Table 1); this variation of orderings was done so that any difference between the games could be attributed to a treatment effect rather than learning from one game to the other. Subjects remained in the same role (buyer or seller) in all rounds, but the composition of the groups (containing two buyers and two sellers) was randomly drawn in each round, so that a given subject was grouped with different people from round to round; this was done primarily to lessen the likelihood of repeated–game effects like

[5] If we don't accept these arguments, we are completely at sea, since in that case, almost any pattern of observed behaviour – including any of higher, lower or equal prices in CE compared to BSW – is consistent with equilibrium play.

Table 1: Treatment information

| Game, rounds 1–20 | Game, rounds 21–40 | Independent groups | Subjects |
|---|---|---|---|
| BSW | CE | 7 | 64 |
| CE | BSW | 6 | 64 |

reputation building or dynamic collusion.

The experimental sessions took place at the Scottish Experimental Economics Laboratory (SEEL) at the University of Aberdeen. Subjects were primarily undergraduate students from University of Aberdeen, and were recruited using the ORSEE web–based recruiting system (Greiner, 2004). No one took part more than once. The experiment was run on networked personal computers, and was programmed using the z–Tree experiment software package (Fischbacher, 2007). Subjects were asked not to communicate with other subjects except via the computer program. No identifying information was given about other group members (or anyone else) – again, in an attempt to minimise repeated–game effects.

At the beginning of a session, subjects were seated in a single room and given written instructions for the first twenty rounds.[6] They were informed that the experiment would comprise two halves totalling forty rounds, but details of the second half were not announced until after the first half had ended. The instructions were also read aloud to the subjects, in an attempt to make the rules of the game common knowledge. Then, the first round of play began. After the twentieth round was completed, each subject was given a copy of the instructions for rounds 21–40. These new instructions were also read aloud, before round 21 was played.

Each round began with firms being prompted to choose their prices. In the BSW game, each firm chose one price, which had to be a whole–number multiple of £0.01, between £10 and £20 inclusive.[7] In the CE game, each firm chose single–buyer and multi–buyer prices in this range. The CE treatment instructions explicitly stated that there were no other restrictions on these prices; in particular, the multi–buyer price could be more than, less than, or equal to the single–buyer price. After the sellers had entered their prices, buyers observed these prices and were prompted to choose which firm to visit.[8] Once they had done so, the round ended and subjects received feedback. Firms were informed of all prices (own and rival's), how many buyers visited them, the quantity sold and profit. Buyers were informed of all prices, which firm each buyer visited, the quantity bought and profit.

At the end of the fortieth round, subjects were paid, privately and individually. For each subject, two rounds from each block of twenty were randomly chosen, and the subject was paid his/her earnings in those rounds, plus a £3 show–up fee. Subjects' total earnings averaged about £20, for a session that typically lasted about 60 minutes.

### 3.2 Experimental results

Table 2 shows some treatment–wide aggregate data from the experiment. Consistent with the theoretical predictions described in Section 2, we observe no substantial difference in single–buyer price between the two treatments,

[6]Sample instructions, from this experiment and the follow–up experiment reported in Section 4, can be found in the Appendix. Other sets of instructions, and the raw data from both experiments, are available from the corresponding author upon request.

[7]Coles and Eeckhout (2003) show that choosing a price outside [10, 20] is a dominated strategy in the two–price game; the same is clearly true in the one–price game.

[8]Within a round, the two firms in a market were labelled as "Seller 1" and "Seller 2", so that buyers could make clear which one they wanted to visit. These labels were chosen randomly in each round, so that a given firm was likely to be called each of "Seller 1" and "Seller 2" about half of the time, and buyers were not labelled at all – again, in an attempt to prevent repeated–game effects.

whereas transaction price, seller profit and market efficiency are actually *lower* in the CE treatment than in the BSW treatment.[9] Non–parametric statistical tests find that one cannot reject the null hypothesis that single–buyer prices, seller revenue and seller profits are equal between the two treatments (Wilcoxon signed–ranks test for matched samples, session–level data, $p > 0.20$ for price choices, transaction prices and profits).[10] On the other hand, the difference in efficiency seen in the table is significant, albeit only at the 10% level (Wilcoxon test, session–level data, $p \approx 0.074$). Additionally, the table shows that multi–buyer prices are *lower* on average than single–buyer prices

