



Tacit Collusion in Price-Setting Duopoly Markets:  
Experimental Evidence<sup>\*</sup>

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## **Tacit Collusion in Price-Setting Duopoly Markets: Experimental Evidence**

### **Abstract**

We study the effect of demand structure on the ability of subjects to tacitly collude on prices by considering Bertrand substitutes and Bertrand complements. We find evidence of collusion in the complements treatment, but no such evidence in the substitutes treatment. This finding is somewhat in contrast with Potters and Suetens (2007) who observe tacit collusion in two treatments with similar underlying demand structures but with no market context.

**JEL Codes:** C9, L1

**Keywords:** collusion, Bertrand, experiment

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## *1. Introduction*

For decades economists have studied oligopoly behavior using laboratory experiments. Much attention has been devoted to identifying factors that facilitate tacit collusion. We contribute to this literature by studying the effect of demand structure on the ability of subjects to collude within the price-setting model. Specifically, we consider Bertrand substitutes and Bertrand complements.<sup>1</sup> In the case of substitutes, the model generates upward sloping reaction functions in prices. Hence, theory predicts that if one seller moves away from the Nash solution toward the collusive outcome the other seller has a unilateral incentive to respond by raising price toward the collusive outcome. Alternatively, in the case of complements, the model generates downward sloping reaction functions. So a unilateral deviation from the Nash solution toward the collusive outcome will provide a unilateral incentive for the other seller to adjust price in the opposite direction. Based on the slopes of the reaction functions, it is reasonable to expect that sellers of substitute goods might find it easier to collude tacitly than sellers of complement goods (Holt, 1995). This argument is not entirely compelling since the incentives are in terms of myopic best responses to past decisions of the other seller. Moreover, the idea is somewhat at odds with economic intuition since sellers offering competing (substitute) products could reasonably be expected to engage in aggressive price slashing behavior. In contrast, sellers of complementary goods might view the other person as more of a partner than a rival, thus fostering cooperation.

Two related papers suggest that subjects in experiments find it easier to tacitly collude when market structure generates upward sloping reaction functions. In a recent survey, Suetens

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<sup>1</sup> Note that we refer to goods from a consumption perspective rather than a production perspective. Specifically, we use the term “substitute goods” to refer to goods with a positive cross price elasticity of demand. Some studies in this area define the relationship between goods based on producers’ reaction functions, which can be affected by cost considerations as well as demand effects. For example, the term “strategic substitutes” refers to downward sloping reaction functions and the term “strategic complements” refers to upward sloping reaction functions.

and Potters (2007) compared results from a series of Bertrand and Cournot experiments and concluded that subjects colluded more when the decision task was choosing price versus choosing quantity. One possible explanation for this finding is that reaction functions are upward sloping in Bertrand (substitutes) games and downward sloping in Cournot games. However, the different market choice variables (price versus quantity) cannot be ruled out as an explanation for the observed differences in collusion. As a follow up to this survey, Potters and Suetens (2007) conducted experiments with no market context. They included treatments with upward sloping and downward sloping reaction functions. Consistent with their survey of previous work, they conclude that there is more collusion with upward sloping reaction functions in their context-free experiment.

A number of market experiments have focused on identifying other conditions that are favorable to seller collusion. These studies vary in terms of the number of firms per market, whether or not subjects have multiple interactions with the same rival, whether or not subjects face capacity constraints, and the amount of information subjects receive about rivals' decisions and earnings.<sup>2</sup> We contribute to this literature by examining the effect of market structure within the price-setting model. Hence, we eliminate any differences in behavior that might result from choosing quantity rather than price. Further, we include market context in our experiments, since tacit collusion is generally a market phenomenon. Our experimental design is described in detail in the next section. Section 3 presents our results, and Section 4 concludes.

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<sup>2</sup> See, for example, Dufwenberg and Gneezy (2000) on the effect of number of firms, Feinberg and Sherman (1988) on the effect of repeated matchings, Sherman (1971) on the effect of capacity costs, and Huck, Normann and Oechssler (2000) on the effect of information about other's choices and earning. Engel (2007) contains a comprehensive list of experimental papers related to collusion.

