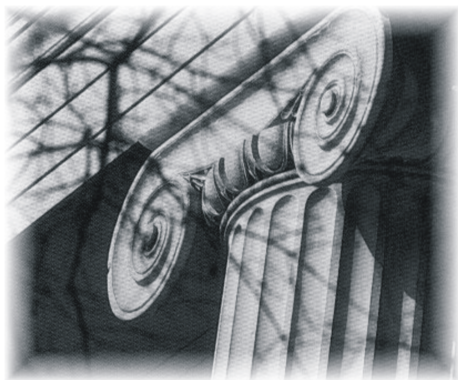
THE UNIVERSITY OF ALABAMA

ECONOMICS, FINANCE AND LEGAL STUDIES

WORKING PAPER SERIES



Working Paper No. 11-05-01

Tacit Collusion in Price Setting Oligopoly: A Puzzle Redux

Matthew J. Van Essen
William B. Hankins

Tacit Collusion in Price Setting Oligopoly: A Puzzle Redux

Matt Van Essen* William B. Hankins

May 26, 2011

Abstract

We study tacit collusion in price setting duopoly games with strategic complements and substitutes. A recent paper by Anderson, Freeborn, and Holt (2010) finds that pricing games with strategic substitutes tend to foster more tacit collusion when compared to games with strategic complements. This finding is in contrast with previous studies and seems to be driven by a failure of their study to control for strategic incentives across treatments (via the absolute slope of the firms' reaction functions). We correct this issue and find no significant differences in tacit collusion between treatments where firms have reaction functions with the same absolute slope. In addition, we find the Nash equilibrium analyzed to be a good predictor of aggregate behavior in all six treatments as well as support for the claim that tacit collusion diminishes as the slope of firms' reaction functions get closer to zero.

1 Introduction

This paper concerns the determinants of tacit collusion in duopoly markets. While factors such as group size and communication are well known ingredients for cooperation, a growing body of experimental evidence suggests

*Department of Economics, Finance, and Legal Studies; University of Alabama; mjvanessen@cba.ua.edu.

tacit collusion is also fostered in games with strategic complements (as opposed to strategic substitutes).[1] There is little theoretical work to support this empirical regularity. However, the robustness of these observations has generated several recent studies. Suetens and Potters (2007) survey results from several Bertrand and Cournot experiments and find that subjects in price setting experiments are more likely to collude than subjects in quantity setting experiments.[2] In a related study, Potters and Suetens (2009) eliminate the market framing and conduct a well controlled experiment with games of strategic substitutes and strategic complements. Consistent with their survey, they find more evidence of collusion in their treatments with strategic complements. Recently, a tension in the literature has arisen which questions the robustness of this claim. Anderson, Freeborn, and Holt (2010), hereafter AFH, look at two Bertrand pricing games, one with strategic substitutes and the other with strategic complements.[3] They find significantly more tacit collusion in the substitutes case and credit this difference in their results to a *framing effect* – i.e., their experiment was framed as an oligopoly setting as opposed to a neutral framing like Potters and Suetens (2009). This conclusion, however, is not justified from their experimental design.

AFH have two treatments: a pricing game with strategic complements and a pricing game with strategic substitutes. However, more is being changed between these treatments than just the strategic relationship of the two firms. AFH also change how *responsive* firms are to a change in their rival's action. In other words, they are also changing the absolute value of the slope of the reaction functions for the firms in their two treatments.[4] This difference in slope value affects the theoretical speed of convergence. Moreover, this difference might have played an important factor in the observed data. To illustrate consider the following comparison. In AFH's strategic comple-

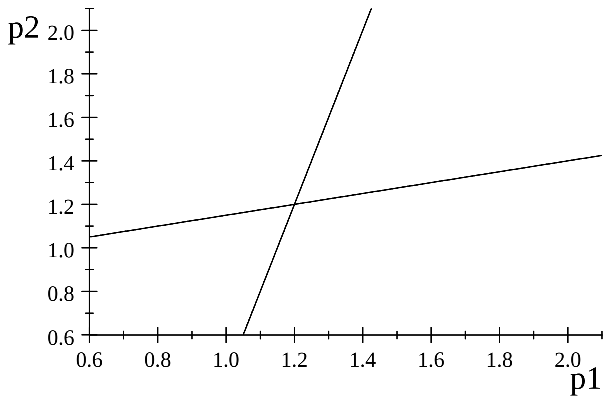
[1]A game is one of strategic complements (substitutes) if each player's best response function is increasing (decreasing) in the actions of his rivals. See, for example, Bülow, Geanakoplos, and Klemperer (1985).

