Risk Aversion and Tacit Collusion in a Bertrand Duopoly Experiment

Lisa R. Anderson
College of William and Mary

Beth A. Freeborn
College of William and Mary

Jason P. Hulbert
College of William and Mary

College of William and Mary
Department of Economics
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Abstract

We investigate the relationship between collusive behavior in Bertrand oligopoly experiments and subject heterogeneity in risk preferences. We find that risk aversion is positively associated with tacit collusion when the goods are complements, but find no evidence of collusive behavior when the goods are substitutes. Furthermore, risk aversion is associated with lower prices with complement goods, but does not impact pricing behavior with substitute goods. In both treatments, we find that subjects tend to follow the price change of the other seller. In the complements treatment, however, this tendency increases with the degree of risk aversion.

JEL Codes: Bertrand duopoly, risk aversion, collusion, experiment

Keywords: C9, L1

Lisa R. Anderson
College of William and Mary
Department of Economics
Williamsburg, VA 23187
lisa.anderson@wm.edu

Beth A. Freeborn
College of William and Mary
Department of Economics
Williamsburg, VA 23187
bafree@wm.edu

Jason P. Hulbert
College of William and Mary
Department of Economics
Williamsburg, VA 23187
jphulb@wm.edu

1. Introduction

While early experimental research focused on identifying overall patterns of behavior, recent work has turned to studying the importance of subject pool heterogeneity on outcomes. In this paper, we study how a specific individual characteristic affects the degree of tacit collusion in Bertrand duopoly markets. Specifically we focus on heterogeneous risk preferences, since they are straightforward to measure with an experiment and have been shown to influence behavior in other experimental settings related to cooperative behavior.

In related work, Asplund (2002) analyzes the behavior of risk averse firms (relative to risk neutral firms) in a theoretical model of duopoly where strategies can be either complements or substitutes and that allows for either demand or cost uncertainty. Asplund's model is relevant to this paper in two regards. First, Asplund provides intuition on the role of risk aversion in firm behavior: a risk averse firm is willing to accept lower profits in 'good' high profit states in return for higher profits in 'bad' low profit states. Asplund (2002), Jellal and Wollf (2005), and Banal-Estañol and Ottaviani (2006) suggest a variety of reasons why firms might be risk averse, such as non-diversified owners, liquidity constraints, a risk-averse manager whose pay is linked to the firm's profits, etc. Asplund (2002) and Jellal and Wollf (2005) additionally refer to empirical literature on hedging behavior (Nance et al. 1993 and Geczy et al. 1997) as evidence that firms may behave as though they are risk averse. If risk averse firms behave differently than risk neutral firms, then risk aversion may also impact the tendency for firms to tacitly collude. Second, Asplund shows that the relationship between risk aversion and market outcomes depends on both the nature of competition (the sign of the slope of the reaction function) and the source of the uncertainty. Hence, if experiments differ in the games played or the source of uncertainty, it is likely that researchers may find different results vis-à-vis the relationship between risk aversion and outcomes.

One of the earliest studies to control for risk preferences in the analysis of experimental outcomes is Millner and Pratt (1991), which reports that more risk averse subjects spend less in rent seeking contests than their less risk averse counterparts. Both Levati, Morone and Fiore (2009) and Charness and Villeval (2007) report that more risk averse subjects contribute less to a public good than less risk averse subjects, while the latter also finds that risk averse subjects are more likely to opt for an absolute payment scheme over a tournament payment scheme in a real effort task. Closely related to our study of collusion in a price setting market, Sabater-Grande and Georgantzis (2002) investigate how subjects' attitudes towards risk affect both the outcomes and behavior patterns in a repeated prisoner's dilemma experiment. They find that risk aversion is negatively correlated with both the frequency of collusive outcomes and in some circumstances a subject's willingness to follow an opponent's move towards collusion. Although other researchers have investigated the relationship between risk aversion and cooperation or competition in other settings, to our knowledge risk preferences have not been explored as a contributing factor to collusion in a market setting. It is natural then to extend this line of research to market experiments since there is still not a clear consensus regarding what factors may facilitate tacit collusion.[1]

We specifically study a market experiment where subjects act as firms and choose price to maximize profit, as opposed to a prisoner's dilemma or public good experiment. Our market experiment is also different from most of the previous work in the source of uncertainty. Sabater-

[1] Engel (2007) summarizes results from 154 experimental papers on collusion in oligopoly covering 500 different experimental settings and notes that there are still many open questions concerning the interactive effects of design treatments on collusion.