## 2. *Experimental Design*

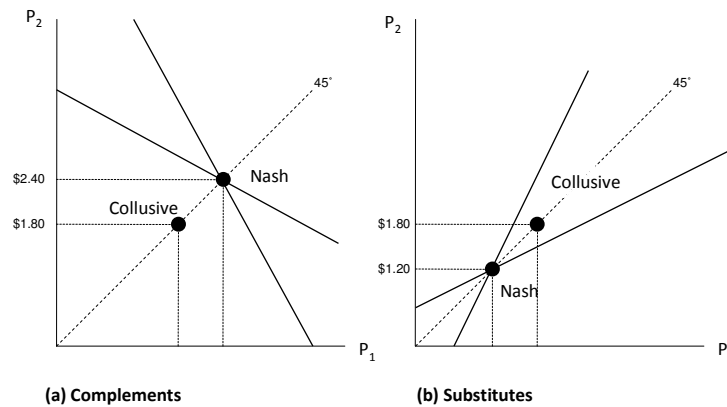
We recruited 128 subjects from undergraduate classes at the College of William and Mary. Subjects participated in a repeated duopoly price-setting game in either a complements treatment or a substitutes treatment.<sup>3</sup> The complements design is based on the following demand curve:  $Q_1 = 3.60 - 0.5P_1 - 0.5P_2$ , where  $Q_1$  represents the quantity sold by firm 1,  $P_1$  represents the price set by firm 1, and  $P_2$  represents the price set by firm 2. The Nash equilibrium price is \$2.40 in this treatment. The substitutes design is based on the following demand curve:  $Q_1 = 3.60 - 2P_1 + P_2$  and the Nash price is \$1.20. In both designs there is no marginal cost of production and a fixed cost of \$2.18 per round. With this fixed cost, earnings for colluding are fifty percent higher than earnings at the Nash equilibrium. Subjects earn \$0.70 per person at the Nash equilibrium and earn \$1.06 per person at the collusive outcome. Another important feature of this set of parameters is that the difference between the collusive price and Nash price is the same (60 cents) in both designs. In addition, the collusive price is the same for both designs and is \$1.80.<sup>4</sup> Figure 1 presents the best-response functions for the two treatments. Notice that the collusive (joint profit maximizing) price is below the Nash price in the complements case on the left side, and above the Nash price in the substitutes case, shown on the right.

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<sup>3</sup> Experiments were conducted using the Veconlab website developed by Charles Holt at the University of Virginia.

<sup>4</sup> Suetens and Potters (2007) report a “Friedman Index” to measure the sustainability of collusion. It is calculated as the collusive profit minus the Nash profit (the potential gain from colluding) divided by the maximum profit from a unilateral defection minus the collusive profit (the potential gain from defecting on a collusive agreement). The five studies they reviewed have indexes ranging from 0.32 to 1.00. The parameters in our experiment generate a Friedman Index of 0.88 in both treatments, which is higher than three of the five studies reviewed in Suetens and Potters (2007).

Figure 1: Best-Response Functions:  
Bertrand Differentiated Products

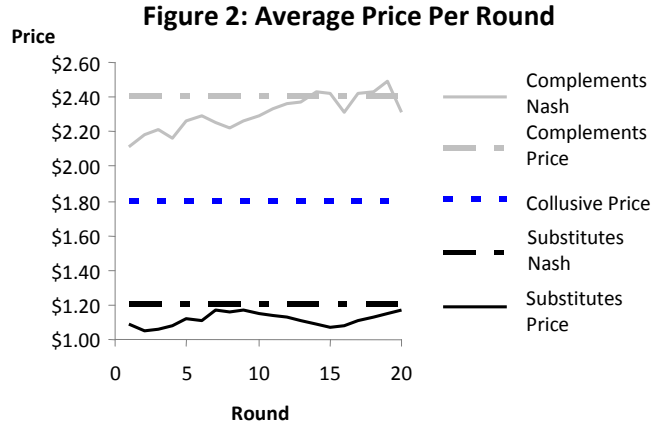


The Appendix contains instructions for the experiment. Subjects selected prices and pairs were able to go at their own pace. Half of the subjects in each treatment interacted for 10 rounds, and half interacted for 20 rounds, but they were not told the number of rounds in advance. Subjects were told that they were matched with the same person for each round. In addition, subjects were told the equation for demand and at the end of each round they were told the price charged by the other seller. Average earnings were \$6.42 in the sessions with 10 rounds and \$10.74 in the sessions with 20 rounds. Earnings also varied considerably based on the treatment, as described below.