[2]Their study is motivated by observations made by Holt (1995) who observes price setting oligopoly experiments tend to exhibit more collusion than quantity setting oligopoly experiments.

[3]AFH's "substitutes" treatment refers to the type of goods that the two firms sell not the strategic relationship (which is one of strategic complements). Similarly, their "complement" goods treatment is a game with strategic substitutes. We only refer to the treatements by the strategic relationship induced.

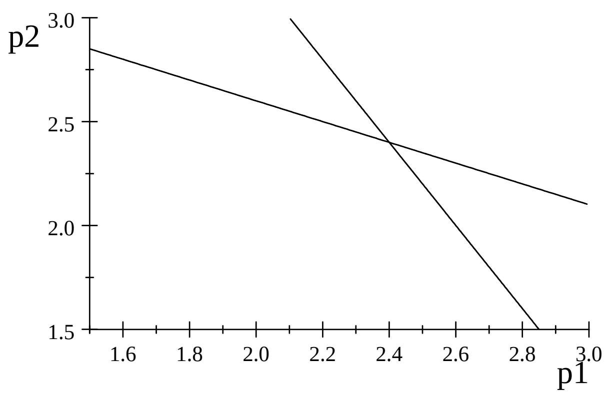
[4]The slope of a reaction function is how much a firm's optimal response should change when the other firm increase their price by a marginal amount.

ments treatment the slope of each player's reaction function was $\frac{1}{4}$. This is illustrated below using the parameters from their experiment.[5]



Reaction Curves: AFH Strategic Complements Treatment (Slope $=\frac{1}{4}$)

So, if a firm is best responding, a 4 unit increase in the price of the other firm should lead to a *one* unit increase in own price. In AFH's pricing game with strategic substitutes the slope of each player's best response function was $-\frac{1}{2}$. Again the best responses are illustrated below.[6]



Reaction Curves: AFH Strategic Substitute Treatment (Slope $= -\frac{1}{2}$)

Now, if a firm is best responding, a 4 unit increase in rival's price leads to a *two* unit decrease in own price. Clearly, the firms' best responses are

[5] The boundaries of the graph is the exact price space used in AFH: 0.6 to 2.10.
[6] The bounds for the strategy space are 1.5 to 3.

more responsive in the strategic substitute treatment. It is therefore unclear whether the differences in their treatments are due to the changes in strategic environment (i.e., complements or substitutes), the change in strategic sensitivity of the firms (i.e., differences in slope magnitudes of the best reply), the framing, all of the above, or none of the above.

This paper eliminates the ambiguity in the AFH study and examines the role of the strategic setting on tacit collusion in a number treatments. We replicate the market framing of AFH for price setting oligopoly, but control for the absolute slope magnitude of the reaction functions. The market framing is important as it helps to remove "social norms" of cooperation and allows us to focus on more strategic topics.[7] In addition, we systematically adjust the absolute slopes of the reaction functions in the two strategic settings to investigate the ease of tacit collusion under a variety of different incentive environments. Our design uses six separate treatments to tease out the different effects. In particular, we index our treatments by the type of strategic relationship between the firms; and the absolute slope magnitude of each firm's reaction function. We look at three different absolute slopes: $\frac{1}{4}$, $\frac{1}{3}$, and $\frac{1}{2}$. Thus, our experiment has three pricing games with strategic complements where the firms' reaction functions have constant slopes $\frac{1}{4}$, $\frac{1}{3}$, and $\frac{1}{2}$; and three pricing games with strategic substitutes where the firms' reaction functions have constant slopes $-\frac{1}{4}$, $-\frac{1}{3}$, and $-\frac{1}{2}$.