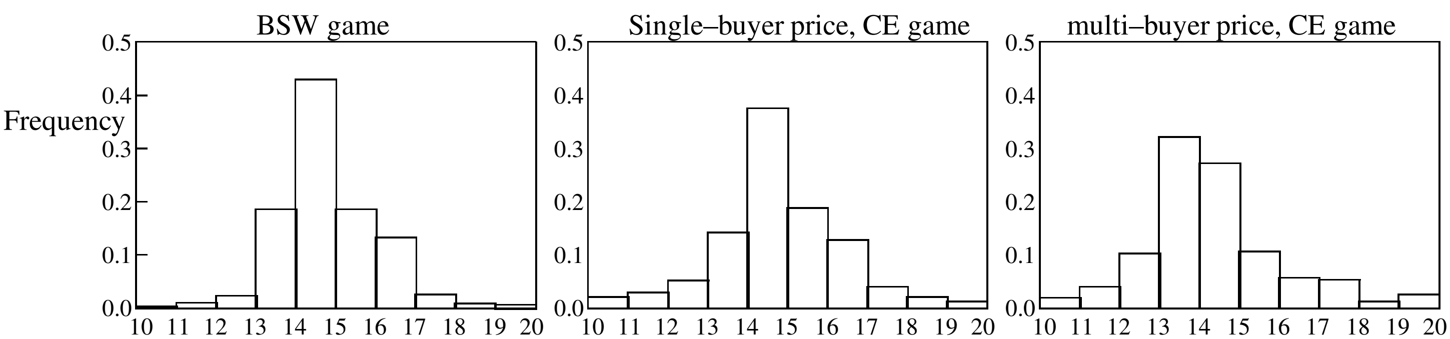
Table 2: Aggregate treatment–wide averages (standard deviations in parentheses)

| | BSW game | CE game |
|---|---|---|
| Single–buyer price choice (£) | 15.13 (1.22) | 15.15 (1.61) |
| Multi–buyer price choice (£) | — | 14.64 (1.75) |
| Efficiency | 0.761 (0.427) | 0.745 (0.436) |
| Transaction price (£) | 14.99 (1.12) | 14.83 (1.63) |
| Seller profit (£) | 3.79 (2.34) | 3.60 (2.54) |

in the CE treatment, and indeed lower than prices in the BSW treatment. These differences are at least marginally significant (Wilcoxon test, session–level data, $p \approx 0.055$ versus single–buyer prices in the CE treatment, $p \approx 0.007$ versus prices in the BSW treatment).

The other noteworthy results involve the *dispersion* of prices, rather than their absolute level. Table 2 indicates that dispersion of both single–buyer and multi–buyer prices in the CE game is higher than price dispersion in the BSW game. More detail can be seen in Figure 1. The distribution of prices in the BSW game is fairly tight, with a

Figure 1: Histogram of prices – BSW game, CE game (single–buyer and multi–buyer prices)




Price *(note: the height of the column between price $n$ and price $n+1$ is proportional to the frequency of price choices in the interval $(n, n+1]$ (except in the case of $[10, 11]$)*

[9]As mentioned earlier, we define efficiency as the actual quantity traded divided by the maximum possible quantity traded, yielding a value between zero and one. An obvious way to quantify the prevalence of frictions in the market (or the level of coordination failure) is to take one minus this value. Note also that we distinguish in the table between price choices (unconditional) and transaction prices (conditional on selling a unit).

[10]See Siegel and Castellan (1988) for descriptions of the non–parametric statistical tests used in this paper. We note that these tests tend to err on the conservative side, as they treat an entire group over all rounds as a single observation. However, we believe this is appropriate, since more disaggregated data cannot be considered to be independent of each other. We also note that additional tests using the data from the last ten rounds of each game yielded similar results to the ones reported here for all twenty rounds of each game, suggesting that even after subjects have gained experience in the environment, results are qualitatively the same.

mode between 14 and 15. single–buyer prices in the CE game are centred in the same interval, but their distribution has wider tails (suggesting more dispersion). The distribution of multi–buyer prices also has wide tails, but its mode is between 13 and 14. Both the difference in dispersion between single–buyer price and BSW treatment and that between multi–buyer price and BSW treatment are significant ($p \approx 0.011$ and $p \approx 0.020$ respectively).[11] On the other hand, we do not find significant differences in dispersion between the single–buyer and multi–buyer prices within the CE treatment ($p > 0.20$), even though the theoretical prediction of Coles and Eeckhout's model (unique single–buyer price of 15, continuum of multi–buyer prices between 10 and 20) suggests that multi–buyer prices might have been expected to have higher dispersion.

# 4 A follow–up experiment

The experiment described up to now was based on the 2x2 case (2 buyers and 2 sellers). While this case has the virtue of simplicity – being the simplest non–trivial version of the BSW and CE models – it has the drawback that predicted prices, when unique, are exactly halfway between buyer value and seller cost. As a result, it is impossible to distinguish equilibrium behaviour from any number of simple rules of thumb, such as the social norm of 50–50 splits, or maximising the minimum payoff within a buyer–seller pair. In this section, we describe a follow–up experiment in which markets comprise different numbers of buyers and sellers: 3 of one and 2 of the other. The 3x2 and 2x3 cases represent the next–simplest versions of the BSW and CE models, and have the advantage of yielding asymmetric theoretical predictions.