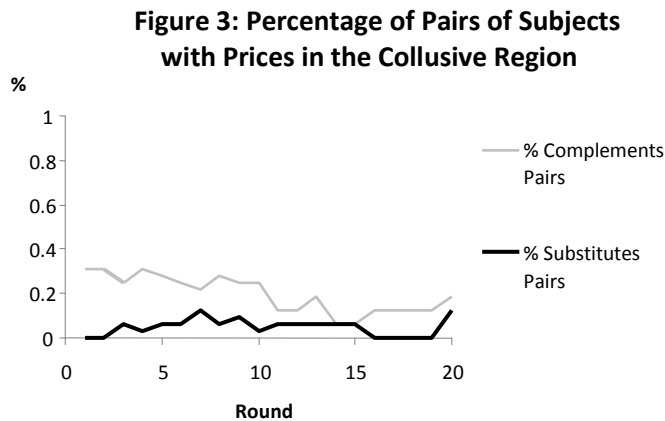
### 3. Results

Figure 2 shows the average price per round for both treatments. In the complements treatment, the average price starts slightly above the midpoint between the collusive price and the Nash price. The average price climbs closer to the Nash price with repetition and oscillates around the Nash price after 13 rounds of play. In the substitutes treatment, the average price rises and falls over time but is always below the Nash prediction. This difference in pricing

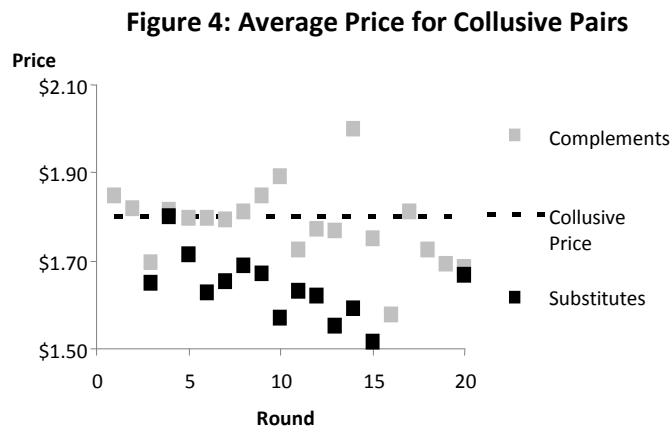
behavior resulted in significantly higher earnings for subjects in the complements treatment relative to the substitutes treatment (74 cents per round versus 44 cents per round, t-stat = 4.80).



Overall, Figure 2 shows that the average price in the complements treatment is closer to the collusive price than the average price in the substitutes treatment. It is possible, however, that subjects are under pricing relative to the Nash prediction in both treatments and this under pricing only appears to be cooperative behavior in the complements treatment because the collusive price is below the Nash price.



To further investigate the amount of collusion across the two treatments, we defined the “collusive region” as the range of prices within 30 cents of the collusive price.<sup>5</sup> Then we identified matched pairs of subjects who priced in this region. We focus on pairs of subjects rather than individuals who priced cooperatively because collusion in a duopoly setting is only relevant and more likely to be sustained when both players choose the cooperative outcome. Figure 3 shows the percentage of pairs in the collusive region by round and treatment. Overall, there are significantly more collusive pairs in the complements treatment than in the substitutes treatment (t-stat = 7.20).<sup>6</sup> Furthermore, within this collusive region subjects in the complements treatment price significantly closer to the collusive price than subjects in the substitutes treatment (t-stat = 5.15). Figure 4 shows average prices by round for the pairs of subjects who priced in the collusive range.