We posit that the differences between the complements and substitutes treatments reported by AFH to Potters and Suetens (2009) can be explained by the failure of the AFH design to control for the absolute slope *magnitude* of the firms' reaction functions. Additionally, our design is well poised to make inferences about changes in subjects' behavior when the slopes of the reaction functions get closer to zero (i.e., $\frac{1}{2} \to \frac{1}{3} \to \frac{1}{4}$). Zero is an interesting theoretical benchmark since if all players have reaction functions with a zero slope, then the players all have dominant strategy. We expect tacit collusion to be more difficult the closer players get to having a dominant strategy. Thus, if we compare treatments with strategic complements, games with "flatter" reaction functions should exhibit less tacit collusion – since there are stronger profit incentives for firms to deviate from a collusive agreement.

This hypothesis also has empirical precedent. For instance, Cox and

[7] For instance, Engel (2007) provides an analysis/ categorization of a large number of oligopoly experiments. It is mentioned that neutral framed experiments exhibit more collusion than market framed experiments.

Walker (1998) look at two Cournot quantity setting games and purposely manipulate the slope of the reaction equations. Their first game yields standard downward sloping reaction equations (with slope $-\frac{1}{2}$). The second game yields reaction equations with slopes less than -1.[8] They find behavior quickly converges to the Nash equilibrium in the normal case, but is scattered in the second case. Other examples can be found in the experimental mechanism design literature. For instance, Chen and Gazzale (2004) choose mechanism parameters to manipulate the gradient of players' best replies for Varian's compensation mechanism. They find performance along the threshold of supermodularity and submodularity is superior to mechanisms induced with parameters far from this threshold. This result is consistent with the notion that flatter reaction functions yield faster convergence to equilibrium. Similarly, Van Essen (2010) compares two Nash efficient Lindahl mechanisms and finds that parameter conditions where players *almost* have a dominant strategy tend to perform better than other treatments for both mechanisms.

The rest of the paper proceeds as follows: in section 2 we describe our experimental design; section 3 describes the experimental procedures; in section 4 we present our results; and section 5 concludes.

2 Experimental Design

Following AFH, we control for potential "action" framing effects by restricting attention to duopoly models where each of the two firms choose a price (as opposed to a quantity). The duopoly pricing game is defined as follows: firm i and firm j interact with one another through their choice of prices p_i, $p_j \in [\underline{p}, \bar{p}]$. These prices jointly determine the quantity demanded from each firm (via the firm's demand) and consequently their profit. The demand function for each firm i is of the form $Q_i(p_i, p_j) = \max\{0, a - bp_i - dp_j\}$, where $a > 0$, $b > 0$, and d are parameters. Firm i's profit function is $\pi_i(p_i, p_j) = Q_i(p_i, p_j)p_i - F$, where F is a fixed cost. There is no marginal cost of production.

The parameters a, b, d, and F were varied in the experiment to create 6 different strategic environments. These parameters, along with the equilibrium values for the experiment are listed in the table below. Each column of the table refers to a treatment. For each treatment, the rows of the table

[8] This game has three equilibria. The one in the interior is unstable. The two boundary equilibria are stable.

list the treatment parameters (a, b, d, and F), the firm's Nash equilibrium strategy p^{NE}, the symmetric collusive price p^C, and, finally, the lower and upper bounds imposed on prices $\underline{p}$ and $\bar{p}$. The treatments are indexed by the letters C or S depending on the type of strategic environment, and a number which indexes the absolute slope magnitude for each firm's reaction correspondence. For instance, $C25$ refers to the strategic complements treatment where the slope of each firm's reaction correspondence was equal to $\frac{1}{4}$. Analogously, $S50$ refers to the strategic complements treatment where the slope of each firm's reaction correspondence was equal to $-\frac{1}{2}$.