This new experiment took place in Australia, in contrast to the old experiment which took place in the UK. Due to differences in money systems and the cost of living, some features of the new experiment differed from the old one. We discuss the (very minor) differences that are relevant to the theory here; those involving implementation in the experiment are discussed in Section 4.1.

In the 3x2 market, there are three buyers and two sellers; in the 2x3 market, there are two buyers and three sellers. Each seller is able to produce one unit at zero cost; each buyer values the first unit consumed at 20.[12] Sellers cannot produce more than one unit, and buyers place no value on the second or any additional units. Price posting is exactly as before, as is the information buyers have when choosing whom to visit, and the way payoffs are computed.

Some theoretical predictions for the 3x2 and 2x3 markets are shown in Table 3, under the same assumptions detailed in Section 2 for the 2x2 market (see also Note 4). The table makes clear that a quite small asymmetry in

[11] The effects of this price dispersion are also seen in transaction prices and sellers' profits, both of which have significantly higher variance in the CE treatment than in the BSW treatment ($p < 0.001$ and $p \approx 0.009$ respectively). We also note that even though price dispersion of multi–buyer prices is substantial, there is weak evidence that subjects do manage a limited amount of coordination. Perhaps the best indicator of this comes from Spearman's measure of association $r_s$: a non–parametric analogue to the correlation coefficient. When $r_s$ between Firm 1's and Firm 2's multi–buyer prices is computed separately for each individual group, we find that for only two of the thirteen groups is it even positive, and for only one of these is it significantly larger than zero ($p \approx 0.05$) – suggesting that *within each group*, there is little or no association between competing firms' prices. When $r_s$ between Firm 1's and Firm 2's multi–buyer prices is computed for the entire sample, however, its value of approximately +0.21 is highly significant ($p < 0.001$), suggesting substantial positive correlation at the aggregate level. While we must be careful interpreting these measures here (since they combine observations that are not independent) the combination of *no significant association within groups* and *strongly significant association in the aggregate* suggests (a) within a group, firms achieve a degree of convergence, but (b) different groups converge to different prices (as one might expect given the multiple symmetric equilibria of the game).

[12] This cost–value pair implies a surplus of AUD 20 for each transaction, as compared to £10 in the original experiment. For the sake of comparison, the market exchange rate between Australian dollars and British pounds in January 2012 averaged about 1.50 AUD/GBP, while the *Economist*'s Big Mac index estimated their purchasing powers at approximately 1.93 AUD = 1 GBP on 11 January 2012 (Economist, 2012).

the market (one additional buyer or seller) has a large effect on prices. Instead of price being at the midpoint of seller cost and buyer value (as in the 2x2 case), it is three times closer to one of these points than the other – and the change is in opposite directions in the two markets. As before, efficiency is defined as the ratio between the

Table 3: Theoretical predictions for follow–up experiment

| | 3 buyers, 2 sellers (3x2) | | 2 buyers, 3 sellers (2x3) | |
|---|---|---|---|---|
| | BSW game | CE game | BSW game | CE game |
| Single–buyer price choice ($) | 14.55 | 14.55 | 5.45 | 5.45 |
| Multi–buyer price choice ($) | — | *ind.* | — | *ind.* |
| Efficiency | 0.875 | 0.875 | 0.833 | 0.833 |
| Transaction price ($) | 14.55 | *ind.* | 5.45 | *ind.* |
| Seller profit ($) | 12.73 | *ind.* | 3.03 | *ind.* |
| Buyer profit ($) | 3.18 | *ind.* | 12.12 | *ind.* |

*Note: "ind." = indeterminate.*

expected number of units exchanged in the market and the maximum number that could possibly be traded (which is still always two).[13]

Thus, as in the 2x2 case, both single–buyer prices and efficiency are predicted to be equal for the BSW and CE games in a given market, and the multi–buyer price in the CE game is indeterminate (except that it must be equal for all sellers in the market).

### 4.1 Experimental design and procedures

There were a total of twelve experimental sessions, each with 10 subjects. Each session comprised twenty rounds of the BSW game and twenty rounds of the CE game; the order was perfectly counterbalanced (see Table 4). Each session used only one type of market: either 3 buyers and 2 sellers (3x2) or 2 buyers and 3 sellers (2x3). As before,

Table 4: Treatment information for follow–up experiment

| Type of market | Game, rounds 1–20 | Game, rounds 21–40 | Independent groups | Subjects |
|---|---|---|---|---|
| 3x2 | BSW | CE | 3 | 30 |
| | CE | BSW | 3 | 30 |
| 2x3 | BSW | CE | 3 | 30 |
| | CE | BSW | 3 | 30 |

subjects remained in the same role in all rounds, but the members of a particular market were randomly drawn in each round.