Grande and Georgantzis (2002) and Levati, Morone and Fiore (2009) include uncertainty in the design of the experiment by either introducing a probability of (no) continuation of the experiment or implementing uncertainty in the payoffs. Sabater-Grande and Georgantzis (2002) note, however, that "risk aversion may be relevant simply because a player's opponent is a source of uncertainty" (p. 37). Charness and Villeval (2007) also refer to the subject's opponent as a source of uncertainty when explaining their finding that risk averse subjects contribute less to a public good: "…this makes sense since cooperating in [a public goods game] is taking the risk of being a sucker if the team comprises free riders" (p 24). In our Bertrand experiments, the primary source of uncertainty that a subject faces is in the actions of the other player.

We study Bertrand markets for both substitute and complement goods, allowing us to study the relationship between risk aversion and behavior with both upward and downward sloping reaction functions. One of the recently debated issues in the literature regarding tacit collusion is the relationship between the nature of the interaction of strategic variables (i.e., whether the reaction functions have positive or negative slopes) and the tendency to collude. The resolution of this debate has important implications regarding the relative efficiency of various market institutions, specifically that of Bertrand versus Cournot markets. One argument is that collusion is more likely in Bertrand markets where goods are substitutes since prices are strategic complements (i.e., reaction functions are upward sloping); in this case, even a purely self-interested player should respond to a move towards the collusive outcome by their opponent with a move in the same direction. Conversely, quantities are strategic substitutes (i.e., reaction functions are downward sloping) in Cournot markets, so a move in the direction of collusion by one player results in a move in the opposite direction by a self-interested player. Two recent papers present conflicting evidence on the effect of the nature of strategic interaction on collusion. Suetens and Potters (2007) review results from five separate papers and conclude that "Bertrand colludes more than Cournot." In contrast, Davis (2008) finds no more collusive behavior in Bertrand markets than in Cournot markets. Subject pool heterogeneity might contribute to this disparity in results.[2]

Given prior evidence that risk aversion is related to cooperative behavior in other contexts, our objective is to determine if risk aversion can help identify cooperative players in a market experiment. We use the Holt and Laury (2002) lottery choice instrument to construct a measure of risk preference. We focus on Bertrand markets with complement and substitute goods to control for any possible effect of market context (quantity choice versus price choice) on decisions.[3] We find that risk aversion is related to collusion in our Bertrand complements markets. However, unlike Sabater-Grande and Georgantzis (2002) and Levati, Morone and Fiore (2009), we find evidence that risk aversion is *positively* associated with cooperative behavior in the complements treatment. Section 2 below describes our experimental design, section 3 discusses results and section 4 concludes.

2. Experimental Design

We recruited 128 subjects from undergraduate classes at the College of William and Mary. Subjects first participated in a lottery choice experiment designed to elicit a measure of risk aversion (Holt and Laury, 2002). This exercise is regarded by many as the "gold standard"

[2] In fact, Potters and Suetens (2008) discuss the importance of cooperative individuals in determining aggregate results.

[3] Note that for the remainder of the paper we refer to goods from a consumption perspective rather than a production perspective. We use the term substitutes to refer to goods with a positive cross-price elasticity of demand that have upward sloping reactions functions in price. The term complements refers to goods with negative cross-price elasticity and downward sloping reaction functions.

in risk preference elicitation, partly because it is simple to use and very easy for subjects to understand. Further, Harrison et al. (2005) show that the Holt and Laury (2002) task elicits a measure of risk preference that is stable within subjects over time, and recent studies have validated the measure by showing that it is linked to real-world risky behaviors (e.g., Elston et al. 2005; Lusk and Coble 2005; Anderson and Mellor 2008).