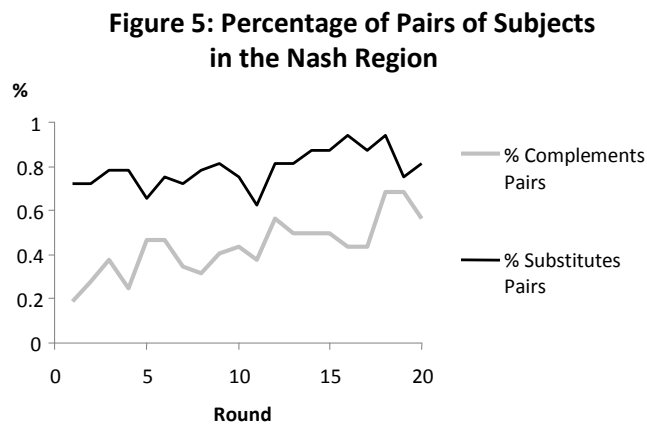
Turning our attention to competitive behavior, we defined the “Nash region” to be prices within 30 cents of the Nash price. Figure 5 shows that there are also significant differences in

<sup>5</sup> We chose 30 cents as the boundary of the collusive region because it is the midpoint between the collusive price and the Nash price. The general shapes and relative positions of the lines in Figure 3 do not change when we reduce the range of this region to be within 10 or 20 cents of the collusive price. Graphs using ranges other than 30 cents are available from the authors upon request.

<sup>6</sup> Note that in the substitutes treatment, there are six rounds with no pairs pricing in the collusive region (rounds 1 and 2 and 16-19). There is at least one pair that prices in the collusive region for all rounds of the complements treatment.



the proportion of pairs who priced in this region (t-stat = -12.84). Over 70% of pairs in the substitutes treatment priced in the Nash region in the first round of decision making compared to only 22% in the complements treatment. In every round more pairs priced in the Nash region for the substitutes than the complements treatment. Looking at average pricing behavior over all rounds, 79% of the pairs of subjects in the substitutes treatment priced in the Nash region while only 44% of the pairs in the complements treatment priced in the Nash region.<sup>7</sup>



As an additional check on how behavior differs across the two treatments, we calculated a standard measure of collusiveness for each duopoly pair:  $\rho = (P_{\text{actual}} - P_{\text{Nash}}) / (P_{\text{collude}} - P_{\text{Nash}})$ . Note that positive values of  $\rho$  indicate collusive behavior, zero indicates pricing at the Nash prediction, and negative values indicate supra-competitive pricing. On average, we found  $\rho = 0.24$  in the complements treatment and  $\rho = -0.13$  in the substitutes treatment. Using the average Friedman value for each subject pair as the unit of observation, these values are significantly different from each other at the 1 % level (t-stat = 4.51).

We next analyze the dynamics of individual price-setting behavior. To identify whether players mimic the price changes of their partners, we regress the change in each seller's price in

<sup>7</sup> Note that Figures 3 and 5 are limited to the *pairs* of subjects that price within the collusive or Nash region, respectively. Some pairs of subjects are not included in these graphs because either both subjects priced outside of the specified region, or one subject priced within the region while the other subject priced outside of the region.

round  $t$  on the other seller's change in price in round  $t-1$ .<sup>8</sup> The lag in the other's price is necessary because people do not observe others' prices until after the round has ended. Table 1 presents the results from estimating models of  $\Delta price_{it} = \beta_0 + \beta_1 \Delta price_{jt-1} + \varepsilon_{it}$ . All models cluster standard errors at the pair level. The models differ in whether we include individual fixed effects or individual random effects. In all models, the effect of the other player's change in price is positive and significant. These results suggest that a price change by one player is generally followed by a move in the *same* direction by the other player, regardless of treatment. Note that the coefficient on the other's lagged price is larger in the substitutes treatment than in the complements treatment. Potters and Suetens (2007) find similar results and suggest that reciprocal behavior in the substitutes treatment may be explained by the slope of the reaction functions. Specifically, with upward sloping reaction functions players should adjust prices in the same direction as a change by the other player. Conversely, in the complements treatment reciprocal behavior cannot be explained by the slope of the reaction functions. With downward sloping reaction functions, players should adjust prices in the opposite direction of a change by the other player.

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<sup>8</sup> In addition to the regressions presented here, we also analyzed individual price-setting behavior in the context of a learning direction theory (see Selten and Buchta, 1998 and Capra et. al, 1999 for more details about this model). For each pricing decision we calculated the individual's best response to the other person's price in the previous round. Then we categorized each price change according to whether it was a movement toward or away from the best response. In both treatments, the number of movements toward the best response was not significantly different from the number of movements away from the best response (p-value = 0.19 for complements and p-value = 0.61 for substitutes). A more complete version of these results is available from the authors upon request.