[13] In these markets, it is usually the case that exactly two units are traded. In the 3x2 market, the exception is when all three buyers visit the same seller, which happens with probability one–quarter. In the 2x3 market, the exception is when both buyers visit the same seller, which happens with probability one–third. In either of these exceptional cases, only one unit is traded.

The experimental sessions took place at Monash University's experimental lab (MonLEE). Subjects were primarily undergraduate students from Monash University, and were recruited using ORSEE. No one took part more than once. The experiment was run on networked personal computers, and was programmed using z–Tree. Subjects were asked not to communicate with each other except via the computer program, and they received no identifying information about each other.

The structure of individual experimental sessions was very similar to the original experiment. Subjects were seated and given written instructions for the first twenty rounds, which were then read aloud in an attempt to make the rules common knowledge. After the twentieth round had finished, new instructions were distributed; these were also read aloud. Each round began with firms being prompted to choose their prices, which were restricted to be whole–number multiples of AUD 0.05 (the smallest unit of physical currency in Australia), between $0 and $20 inclusive. After the sellers had entered their prices, buyers observed these prices and were prompted to choose which firm to visit. End–of–round feedback for firms consisted of all prices in their market, how many buyers visited them, quantity sold and profit. Buyers were informed of all prices, which firm they visited, how many buyers in total visited that firm, quantity bought and profit.

Subjects were paid, privately and individually, at the end of the experiment according to three randomly–chosen rounds from each block of twenty, plus a $10 show–up fee. Sessions typically lasted about 75 minutes, and total earnings averaged about $70 for those in the favoured side of the market (buyers in the 2x3 market and sellers in the 3x2 market) and $35 for those in the unfavoured side.[14]

## 4.2 Results

Table 5 shows aggregate statistics from the follow–up experiment. (Recall that prices can vary from 0 to 20 here, as compared with 10–20 in the original experiment.)

Table 5: Aggregate treatment–wide averages in follow–up experiment (standard deviations in parentheses)

| | 3 buyers, 2 sellers (3x2) | | 2 buyers, 3 sellers (2x3) | |
|---|---|---|---|---|
| | BSW game | CE game | BSW game | CE game |
| Single–buyer price choice ($) | 13.35 (3.48) | 13.02 (3.82) | 7.98 (2.36) | 7.18 (2.54) |
| Multi–buyer price choice ($) | — | 13.59 (3.61) | — | 7.10 (2.88) |
| Efficiency | 0.852 (0.356) | 0.846 (0.364) | 0.833 (0.746) | 0.815 (0.748) |
| Transaction price ($) | 13.12 (3.48) | 13.35 (3.71) | 7.43 (2.01) | 6.52 (1.89) |
| Seller profit ($) | 11.18 (5.66) | 11.29 (5.91) | 4.13 (3.99) | 3.54 (3.54) |
| Buyer profit ($) | 3.91 (4.30) | 3.75 (4.32) | 10.48 (5.04) | 10.98 (5.52) |

The most easily visible result is that average prices are well away from the $10 price that yields a 50–50 split

[14] Average payments to subjects are higher in the follow–up experiment than in the original one. This is due partly to our having to compensate for the higher cost of living in Australia than in the UK (as mentioned already), and partly to the need to ensure that even subjects in the unfavoured role were likely to receive reasonable payments – an issue that did not arise in the original experiment, due to its use of symmetric 2x2 markets only. Even with these higher averages, some subjects – due to bad luck, bad decisions, or both – earned fairly low payments. Out of the 72 subjects assigned an unfavoured role (buyer in a 3x2 market or seller in a 2x3 market), 9 earned $10 or less beyond the show–up fee.

of the surplus between buyer and seller.[15] Moreover, for both markets, the direction of deviation from $10 is in the direction implied by the theoretical prediction (recall Table 3): a higher price when sellers have the market power (the 3x2 market) and a lower price when buyers have the market power (the 2x3 market). All of these differences are statistically significant (Wilcoxon signed–ranks test, session–level data, $p < 0.05$ for all price choices and transaction prices in both games and both markets).[16]

On the other hand, the magnitudes of the deviations from $10 are typically less than those implied by the theoretical prediction, suggesting that while strategic considerations play a major role in subject behaviour in these markets, other considerations seem to matter as well. In the 2x3 market, observed price choices in the BSW game and single–buyer price choices in the CE game, as well as transaction prices in BSW, are significantly larger than the theoretical prediction of approximately $5.45 (Wilcoxon test, session–level data, $p < 0.05$ in all cases). While there is no unique theoretical prediction for the multi–buyer price choice and transaction price in CE, the observed averages for both of these are also significantly larger than $5.45 ($p < 0.05$ in both cases). In the 3x2 market, differences between theory and observed averages in the BSW game are not significant ($p > 0.10$ for both price choices and transaction prices), while observed single–buyer prices in the CE game are significantly lower than the theoretical prediction of approximately $14.55 ($p < 0.05$). Again, there is no unique theoretical prediction for the multi–buyer price choice and transaction price in CE, but transaction prices are (weakly) significantly lower than $14.55 ($p \approx 0.078$), while there is no significant difference between observed multi–buyer prices and $14.55 ($p > 0.10$).