Table 1: Experimental Parameters

	Treatment					
	C25	**S25**	**C33**	**S33**	**C50**	**S50**
a	3.6	5.2	1.69	7.6	0.25	3.6
b	2	0.5	1.5	1.5	4	0.5
d	-1	0.25	-1	1	-4	0.5
F	2.18	7.95	0.37	4.72	-0.68	2.18
p^{NE}	1.2	4.16	0.85	1.9	0.06	2.40
p^C	1.80	3.47	1.69	1.52	1.5	1.80
$\underline{p}$	0.75	3.07	0.52	0.96	0	1.35
$\bar{p}$	2.25	4.57	2.02	2.46	1.5	2.85

Since the firms are symmetric, the strategic environment is determined by the sign of $\frac{\partial^2 \pi_i}{\partial p_i \partial p_j} = -d$. If $d < 0$, we have strategic complements. If $d > 0$, we have strategic substitutes. It is also straightforward to verify that all of the games induced by our experimental parameters are supermodular games.[9] There are two requirements: first, the strategy space for each player is compact; second, increasing differences requires $\frac{\partial^2 \pi_i}{\partial p_i \partial p_j} \geq 0$. The first requirement is trivial. The second requirement is clearly satisfied for the strategic complements case. Since we have a duopoly, increasing differences is also satisfied for the substitutes case by reversing the ordering for player j's pricing decision – i.e., $\frac{\partial^2 \pi_i}{\partial p_i \partial(-p_j)} \geq 0$.[10] Milgrom and Roberts (1991) have shown that supermodular games with a unique equilibrium have nice stability properties. In particular, the unique equilibrium is stable under adaptive learning dynamics such as myopic best reply and fictitious play.

[9] For an introduction to supermodularity and supermodular games the reader is directed to Amir (2005).

[10] This order reversal trick does not work for $N > 2$.

There are two more features of our design. Parameters are chosen for each treatment so that the profits in the symmetric collusive outcome and the Nash equilibrium outcome are the same for both firms at $1.06 and $0.70 respectively in each of the six treatments. These are the same profit numbers used by AFH. Finally, we choose the price intervals so that $\bar{p} - \underline{p} = 1.50$ (the same length as AFH) taking care that neither the Nash equilibrium nor the collusive outcome are exactly in the middle of the price interval.

3 Experimental Procedures

Laboratory sessions were conducted in the Economic Science Laboratory (ESL) at the University of Arizona. All subjects were undergraduate students recruited via E-mail from the ESL's online subject database. Several sessions were conducted for each treatment. Each session was typically composed of about 30 people who were randomly assigned to 14-15 groups of two. In total we had thirteen pairs for the C25, S25, and C50 treatments; twelve pairs in the S50 treatment; and, finally, eleven pairs in the C33 and S33 treatments. A total of 146 students participated in the experiment. To keep the experimental environment as close as possible to AFH, the experiment was computerized using VECONLAB.[11] Subjects interacted with one another through their decisions over computer terminals. Subjects were given time to read the instructions, after which the experimenter entertained questions. All sessions were conducted by the first author. Each subject was endowed with $5, played 20 periods of their respective treatment, and remained in the same group for the entire session. No session lasted more than 60 minutes. At the end of the experiment subjects were paid their cumulative earnings with no exchange rate.[12] No subject participated in more than one treatment.

4 Results

In this section, we present the results from the experiment. The first subsection compares subjects' behavior to the Nash equilibrium pricing benchmark. The second subsection looks for evidence of cooperative behavior. We first

[11] Since the instructions on VECONLAB are pre-set, the wording subjects saw for our experiment is identical to the AFH experiment.

[12] On average, this amount was $18.