Table 1: Regression of Change in Individual's Price

Panel A: Complement Goods		
	<b>Model 1</b>	<b>Model 2</b>
Lagged Change in Other Seller's Price	0.0866*	0.0870*
Control for Individual	Fixed Effects	Random Effects
Panel B: Substitute Goods		
	<b>Model 1</b>	<b>Model 2</b>
Lagged Change in Other Seller's Price	0.1447***	0.1484***
Control for Individual	Fixed Effects	Random Effects

\*, \*\*, \*\*\* indicate significantly different from 0 at the 10%, 5% and 1% level.

### 3. Discussion

We compare collusive behavior in Bertrand duopoly experiments with substitute goods versus complementary goods. We find moderate tacit collusion with complementary goods but no systematic tacit collusion with substitute goods. These results combined with two recent related studies suggest that market structure is not the only determinant of collusive behavior in these experiments. Suetens and Potters (2007) compare measures of collusion in Bertrand and Cournot games from five separate experimental studies. All of the studies included Bertrand games and Cournot games and only modeled competition for substitute goods. Overall, Suetens and Potters (2007) report some evidence for tacit collusion in Bertrand markets, but no such evidence in Cournot markets. This difference in results might be explained by context (price choice versus quantity choice) or by demand structure (the Bertrand games had upward sloping reaction functions and the Cournot games had downward sloping reaction functions).

We can further explore this by comparing our results for Bertrand complements to the Cournot results that are reviewed in Suetens and Potters (2007). Mathematically, our Bertrand complements problem is identical to a Cournot substitutes game in the sense that reaction

functions are downward sloping and the competitive level of the choice variable is greater than the collusive level. All five of the Cournot studies report subjects choosing quantities that were higher than the Cournot Nash levels. In contrast, we find a moderate degree of collusion with a similar demand structure but with a price choice, rather than a quantity choice, problem. This suggests that context might be an important determinant of tacit collusion.

To further explore the effect of context, our results can be compared to the context-free experiments presented in Potters and Suetens (2007). They studied four experimental treatments that varied in terms of the slope of the reaction functions and the relative positions of the Nash prediction and the collusive solution in the strategy space. Two treatments had upward sloping reaction functions and two treatments had downward sloping reaction functions. Each of those pairs had a treatment with the Nash prediction above the collusive solution and a treatment with the Nash below the collusive outcome.

The subjects in Potters and Suetens (2007) were Dutch college students. They played in fixed pairs and were told there would be 30 rounds. Further, at the end of each round they were given all information about their opponent's choices and earnings. Unlike the previous work in this area, the experiment had no market context. Subjects did not choose prices or quantities; rather they picked a number between 0 and 28. The Nash choice was 14 (the midpoint) across all treatments, and the collusive choice was either 2.5 or 25.5 depending on the treatment. Potters and Suetens (2007) report subjects' choices are generally between the Nash prediction and the collusive outcome in all four treatments, regardless of whether the Nash is above or below the collusive outcome. They calculate the degree of collusiveness for all four treatments and conclude that the slope of the reaction function was an important determinant in the degree of

collusion, but behavior did not vary significantly depending on whether or not the collusive outcome was higher or lower than the Nash prediction.

The Potters and Suetens (2007) treatment with downward sloping reaction functions and the collusive choice lower than the Nash choice is comparable to our complements treatment. They report  $\rho = 0.24$  in this case, which is identical to our finding. Potters and Suetens (2007) find the highest degree of collusion ( $\rho = 0.42$ ) in their treatment with upward sloping reaction functions and the collusive choice greater than the Nash choice. We find very different results in our comparable (substitutes) treatment ( $\rho = -0.13$ ). It is possible that context about the choice problem tends to depress cooperative behavior when sellers view themselves as adversaries. This is consistent with research from ultimatum game experiments. Hoffman et al. (1994) found that offers were closer to the Nash prediction when the game was presented in a market context as opposed to a bargaining context.