Moving to comparisons between the BSW and CE games, we find only fairly minor differences (like in the original experiment). Average price choices in the BSW game are higher than single–buyer prices in the CE game in both markets, but multi–buyer prices are higher than either in the 3x2 market and lower than either in the 2x3 market. As in the original experiment, we find lower efficiency in CE than in BSW, for both 3x2 and 2x3 markets. For transaction price, seller profit, and buyer profit, the CE game in both markets is closer to the theoretical prediction than the BSW game. However, none of the differences observed in the 3x2 market are statistically significant, while in the 2x3 market, BSW price choices are significantly higher than both CE single– and multi–buyer price choices (Wilcoxon test, session–level data, $p \approx 0.078$ in both cases), and the differences in transaction prices ($p \approx 0.078$) and seller profits ($p \approx 0.047$) are also significant. Looking at the standard deviations in Table 5, we see that price choices show less dispersion in BSW than in CE (for either single– or multi–buyer prices) in both markets, as was seen in the original experiment; however, another Wilcoxon test shows that the only significant difference is the one between BSW and CE single–buyer prices in the 3x2 market ($p \approx 0.047$).[17]

[15] Prices are even farther from those that would equalise expected profit over *all five* agents in the market: $8 in the 3x2 market and $12 in the 2x3 market.

[16] We can also compare averages between the 2x3 and 3x2 markets directly for a given game. Robust rank–order tests, using session–level data, find that single–buyer and transaction prices and seller profits in both games, and multi–buyer prices in the CE game, are significantly higher, and buyer profits in both games are significantly lower, in the 3x2 market compared to the 2x3 market ($p < 0.005$ in all cases). Critical values for the robust rank–order test are from Feltovich (2005). On the other hand, we avoid making direct comparisons between either of these markets and the 2x2 market, due to the many uncontrolled differences between our original experiment and this follow–up experiment.

[17] As in the original experiment (see Note 11), we see evidence of successful coordination in observed multi–buyer prices based on the combination of significant positive correlation in the aggregate and near–zero correlation within each session. In the 3x2 markets at the aggregate level, Spearman's measure of association between Firm 1's and Firm 2's multi–buyer prices is $r_s \approx +0.32$, which is significantly different from zero ($p < 0.001$), while in the six individual sessions, this correlation is actually negative in three, and insignificant in two of the remaining three. In the 2x3 markets, the presence of three firms instead of two means that three distinct pairwise correlations can be calculated (Firm 1 vs. Firm 2, Firm 2 vs. Firm 3, Firm 1 vs. Firm 3). At the aggregate level, the three resulting values of $r_s$ are +0.27, +0.19, and +0.23; all three are significantly different from zero ($p < 0.001$). Of the eighteen individual–session values, by contrast, eight are

## 5 Discussion

We conduct a laboratory experiment to understand behaviour in two versions of a posted–price, directed–search environment. In the one–price "BSW" model (based on Burdett, Shi and Wright, 2001), each seller posts a single price, which buyers observe before deciding which firm to visit. The two–price "CE" model (based on Coles and Eeckhout, 2003) is similar, except that sellers can post a slightly more complex pricing schedule, comprising a single–buyer price (in effect when exactly one buyer visits) and a multi–buyer price (in effect when more than one visits). As Burdett, Shi and Wright (2001) and Coles and Eeckhout (2003) make clear, theoretical analysis provides few general implications; even accepting their (quite reasonable) equilibrium selection arguments, the multiplicity of equilibria in the CE model prevents qualitative predictions about transaction prices or seller profits between the models. Experimental methods are thus well suited to overcoming this indeterminacy.