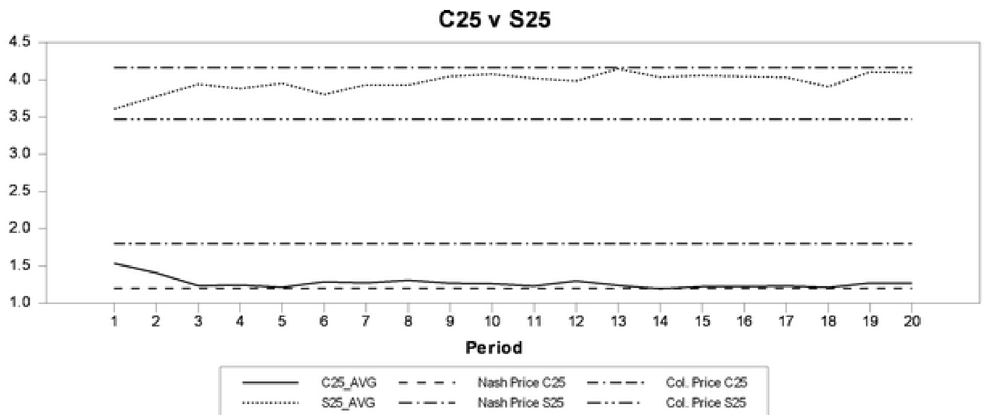


Figure 1: Average Prices for C25 and S25 Treatments

compare treatments with the same absolute slope. Afterward, we make comparisons of cooperative behavior within the strategic setting by comparing all of the strategic complement treatments, and then all of the substitute treatments. Finally, we examine pricing dynamics for the treatments with some simple econometrics.

4.1 Convergence to Nash Equilibrium

We are interested in whether firm behavior converges to the Nash equilibrium, or if it diverges, does it approach a collusive outcome. Figures 1-3 plot the average prices for each of the six treatments. Also included in the figures are the Nash equilibrium prices and the symmetric collusive prices. Each figure compares treatments with reaction functions that have the same absolute slope: Figure 1 compares treatments S25 and C25; Figure 2 compares treatments S33 and C33; and, Figure 3 compares treatments S50 and C50.

At a cursory glance, average prices are converging to the Nash equilibrium prediction in all of the treatments. In particular, average prices in S25 and C25 treatments appear to get very close to the Nash equilibrium. The S33 and C33 treatments converge to the Nash equilibrium prediction in the first half of the experiment, but then diverge slightly in the second half of the experiment. Finally, the behavior in S50 treatment seems to converge quite closely to the Nash prediction, where the C50 treatment, while trending

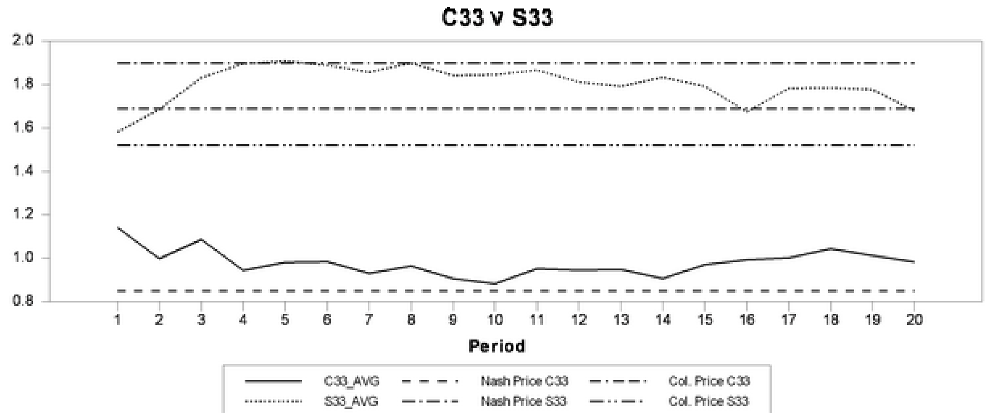


Figure 2: Average Prices C33 and S33 Treatments

in the direction of the Nash prediction, does not get as close as the other treatments. The non-conformity of the C50 treatment is not too surprising since the treatment has several slightly odd features which sets it apart from the other treatments. First, the Nash equilibrium is very close to zero which may not have been attractive to subjects. Second, the symmetric collusive outcome is on the boundary of the choice set.[13]