The lottery choice experiment contains ten pairs of choices between a relatively safe lottery (with a payoff of $4.80 or $6.00) and a relatively risky lottery (with a payoff of $0.30 or $11.55) with different probabilities associated with the high and low payoffs for each of the choices.[4] The probabilities are structured such that the expected payoff of the safe lottery exceeds that of the risky lottery for the first four decisions while the risky lottery has a higher expected payoff for the last six choices. Hence, a risk neutral subject will choose the safe lottery in the first four decisions and the risky lottery in the last six. Holt and Laury (2002) provide additional details about how decisions in the lottery experiment are used to calculate a range of relative risk aversion for each subject.[5] In the analysis that follows, we use the midpoint of the range of the coefficient of relative risk aversion (hereafter, mid-CRRA) for each subject to capture risk tolerance, where higher midpoints represent higher levels of risk aversion. Table 1 shows a summary of results from the lottery choice experiment. Consistent with previous research, the majority of subjects fall into the risk averse range. The overall distribution of

[4] The decision sheet for the lottery choice experiment is presented in Appendix A. The average payoff for the lottery choice experiment was $6.65.

[5] The utility from an amount of money x is $U(x) = \frac{x^{1-r}}{1-r}$, where r is the coefficient of relative risk aversion. The point at which the subject switches from the relatively safe lottery to the relatively risky lottery can be used to establish a range on r for that subject. See Holt and Laury (2002) and Anderson and Mellor (2008).

subjects across risk categories is similar to that reported by Holt and Laury (2002) in their low real payoff treatment.[6]

Table 1: Distribution of Risk Aversion Parameter

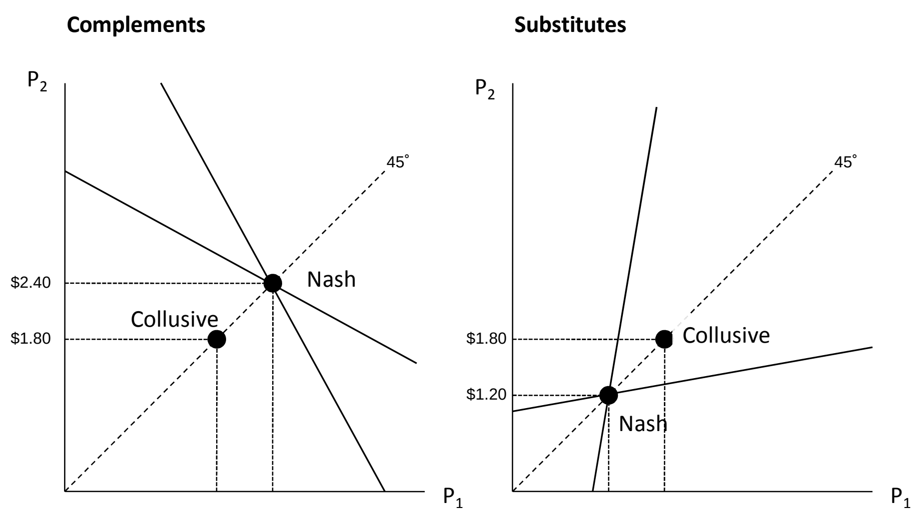
Range of Relative Risk Aversion	Risk Preference	Proportion of Choices
$r < -0.95$		0.00
$-0.95 < r < -0.49$	Risk Loving Range	0.01
$-0.49 < r < -0.15$		0.06
$-0.15 < r < 0.15$	Risk Neutral Range	0.19
$0.15 < r < 0.41$		0.16
$0.41 < r < 0.68$		0.27
$0.68 < r < 0.97$	Risk Averse Range	0.21
$0.97 < r < 1.37$		0.07
$1.37 < r$		0.02