In summary, we find no collusion in price-setting markets with substitute goods and a moderate amount of tacit collusion in price-setting markets with complements. In both treatments, prices move closer to the Nash prediction with repetition and, in general, prices are closer to the Nash than to the collusive price. Our results are in contrast to some previous studies and suggest that market context might affect behavior in important ways. Comparing our results to Potters and Suetens (2007), we provide context and find less cooperation in our experiments with substitute goods. An obvious direction for future research is to extend this study to include quantity-choice context with substitute and complement goods.

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Appendix A: Instructions for Complements Treatment  
(for referee use only, copied from vecon.econ.virginia.edu/admin.php)

Page 1

**Rounds and Matchings:** The experiment sets up markets that are open for a number of **rounds**. Note: You will be matched with the **same** person in all rounds.

**Interdependence:** The decisions that you and the other person make will determine your earnings.

**Price Decisions:** Both you and the other person are sellers in the same market, and you will begin by choosing a **price**. You cannot see the other's price while choosing yours, and vice versa.

**Sales Quantity:** A lower price will tend to increase your sales quantity, and a higher price charged by the other seller will tend to lower your sales quantity. This is because consumers use your product together with the other's product, so an increase in their price will reduce your sales.

Page 2

**Price and Sales Quantity:** Your price decision must be between (and including) **\$1.50** and **\$3.00**; use a decimal point to separate dollars from cents.

**Production Cost:** Your cost is **\$0.00** for each unit that you sell. However, you must pay a fixed cost of **\$2.18** for a license to operate, regardless of your sales quantity. So your total cost is \$2.18, regardless of how many or few units you produce.

**Consumer Demand:** The quantity that consumers purchase depends on all prices. Your sales quantity will be determined by your price (P) and by the other seller's price (A): **Sales Quantity = 3.60 - 0.50\*P - 0.50\*A**

Negative quantities are not allowed, so your sales quantity will be 0 if the formula yields a negative quantity.

**Sales Revenue:** Your sales revenue is calculated by multiplying your production quantity and the price. Since your sales are affected by the other's price, you will not know your sales revenue until market results are available at the end of the period.

Page 3

**Earnings:** Your profit or earnings for a round is the difference between your sales revenue and your production cost. If Q is the quantity you sell, then total revenue is (**Q\*price**), total cost is **\$0.00** + fixed cost of **2.18**, so earnings = Q\*(price) - \$2.18.

**Cumulative Earnings:** The program will keep track of your total (cumulative) earnings. Positive earnings in a round will be added, and negative earnings will be subtracted.

**Working Capital:** Each of you will be given an initial amount of money, **\$0.00**, so that gains will be added to this amount, and losses will be subtracted from it. This initial working capital will show up in your cumulative earnings at the start of round 1, and it will be the same for everyone. There will be no subsequent augmentation of this amount.

In the following examples, please use the mouse button to select the **best** answer. Remember, your sales quantity =  $3.60 - 0.50 * \text{Price} - 0.50 * (\text{Other Price})$

**Question 1:** Suppose that both sellers choose equal prices and that the total sales for both sellers combined is Q units, then each seller has a sales quantity of:

- a) 2Q
- b) Q/2.

**Question 2:** A higher price will increase both the price-cost margin and the chance of having a positive sales quantity.(True/False)

- a) True.
- b) False.

**Question 1:** Suppose that both sellers choose equal prices and that the total sales for both sellers combined is Q units, then each seller has a sales quantity of:

- (a) 2Q
- (b) Q/2

Your answer, (b) is **Correct**. The sales quantity formula divides sales equally when prices are equal.

**Question 2:** A higher price will increase both the price-cost margin and the chance of having a positive sales quantity.(True/False)

- (a) True.
- (b) **False**.

Your answer, (b) is **Correct**. The chances of making sales go down as price is increased.

**Matchings:** Please remember that you will be matched with the **same** person in all rounds.

**Earnings:** All people will begin a round by choosing a number or "price" between and including **\$1.50** and **\$3.00**. Remember, your sales quantity =  $3.60 - 0.50 * \text{Price} + -0.50 * (\text{Other Price})$  Your total cost is **\$0.00** times your sales quantity, plus your fixed cost **\$2.18**, and your total sales revenue is the price times your sales quantity. Your earnings are your total revenue minus your total cost. Positive earnings are added to your cumulative earnings, and losses are subtracted.