Simple time trend regressions confirm these observations. However, in order to formalize convergence, we need a notion of distance. The following distance measure is natural.[14] Specifically, for each treatment group $G \in \{C25, S25, C33, S33, C50, S50\}$, we measure how close each group gets to the equilibrium profile of prices. At each round t and each pair $g \in G$, we observe a pair of prices p_{1t}^g and p_{2t}^g from Firm 1 and Firm 2 respectively. The Nash equilibrium prices are (p^{NE}, p^{NE}). The average "city block" distance from equilibrium for group g at time t is defined as

$$D_t^g = \frac{1}{2}|p_{1t}^g - p^{NE}| + \frac{1}{2}|p_{2t}^g - p^{NE}|.$$

[13]This is since if both firms charge the same price there is no reduction in individual firm quantity demanded no matter how large the price. Consequently, firms should match each other's prices and charge the highest price possible which is on the boundary.

[14]This metric was used in Van Essen, Lazzati, and Walker (2011) to measure convergence of behavior to Nash equilibrium.

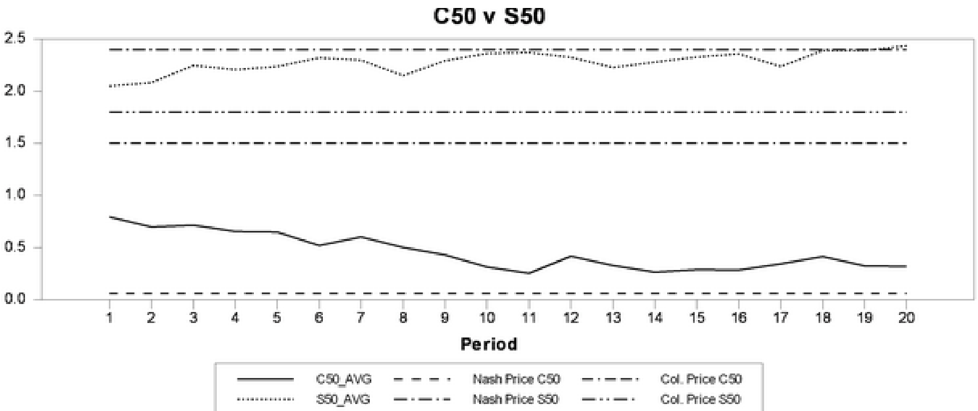


Figure 3: Average Prices for C50 and S50 Treatments

This measure approaches zero as $p_{1t}^g \to p^{NE}$ and $p_{2t}^g \to p^{NE}$. For the time trend regressions, we compute D_t^g for each $g \in G$ and then regress average group distance $\sum_{g \in G} D_t^g$ on time and a constant. The constant in the regression measures the average initial distance from Nash equilibrium. The sign on the time coefficient indicates whether play is converging to Nash equilibrium (i.e., negative coefficient) or diverging from Nash equilibrium (i.e., a positive coefficient). Table 2 summarizes the results of the six regressions.[15]

Treatment	**C25**	**S25**	**C33**	**S33**	**C50**	**S50**
Round	-0.013 ***	-0.015 ***	-0.005 **	-0.004	-0.024 ***	-0.005 ***
	0.001	0.001	0.002	0.003	0.004	0.002
Constant	0.476 ***	0.468 ***	0.377 ***	0.282 ***	0.657 ***	0.386 ***
	0.015	0.018	0.024	0.033	0.043	0.021
Adj. R^2	0.836	0.851	0.232	0.036	0.698	0.311
Prob>F	0.000	0.000	0.018	0.209	0.000	0.006

Table 2: Average Distance from Nash Equilibrium over Time

[15] The top number in each cell corresponds to the regression coefficients. The bottom number corresponds to the standard error. *, **, *** indicates significance at .10, .05, and .01 levels, respectively.

For nearly, all of the treatments, we have negative and significant slope coefficients indicating that pricing is, on average, converging to the Nash equilibrium – albeit slowly for some treatments.[16] Interestingly, the C25 and S25 treatments are nearly identical in terms of starting position and convergence. This is apparent from Figure 1 where the two graphs closely mirror one another for the twenty rounds. The C33 and S33 treatments also have very similar convergence rates to one another. The C50 and S50 treatments differ in both rate of convergence and initial distance from equilibrium. The C50 treatment starts the furthest from equilibrium (of all the treatments), but improves the most rapidly.