Subjects were then randomly assigned to a partner and participated in a repeated duopoly price-setting game in either a complements treatment or a substitutes treatment.[7] In both designs there is no marginal cost of production and a fixed cost of \$2.18 per round. The complements design is based on the following demand curve: $Q_i = 3.60 - 0.5P_i - 0.5P_j$, where Q_i represents the quantity sold by firm i, P_i represents the price set by firm i, and P_j represents the price set by firm j. The symmetric Nash equilibrium price is \$2.40 in this treatment. The substitutes design is based on the demand curve $Q_i = 3.60 - 2P_i + P_j$ resulting in a symmetric Nash equilibrium price of \$1.20. The collusive price is the same for both designs and is \$1.80. An 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 both treatments, subjects earn \$0.70 per person at the Nash equilibrium and earn \$1.06 per person at the collusive outcome, which represents a fifty percent earnings premium for colluding. Figure 1 presents the best-response functions for the

[6] Holt and Laury (2002) report that, in their low payoff treatment, 8%, 26% and 66% of their subjects are risk loving, risk neutral, and risk averse, respectively.
[7] Experiments were conducted using the Veconlab website developed by Charles Holt at the University of Virginia.

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.

Figure 1: Best-Response Functions
Bertrand Differentiated Products



The Appendix contains the detailed instructions for the Bertrand experiment. Half of the pairs in each treatment interacted for 10 rounds, and half interacted for 20 rounds. To avoid end game effects, subjects were not told the number of rounds in advance. Subjects were told that they would be matched with the same person for each round. In addition, subjects were told the equation for demand and it was common knowledge that all subjects within a session faced the same demand curve and costs. Finally, at the end of each round subjects were told the price charged by the other seller.[8] Average earnings were $6.42 in the sessions with 10 rounds and $10.74 in the sessions with 20 rounds.

[8] Full information about rival's decisions, the small number of sellers (2) and passive buyers are elements of the experiment designed to elicit collusive behavior in the absence of discounting. For more, see Feinberg and Husted (1993).

3. Results

We first describe the distribution of risk preferences amongst the subjects who played the two treatments. Subjects were randomly assigned to a treatment (substitutes or complements) and the mid-CRRA for each subject was elicited prior to the Bertrand experiment. The average mid-CRRA is equal to 0.4755 for the 63 subjects in the substitutes treatment and 0.4190 for the 61 subjects in the complements treatment.[9] A Wilcoxon rank-sum test fails to reject the null hypothesis that the distribution of mid-CRRA is the same across the two treatments (z-stat -1.070, p-value 0.2845). To compare behavior across risk categories we begin by categorizing subjects as risk averse if their mid-CRRA is greater than 0.15 and non-risk averse otherwise. The proportion of subjects who are not risk averse is not significantly different across substitutes and complements.[10]

Anderson, Freeborn and Holt (2009) report large differences in collusive behavior between the complements and substitutes treatments, so all of the following analyses are done separately for the two treatments. To first analyze collusive behavior, we employ a standard measure of the degree of collusiveness: $\rho = (\text{Price}_{\text{actual}} - \text{Price}_{\text{Nash}}) / (\text{Price}_{\text{collude}} - \text{Price}_{\text{Nash}})$. We calculate the average ρ for each player over all rounds. Note that positive values of ρ indicate collusive behavior, a value of zero indicates pricing at the Nash prediction, and negative values indicate supra-competitive pricing. Additionally, ρ can be used to compare the degree of collusive behavior across the two treatments, even though they differ in the location of the collusive price relative to the Nash (i.e. collusion implies lower prices in the complements game

[9] Three subjects are omitted from this analysis due to a missing value for mid-CRRA (missing values are generated when subjects make an irrational decision in the lottery choice experiment by choosing a certain low payoff over a certain high payoff). One subject participated in the Bertrand experiment but did not participate in the lottery choice experiment. This results in a total of 124 observations.
[10] The proportion non-risk averse for substitutes is 0.2698 and for complements is 0.2623. Using a Wilcoxon rank-sum test, the z-statistic is -0.095 and the p-value is 0.9246.

and higher prices in the substitutes game). Averaging over subjects and rounds, Anderson, Freeborn and Holt (2009) find the degree of collusiveness is 0.24 in the complements treatment and -0.13 in the substitutes treatment. These values are significantly different from each other at the 1% level.[11]