The main results – from our original experiment based on a 2x2 market (i.e., 2 buyers and 2 sellers) and a follow–up experiment based on 2x3 and 3x2 markets – are as follows. Allowing distinct single–buyer and multi–buyer prices – i.e., moving from the Burdett–Shi–Wright setting to the Coles–Eeckhout setting – does not alleviate the coordination problem arising from directed search, as observed market efficiency is actually lower in the CE treatment compared to the BSW treatment (though the difference is not always significant). That is, frictions actually weakly increase when sellers are given the ability to post more complex pricing schedules. Also, contrary to Coles and Eeckhout's original conjecture about firms' use of the multi–buyer price to extract more surplus, but consistent with their theoretical results, allowing the multi–buyer price does not lead to increased seller profits, since on average, multi–buyer prices in the two–buyer treatment are not higher than either single–buyer prices in that treatment or prices in the BSW treatment; rather, they are either significantly lower or not statistically distinguishable. Finally, we do not observe sellers converging on a single multi–buyer price, or even a tight distribution of them, suggesting that the multiplicity of equilibria in the Coles and Eeckhout's model is as severe a problem behaviourally as they showed it is theoretically.

Amongst our results, the most puzzling one is probably the failure to observe high multi–buyer prices in the CE treatment. Why do sellers not attempt to take advantage of local market power when they have it (those times when they are visited by more than one buyer), and what are they doing instead? We don't have a definitive answer to these questions, but we can speculate based on a few post–experiment conversations with subjects who had played the role of seller.[18] In the 2x2 and 2x3 markets, the multi–buyer price is realised only in the relatively unlikely event that both buyers choose the same seller, giving it an element of "cheap talk". Because of this, sellers may have been more likely to view the multi–buyer price as an opportunity to "lure customers in" by setting it at a low value, and then likely being able to collect the single–buyer price instead, rather than potentially scaring them off by setting it near buyers' valuation in an attempt to exploit buyer competition. Some suggestive evidence that this might actually be happening is the observation (see Tables 2 and 5) that in the 2x2 and 2x3 markets, multi–buyer prices are lower on average than single–buyer prices, while in the 3x2 market – where 3 buyers and 2 sellers mean that the multi–buyer price is much more likely to obtain, and hence not cheap talk – multi–buyer prices are *higher* on average than single–buyer prices (though not significantly so).

The possibility that the multi–buyer price is used by sellers in a way quite different from what Coles and Eeckhout (and we) envisioned, suggests that a multi–buyer price – posted in advance and unchangeable afterwards – may

negative, and only four of the ten positive values are significantly different from zero.

[18] We don't attempt to argue that a handful of conversations with an unrepresentative sample of subjects proves anything about subject behaviour in general, but we do think the type of behaviour described here is reasonable.

not be the most appropriate way to model sellers' ability to take advantage of buyer competition. Other ways exist in the literature. For example, Virág (2010) considers directed search where goods are exchanged in second–price auctions, and where sellers' reserve prices are known by buyers when they choose which seller to visit.[19] In the environment we have studied, this entails setting a single–buyer price equal to the reserve price chosen by the firm, and (in equilibrium) a multi–buyer price equal to buyers' common valuation. Another reasonable assumption could be decentralised pairwise bargaining between the seller and each individual buyer when multiple buyers visit the same seller; solution concepts such as the core would then imply a price equal to buyer valuation in this case as well. Future research may examine whether transaction prices, efficiency, and other variables are affected by moving from the BSW game to one where there is common knowledge of either a second–price auction or pairwise bargaining when multiple buyers visit the same seller, or even one where a multi–buyer price equal to buyers' valuation is simply imposed.

We recognise the risks in drawing broad conclusions based on the results of a small–scale empirical test; we therefore hope that other researchers will be encouraged to replicate and extend our results. Should our results prove to be robust, they carry clear implications for researchers interested in directed search. Coles and Eeckhout's extension of Burdett, Shi and Wright's model is a step in the direction of more realism – real firms often do have the ability to adjust prices according to current demand for their products (though as we've noted, there are other ways of modelling this ability) – and it seems intuitively reasonable to expect (as Coles and Eeckhout originally conjecture) that giving firms such additional latitude can enhance their profits. However, Coles and Eeckhout show theoretically that this need not be the case: allowing distinct single–buyer and multi–buyer prices can lead to higher, lower or equal firm profits. Our results suggest that empirically as well, giving firms this flexibility has little effect on market outcomes, and to the extent that there is an effect, frictions in the economy increase and firms suffer (suggesting that in the longer term, firms might well revert to a single price anyway).

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[19] A related approach is that of Geromichalos (2011), who allows sellers to post very general pricing mechanisms, including auctions and fixed prices (both of which are consistent with equilibrium behaviour in his model).

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# A Instructions from the experiment

Below is the text of instructions for our 2x2 market with BSW-CE ordering, followed by that for our 3x2 market with CE-BSW ordering. Square brackets represent comments that were not in the original instructions. All instructions were on one single-sided page, so there were no page breaks in the original. The instructions for the other treatments are analogous, and available from the corresponding author upon request.