**Rounds:** There will be a number of rounds, and you are matched with the same person in all rounds.



Appendix B: Instructions for Substitutes Treatment  
(copied from Veconlab.Econ.Virginia.edu/admin.htm)

Page 1

**Rounds and Matchings:** The experiment sets up markets that are open for a number of **rounds**. Note: You will be matched with the **same** person in all rounds.

**Interdependence:** The decisions that you and the other person make will determine your earnings.

**Price Decisions:** Both you and the other person are sellers in the same market, and you will begin by choosing a **price**. You cannot see the other's price while choosing yours, and vice versa.

**Sales Quantity:** A lower price will tend to increase your sales quantity, and a higher price charged by the other seller will tend to raise your sales quantity. This is because consumers view the products as similar, so an increase in their price will increase your sales.

Page 2

**Price and Sales Quantity:** Your price decision must be between (and including) **\$0.60** and **\$2.10**; use a decimal point to separate dollars from cents. An increase in the other seller's price will tend to raise the number of units you sell.

**Production Cost:** Your cost is **\$0.00** for each unit that you sell. However, you must pay a fixed cost of **\$2.18** for a license to operate, regardless of your sales quantity. So your total cost is \$2.18, regardless of how many or few units you produce.

**Consumer Demand:** The quantity that consumers purchase depends on all prices, with more of the sales going to the seller with the lowest (best available) price in the market. Your sales quantity will be determined by your price (P) and by the other seller's price (A): **Sales Quantity =  $3.60 - 2.00 * P + 1.00 * A$** . Negative quantities are not allowed, so your sales quantity will be 0 if the formula yields a negative quantity.

**Sales Revenue:** Your sales revenue is calculated by multiplying your production quantity and the price. Since your sales are affected by the other's price, you will not know your sales revenue until market results are available at the end of the period.

Page 3

**Earnings:** Your profit or earnings for a round is the difference between your sales revenue and your production cost. If Q is the quantity you sell, then total revenue is ( **$Q * \text{price}$** ), total cost is **\$0.00** + fixed cost of **2.18**, so earnings =  $Q * (\text{price}) - \$2.18$ .

**Cumulative Earnings:** The program will keep track of your total (cumulative) earnings. Positive earnings in a round will be added, and negative earnings will be subtracted.

**Working Capital:** Each of you will be given an initial amount of money, **\$0.00**, so that gains will be added to this amount, and losses will be subtracted from it. This initial working capital will show up in

your cumulative earnings at the start of round 1, and it will be the same for everyone. There will be no subsequent augmentation of this amount.

Page 4

In the following examples, please use the mouse button to select the **best** answer. Remember, your sales quantity =  $3.60 - 2.00 * \text{Price} + 1.00 * (\text{Other Price})$

**Question 1:** Suppose that both sellers choose equal prices and that the total sales for both sellers combined is Q units, then each seller has a sales quantity of:

- a) 2Q
- b) Q/2.

**Question 2:** A higher price will increase both the price-cost margin and the chance of having a positive sales quantity.(True/False)

- a) True.
- b) False.

Page 5

**Question 1:** Suppose that both sellers choose equal prices and that the total sales for both sellers combined is Q units, then each seller has a sales quantity of:

- (a) 2Q
- (b) Q/2

Your answer, **(b)** is **Correct**. The sales quantity formula divides sales equally when prices are equal.

**Question 2:** A higher price will increase both the price-cost margin and the chance of having a positive sales quantity.(True/False)

- (a) True.
- (b) **False**.

Your answer, **(b)** is **Correct**. The chances of making sales go down as price is increased.

Page 6

**Matchings:** Please remember that you will be matched with the **same** person in all rounds.

**Price Choice:** All people will begin a round by choosing a number or "price" between and including **\$0.60** and **\$2.10**.

**Demand:** Remember, your sales quantity =  $3.60 - 2.00 * \text{Price} + 1.00 * (\text{Other Price})$ .

**Cost:** Your total cost is **\$0.00** times your sales quantity, plus your fixed cost **\$2.18**

**Earnings:** Your earnings are your total revenue (price times sales quantity) minus your total cost. Positive earnings are added to your cumulative earnings, and losses are subtracted.