Given this evidence of collusive pricing in the complements game ($\rho > 0$) and supra-competitive pricing in the substitutes game ($\rho < 0$)[12], our objective is to investigate the relationship between risk aversion and collusive behavior, or lack thereof, in the two treatments. We begin by examining differences in behavior across the two subject groups, risk averse and non-risk averse. In the substitutes treatment, the average degree of collusiveness amongst risk averse players is -0.1395, which is significantly different than zero. For non-risk averse players the average degree of collusiveness is -0.1112, which is not significantly different from zero, likely due to the small sample size.[13] Furthermore, the values of ρ for risk averse and non-risk averse subjects are not significantly different from one another. For the complements treatment, the average degree of collusiveness amongst risk averse players is 0.2917; for non-risk averse players the average degree of collusiveness is 0.0905. As was the case in the substitutes treatment, the average values of ρ for the complements treatment are significantly different from zero for risk averse subjects, not significantly different from zero for non-risk averse subjects, and not significantly different from each other.[14] The small sample size of non-risk averse subjects in both treatments (17 or 16 observations) may contribute to a lack of significance in

[11] The unit of observation for this t-test is the average ρ for each subject with n = 124, t-stat = -5.2062, p-value = 0.0000.
[12] See Anderson, Freeborn and Holt (2009) for a more extensive comparison of collusive behavior across the substitutes and complements treatments.
[13] To test for significance, we use a t-test where the unit of observation is the subject's average ρ in the substitutes treatment. For risk averse players, n = 46, t-stat = -3.4458, p-value =0.0012 and for non-risk averse players n =17, t-stat = -1.0948, p-value = 0.2898.
[14] For risk averse players, n = 45, t-stat = 4.1919, p-value =0.0001 and for non-risk averse players n =16, t-stat = 0.8226, p-value = 0.4236.

player-level comparisons of collusive behavior across the two risk categories. However, the t-test results for risk-averse players are significant and imply that risk averse players price supra-competitively in the substitutes treatment and are moderately collusive in the complements treatment.

We next regress our collusiveness measure ρ on the subject's mid-CRRA. This approach allows for the use of a more precise measure of a subject's attitude towards risk than the dichotomous distinction between risk averse/non-risk averse subjects employed above. We run separate regressions for each treatment, controlling for unobserved subject heterogeneity using random effects and clustering standard errors at the pair level. In the substitutes treatment, the estimated coefficient on mid-CRRA is not significant. Although subjects in the substitutes treatment price supra-competitively, there is no association between this below-Nash pricing and risk aversion. In the complements treatment, however, the estimated coefficient on mid-CRRA is 0.2999 and is significant at the 5% significance level (p-value 0.017); higher levels of risk aversion are associated with *more* collusive behavior.

Table 2: Degree of Collusiveness (ρ) Regressions

	Substitutes	**Complements**
Mid-CRRA	-0.0486 (0.0892)	0.2999** (0.1257)
Constant	-0.1097 (0.0791)	0.1067 (0.0794)
Number of Observations	950	930

Notes: *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust standard errors are in parentheses.

These results suggest that the effect of a subject's risk aversion on their tendency to collude varies by complements or substitutes. However, an alternative explanation consistent with these results is that more risk averse subjects are more likely to price below the Nash price. Recall from the relative positions of the collusive and Nash outcomes in Figure 1 that a tendency for risk averse players to price below the Nash would be consistent with both the negative relationship between a player's risk aversion and collusive behavior in the substitutes treatment and the positive relationship between the two in the complements treatment. To address this possibility, we next focus on the relationship between risk aversion and prices.