**Instructions: first part of experiment [2x2, BSW-CE]**

You are about to participate in a decision making experiment. Please read these instructions carefully, as the money you earn may depend on how well you understand them. If you have a question at any time, please feel free to ask the experimenter. We ask that you not talk with the other participants during the experiment.

This experiment consists of two parts. These instructions are for the first part, which is made up of ***20 rounds***. The second part will also comprise ***20 rounds***; you will receive instructions for it after the first part has ended. Each round in this part consists of a simple market game, played via the computer. At the beginning of the experiment, you are assigned a role: either buyer or seller. ***You will remain in the same role throughout the experiment.***

In each round, the participants in this session are divided into “markets”: groups of four containing ***two buyers*** and ***two sellers***. So, the market you are in will also contain one other participant in the same role, and two in the other role. ***The participants who make up your market will change from round to round.*** You will not be told the identity of the people in your market, nor will they be told yours – even after the session ends.

***The market game:*** In each round, a seller can produce ***one*** unit of a good, at a cost of ***£10***. A buyer can buy up to ***one*** unit of the good, to be immediately resold to the experimenter for ***£20***. No one can buy or sell more than one unit in a round. Sellers begin a round by choosing the prices of their goods, which must be entered as ***multiples of 0.01, between 10 and 20*** inclusive.

After both sellers have chosen prices, each buyer observes these prices, then chooses which seller to visit. If the buyers in a market visit ***different*** sellers, then each buys the seller’s item at the seller’s price. If both visit the ***same*** seller, then either buyer has a ***50%*** chance of being able to buy the seller’s item at the seller’s price. In that case, the other buyer is unable to buy, and the other seller is unable to sell.

***Profits:*** Your profit for the round depends on the round’s result.
- If you are a ***seller*** and you are ***able to sell***, your profit is the price you chose minus £10.00.
- If you are a ***seller*** and you are ***unable to sell***, your profit is zero.
- If you are a ***buyer*** and you are ***able to buy***, your profit is £20.00 minus the price you paid.
- If you are a ***buyer*** and you are ***unable to buy***, your profit is zero.

***Sequence of play:*** The sequence of play in a round is as follows.
(1) The computer randomly forms markets made up of two buyers and two sellers.
(2) Sellers choose their prices.
(3) Buyers observe the sellers’ prices, then each buyer chooses which seller to visit. At this time, each seller is informed of the other seller’s price.
(4) The round ends. Sellers are informed of: own price, other seller’s price, how many buyers visited, quantity sold and profit for the round. Buyers are informed of: both sellers’ prices, which seller each buyer visited, quantity bought and profit for the round.
After this, you go on to the next round.

***Payments:*** At the end of the experiment, ***two*** rounds from this part will be chosen randomly for each participant. You will be paid your total profit from those two rounds. In addition, you will receive £3 for completing the session, and you will have opportunities to earn more in the second part of the session. Payments are made privately and in cash at the end of the session.

### Instructions: second part of experiment [2x2, BSW-CE]

The procedure in this part of the experiment is nearly the same as that in the first part. You will play a similar market game, for 20 additional rounds. Your role (buyer or seller) will remain the same as before, and the participants in your market – a total of 2 buyers and 2 sellers – will still change from round to round.

The difference from the first part of the experiment is that now, sellers choose ***two*** prices: ***one price in case both buyers visit, and one price in case only one buyer visits***. Both of these prices must be entered as ***multiples of 0.01, between 10 and 20*** inclusive. There is no other restriction on these prices: the two-buyer price may be more than, less than, or equal to the one-buyer price.

As before, the buyers observe all seller prices before choosing which seller to visit. If each buyer visits a different seller, then each buyer buys the seller's item ***at the one-buyer price*** that seller chose. If both buyers visit the same seller, then either buyer has a 50% chance of being able to buy that seller's item, ***at the two-buyer price*** that seller chose. As before, in that case the other buyer is unable to buy, and the other seller is unable to sell.

***Sequence of play:*** The new sequence of play in a round is as follows.
(1) The computer randomly forms markets containing two buyers and two sellers.
(2) Sellers choose their one-buyer and two-buyer prices.
(3) Buyers observe all of the sellers' prices, then each buyer chooses which seller to visit. At this time, each seller is informed of the other seller's prices.
(4) The round ends. Sellers are informed of: own prices, other seller's prices, how many buyers visited, quantity sold and profit for the round. Buyers are informed of: both sellers' prices, which seller each buyer visited, quantity bought and profit for the round.
After this, you go on to the next round.

At the end of the experiment, ***two*** rounds from this part will be chosen randomly for each participant. You will be paid your total profit from those two rounds. Your earnings from this part of the experiment will be added to your earnings from the previous part.