The average price in the substitutes game was $1.11 amongst risk averse subjects and $1.14 amongst non-risk averse subjects. Both of these averages are significantly different from the Nash price of $1.20.[15] However, these average prices were not significantly different between the two risk categories (t-stat = -1.3422). In the complements treatment, average prices were $2.25 and $2.37 amongst risk averse and non-risk averse subjects, respectively. The average price was significantly different from the Nash price of $2.40 amongst the risk-averse subjects but not the non-risk averse subjects; they were, however, significantly different from each other (t-stat = -3.3219).[16]

We also use a subject's price relative to their Nash best response to identify collusive behavior. Although a subject does not know the price of the other seller when choosing their own price, they do know the price their opponent selected in the previous period. For each subject we calculate the Nash best response to the partner's price in the previous round and compare it to the price actually chosen. We define this measure as the "deviation from best response." In the substitutes treatment, if a subject prices higher than the best response price in any given round, resulting in a positive deviation, that price choice can be classified as

[15] For risk averse players, n = 46, t-stat = -8.4643, p-value =0.0000 and for non-risk averse players n =17, t-stat = -2.8449, p-value = 0.0048.
[16] For risk averse players, n = 45, t-stat = -8.4360, p-value =0.0000 and for non-risk averse players n =16, t-stat = -1.0592, p-value = 0.2906.

"cooperation-inducing." Alternatively, if a subject prices lower than the best response price in the complements treatment, the deviation is negative and can be classified as cooperation-inducing.

The average deviations from best response price are -0.0604 and -0.1642 in the substitutes and complements treatments, respectively.[17] Within the substitutes treatment, the average price deviation amongst risk averse players was -0.0640 (t-stat = -5.9919); amongst non-risk averse players the average price deviation was -0.0504 (t-stat = -2.5371). The average deviation from best response price is not significantly different across risk averse and non-risk averse subjects in the substitutes treatment (t-stat = -0.6040). In the complements treatment, the average price deviation amongst risk averse and non-risk averse subjects was -0.1944 (t-stat = -8.8745) and -0.0772 (t-stat = -2.0495), respectively. Unlike the substitutes treatment, the average deviation from best response price is significantly different across risk categories for the complements treatment (t stat = -2.6897). Compared to non-risk averse subjects, risk averse subjects in the complements treatment choose prices significantly lower than the optimal price given their opponents' decisions in the previous round.

To further investigate the relationship between risk aversion and pricing, we report two specifications of price regressions for each of the treatments in Table 3. Both specifications control for unobserved individual heterogeneity using random effects and cluster standard errors at the pair level.[18] The independent variable is mid-CRRA, which provides a finer measure of risk aversion than the previous analysis comparing risk averse subjects to non-risk averse subjects. Within each treatment, the first column reports the results from a regression of price on

[17] For both treatments, the average deviation from best response price is significantly negative; for substitutes the t-stat is -6.3990 and for complements the t-stat is -8.6387. Consistent with the result above, this is evidence of collusive pricing in the complements game and of supra-competitive pricing in the substitutes game.
[18] In all specifications, we also include round as a control variable.

mid-CRRA. The second column reports results from a regression of the deviation from best response price on mid-CRRA.

Table 3: Price Regressions

	Substitutes		Complements	
Dependent Variable	Price	Deviation from Best Response	Price	Deviation from Best Response
Mid-CRRA	-0.0292 (0.0535)	-0.0274 (0.0502)	-0.1800** (0.0754)	-0.2293** (0.1090)
Constant	1.1342*** (0.0474)	-0.0414 (0.0405)	2.3360*** (0.0477)	-0.1008 (0.0695)
Number of Observations	950	887	930	869

Notes: *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust standard errors are in parentheses.

In the substitutes treatment, the estimated coefficient on mid-CRRA is not significant in either the price regression or the deviation from best response regression, implying that risk preference does not impact price choice for substitutes goods. In the complements treatment, the estimated coefficient in the price regression on mid-CRRA is negative and statistically significant, suggesting that risk averse players generally choose lower prices when goods are complements. In the deviation from best response regression, the estimated coefficient on mid-CRRA is also negative and significant. Subjects who are more risk averse tend to choose prices lower than the best response price given the previous choice of their opponent. Recall that a negative deviation from best response in the complements game is consistent with cooperation-inducing behavior.

Finally, we look at the dynamics of the subjects' actions; specifically, we examine how a subject's response to a price change made by their opponent is affected by the subject's risk aversion. The dependent variable is the change in the subject's price in round *t* from round *t-1*. The independent variables include the other seller's change in price between rounds *t-1* and *t-2* and the subject's mid-CRRA. Table 4 presents the results. All models cluster standard errors at the pair level. The second column of each treatment includes an interaction term of the mid-CRRA and the change in other seller's price.

In the models excluding the interaction term, the estimated coefficient on competitor's lagged price change is positive and significant in both the substitutes and complements treatments, which is consistent with the results of Potters and Suetens (2008). Subjects tend to respond to a change in the other players price with a change in the same direction, regardless of whether reaction functions are upward or downward sloping. Potters and Suetens (2008) describe this result as endogenous strategic complementarity explained by the presence of reciprocal players.

Table 4: Change in Price Regressions

	Substitutes		**Complements**	
Lagged Change in Other Seller's Price	0.1508*** (0.0401)	0.1040* (0.0579)	0.0948* (0.0469)	-0.0028 (0.0831)
Mid-CRRA	0.0029 (0.0068)	0.0017 (0.0066)	0.0102 (0.0139)	0.0079 (0.0146)
Interaction of Mid-CRRA and Lagged Change in Other Seller's Price		0.0924 (0.0729)		0.2328* (0.1217)
Constant	0.0054 (0.0056)	0.0061 (0.0056)	-0.0006 (0.0097)	0.0003 (0.0103)
Number of Observations	824	824	808	808

Notes:*, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. Robust standard errors are in parentheses.

In the models where the interaction term is included, the estimated coefficient is not significant in the substitutes treatment, implying that risk aversion does not affect how a player responds to her partner's price change in the previous round. In the complements treatment, the coefficient on the interaction term is positive and significantly different from zero. Risk averse players in the complements treatment tend to respond more to a change in the other seller's price than less risk averse subjects. Thus, if one player makes a cooperative-inducing move, a more risk averse partner follows that move to a greater extent, bringing the market closer to a collusive outcome.

4. Discussion and Conclusion

We investigate the relationship between a subjects' risk aversion and the tendency towards tacit collusion in Bertrand duopoly markets. In light of the results of Potters and Suetens (2008), Anderson, Freeborn and Holt (2009) and Davis (2009), we are careful to address how this relationship may depend on the nature of the interaction of the strategic variables (*i.e.*, the sign of the slope of the reaction function). There is very little evidence overall of collusive behavior in the substitutes treatment. In fact, subjects appear to price supra-competitively when goods are substitutes. The degree of competitive pricing behavior in the substitutes treatment is not significantly associated with risk preferences. Within the complements treatment, however, we find evidence that risk aversion is positively correlated with more collusive pricing.

Our result that more risk aversion leads to more cooperative behavior in the complements treatment is in contrast to the findings of Sabater-Grande and Georgantzis (2002), Levati, Morone and Fiore (2009), and Charness and Villeval (2007). Additionally, we find that risk aversion is positively correlated with a subject's responsiveness to her opponent's actions; risk averse players in the complements treatment are more likely to follow their partner's move to collusion. Thus, the endogenous strategic complementarity identified by Potters and Suetens (2008) is affected by a subject's risk aversion.

While Sabater-Grande and Georgantzis (2002) and Levati, Morone and Fiore (2009) find less cooperative behavior with risk averse subjects in prisoner's dilemma and public goods games, their experiments incorporate uncertainty in the design structure. In our experimental design, uncertainty is limited to the behavior of the other player. Given the differences in the source of uncertainty and the fact that we study Bertrand duopoly, it is not unexpected that we find a different relationship between risk aversion and cooperative behavior, particularly in light of Asplund's (2002) result that the effect of risk aversion on duopoly outcomes depends on the nature of competition and the source of uncertainty.

The intuition behind Asplund's (2002) model is helpful in explaining our results. The key intuition is that risk averse firms place more weight on profits in 'bad' states than on profits in 'good' states. In our experiment, the major source of uncertainty is the actions of one's opponent; a subject is uncertain if a move towards collusion will be matched by her opponent or taken advantage of, or whether a defection from collusion will be punished or forgiven. Given the parameters of our experiment, if a player moves away from the collusive outcome and the opponent punishes the player by playing the best response price, profits decrease more in the complements case than in the substitutes case.