### Instructions: first part of experiment [3x2, CE-BSW]

You are about to participate in a decision making experiment. Please read these instructions carefully, as the money you earn may depend on how well you understand them. If you have a question at any time, please feel free to ask the experimenter. We ask that you not talk with the other participants during the experiment.

This experiment consists of two parts. These instructions are for the first part, which is made up of ***20 rounds***. The second part will also comprise ***20 rounds***; you will receive instructions for it after the first part has ended. Each round in this part consists of a simple market game, played via the computer. At the beginning of the experiment, you are assigned a role: either buyer or seller. ***You will remain in the same role throughout the experiment.***

In each round, the participants in this session are divided into "markets": groups of five containing a total of ***three buyers*** and ***two sellers***. ***The participants who are in your market will change from round to round.*** You will not be told the identity of the people in your market, nor will they be told yours – even after the session ends.

***The market game:*** In each round, a seller can produce ***one*** unit of a hypothetical good, at a cost of ***$0***. A buyer can buy up to ***one*** unit of the good, to be immediately resold to the experimenter for ***$20***. It is not possible to buy or sell more than one unit in a round. Sellers begin a round by choosing the prices of their goods. Each seller chooses ***two*** prices: ***a "two-buyer" price in case multiple buyers visit, and a "one-buyer" price in case only one buyer visits***. Prices must be entered as ***multiples of 0.05, between 0 and 20*** inclusive, but there are no other restrictions: the two-buyer price may be more than, less than, or equal to the one-buyer price.

After all sellers have chosen prices, each buyer observes these prices, then chooses which seller to visit. If a buyer is the ***only one*** to visit a particular seller, then that buyer buys the seller's item ***at the seller's one-buyer price***. If ***more than one*** buyer visits the ***same*** seller, then the computer ***randomly*** chooses which buyer is able to buy the seller's item, ***at the seller's two-buyer price***. In that case, a buyer that wasn't chosen is unable to buy. If a seller is not visited by any buyers, that seller is unable to sell.

***Profits:*** Your profit for the round depends on the round's result.
- If you are a ***seller*** and you are ***able to sell***, your profit is the selling price.
- If you are a ***seller*** and you are ***unable to sell***, your profit is zero.
- If you are a ***buyer*** and you are ***able to buy***, your profit is $20.00 minus the price you paid.
- If you are a ***buyer*** and you are ***unable to buy***, your profit is zero.

***Sequence of play:*** The sequence of play in a round is as follows.
(1) The computer randomly forms markets made up of three buyers and two sellers.
(2) Sellers choose their one-buyer and two-buyer prices.
(3) Buyers observe the sellers' prices, then each buyer chooses which seller to visit.
(4) The round ends. Sellers are informed of: own prices, other seller's prices, how many buyers visited, quantity sold and profit for the round. Buyers are informed of: sellers' prices, how many buyers visited the same seller as you, quantity bought and profit for the round.
After this, you go on to the next round.

***Payments:*** At the end of the experiment, ***three*** rounds from this part will be chosen randomly for each participant. You will be paid your total profit from those rounds. In addition, you will receive $10 for completing the session, and you will have opportunities to earn more in the second part of the session. Payments are made privately and in cash at the end of the session.

**Instructions: second part of experiment [3x2, CE-BSW]**

The procedure in this part of the experiment is nearly the same as that in the first part. You will play a similar market game, for 20 additional rounds. Your role (buyer or seller) will remain the same as before, and the participants in your market – a total of 3 buyers and 2 sellers – will be randomly chosen in each round.

The difference from the first part of the experiment is that now, each seller chooses ***only one price,*** which applies ***regardless of how many buyers visit***.

As before, the buyers observe the sellers' prices before choosing which seller to visit. If a buyer is the ***only one*** to visit a particular seller, then that buyer buys the seller's item at that seller's price. If ***more than one*** buyer visits the ***same*** seller, then the computer ***randomly*** chooses which buyer is able to buy the seller's item at that seller's price. In that case, a buyer that wasn't chosen is unable to buy. If a seller is not visited by any buyers, that seller is unable to sell.

***Sequence of play:*** The new sequence of play in a round is as follows.
(1) The computer randomly forms markets containing three buyers and two sellers.
(2) Sellers choose their prices, which must be entered as multiples of 0.05, between 0.00 and 20.00 inclusive.
(3) Buyers observe the sellers' prices, then each buyer chooses which seller to visit.

(4) The round ends. Sellers are informed of: own price, other seller's price, how many buyers visited, quantity sold and profit for the round. Buyers are informed of: sellers' prices, how many buyers visited the same seller as you, quantity bought and profit for the round.

After this, you go on to the next round.

At the end of the experiment, ***three*** rounds from this part will be chosen randomly for each participant. You will be paid your total profit from those rounds. Your earnings from this part of the experiment will be added to your earnings from the previous part.