For example, assume a player in the substitutes treatment moves half-way towards the Nash from the collusive price (a move to a price of $1.50 from a price of $1.80). If the other player punishes the defector by choosing her best response price of $1.275, the defector's profits decrease by $0.4275. Alternatively, in the complements treatment if the defector moves half-way towards the Nash from the collusive price by choosing a price of $2.10 and the other player punishes with a best response price of $2.55, the defector's profits decrease by $0.5625. Even if the other player continues to play the collusive price, moving half-way towards the Nash price only increases profits by \$0.225 for the complements treatment, which is less than the \$0.36 increase in profits for the substitutes case. If the fear of punishment outweighs the gains to cheating more for risk averse subjects and punishment is more severe in our complements treatment, then more risk averse subjects might be more willing to collude (or less likely to defect) in the complements case than in the substitutes case.

We also address the possibility that risk aversion is associated with price; subjects in both treatments appear to be pricing below the Nash price. Our measure of risk aversion, however, has a significantly negative effect on price only in the complements treatment. Sellers of complementary goods may view the other seller as more of a partner than a rival, fostering a cooperative environment and risk averse players may be less likely to deviate from this collusive environment. We find that the response of one player to the other seller's change in price is positive and increasing in the degree of risk aversion in the complements treatment. However, a subject's risk aversion does not affect her response to a competitor's change in price in the substitutes treatment. Overall, our results suggest that the effect of risk aversion on the degree of tacit collusion is dependent on the nature of the strategic variables, and that risk aversion is positively associated with collusive behavior when the goods are complements. Given that risk aversion is negatively associated with price in the case of downward sloping reaction functions (complement goods), one potential direction for future research is to investigate the relationship between risk aversion and collusive behavior in a quantity choice model with both downward and upward sloping reaction functions.

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Appendix A: Decision Sheet for Lottery Choice Experiment

Decision	Option A	Option B	Your Decision Circle One
1	$6.00 if the die is 1 $4.80 if the die is 2-10	$11.55 if the die is 1 $0.30 if the die is 2-10	**A** or **B**
2	$6.00 if the die is 1 -2 $4.80 if the die is 3-10	$11.55 if the die is 1-2 $0.30 if the die is 3-10	**A** or **B**
3	$6.00 if the die is 1-3 $4.80 if the die is 4-10	$11.55 if the die is 1-3 $0.30 if the die is 4-10	**A** or **B**
4	$6.00 if the die is 1-4 $4.80 if the die is 5-10	$11.55 if the die is 1-4 $0.30 if the die is 5-10	**A** or **B**
5	$6.00 if the die is 1-5 $4.80 if the die is 6-10	$11.55 if the die is 1-5 $0.30 if the die is 6-10	**A** or **B**
6	$6.00 if the die is 1-6 $4.80 if the die is 7-10	$11.55 if the die is 1-6 $0.30 if the die is 7-10	**A** or **B**
7	$6.00 if the die is 1-7 $4.80 if the die is 8-10	$11.55 if the die is 1-7 $0.30 if the die is 8-10	**A** or **B**
8	$6.00 if the die is 1-8 $4.80 if the die is 9-10	$11.55 if the die is 1-8 $0.30 if the die is 9-10	**A** or **B**
9	$6.00 if the die is 1-9 $4.80 if the die is 10	$11.55 if the die is 1-9 $0.30 if the die is 10	**A** or **B**
10	$6.00 if the die is 1-10	$11.55 if the die is 1-10	**A** or **B**

Appendix B: 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.

Page 4

In the following examples, please use the mouse button to select the **best** answer. Remember, your sales quantity = **3.60 - 0.50*Price -0.50*(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
- [x] **(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.
- [x] **(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.

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*Price + -0.50*(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 C: 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*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.

Page 4

In the following examples, please use the mouse button to select the **best** answer. Remember, your sales quantity = **3.60 - 2.00*Price + 1.00*(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*Price + 1.00*(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.