At the individual level, firms' pricing decisions exhibit more variation. Using the above notion of distance, we compare the complements and substitutes treatments for each of the three slope treatments at the individual level. Statistical tests are done using the non-parametric Mann-Whitney test.[17] We examine distance from equilibrium for the whole game and the last ten rounds of the experiment. During the first ten rounds, there is a lot of adjustments occurring as subjects are learning to play the game. The last ten rounds are typically a better indicator of the pricing outcomes to which a group converged. For each group g we compute $D^g_{Whole} = \sum_{t=1}^{20} D^g_t$ and $D^g_{Last} = \sum_{t=11}^{20} D^g_t$. The Mann-Whitney test pools the individual distance measure for two treatments and ranks them. The ranks for each treatment are then summed to create a rank sum statistic. This statistic has a known distribution. If two groups are drawn from the same distribution the rank sums should be close, otherwise, we have evidence that the measures are drawn from different distributions. In this event, we reject in favor of a one side alternative hypothesis. This outcome is interpreted as one treatment being more likely to have *higher* values. In the case of distance, for example, the groups in one treatment are on average further from equilibrium than groups in another treatment. In the table below, we report the average distance, the p-value from the Mann-Whitney test, and the conclusion from the statistical test (i.e., the null hypothesis H_0 or the one sided alternative H_a in case of rejection).

[16]The exception to this statement is the S33 treatment. This improves if you regress distance on time and time squared. In this case all the coefficients are significant yielding the more quadratic path observed in the figure.

[17]See, for instance, Siegel and Castellan (1956) p. 128.

Table 3: Distance from Eq. (Whole Game)

		$C25$	$S25$	p-value	Conclusion
1)	Avg. D	0.3418	0.4237	0.036	$H_a : C25 < S25$
		$C33$	$S33$	p-value	Conclusion
2)	Avg. D	0.3467	0.245	0.0743	$H_a : C33 > S33$
		$C50$	$S50$	p-value	Conclusion
3)	Avg. D	0.4029	0.3295	0.1006	$H_0 : C50 = S50$

At the individual level, there is not a robust ranking of the two types of strategic settings. In other words, we cannot conclude that subjects in treatments with strategic complements are always closer to equilibrium on average (or the other way around). Groups in the C25 treatment are on average closer to equilibrium than groups in the S25 treatment. However, groups in the C33 treatment are on average further from equilibrium, and we cannot reject at the ten percent level that the distance yielded by subjects in the C50 treatments were drawn from the same distribution than the S50 groups. Table 4 reports the distance results from the last ten periods of the experiment. None of our are conclusions change significantly relative to the Table 3.

Table 4: Distance (Last 10 Rounds)

		$C25$	$S25$	p-value	Conclusion
1)	Avg. D	0.2675	0.3785	0.0137	$H_a : C25 < S25$
		$C33$	$S33$	p-value	Conclusion
2)	Avg. D	0.3595	0.23	0.0655	$H_a : C33 > S33$
		$C50$	$S50$	p-value	Conclusion
3)	Avg. D	0.2753	0.2975	0.3417	$H_0 : C50 = S50$

4.2 Tacit Collusion

We now look for evidence of collusive (or cooperative) behavior. Following Potters and Suetens (2009), individual group pricing data at each round is indexed by a "degree of cooperation" metric. For each pair g in round t, we observe (p_{1t}, p_{2t}). Let $A_t^g = \frac{p_{1t}+p_{2t}}{2}$. The degree of cooperation is then defined as

$$\rho_t^g = \frac{A_t^g - p^{NE}}{p^C - p^{NE}}.$$

Note, $\rho_t^g = 0$ when the average price of group g is equal to the Nash equilibrium. In other words, $\rho_t^g = 0$ when the market price is equal to the Nash equilibrium market price; $\rho_t^g = 1$ when the average price of group g is equal to the symmetric collusive price. Average prices between these two benchmark prices yields a ρ between 0 and 1. If $\rho < 0$, the market price is more competitive than Nash. Similarly, if $\rho > 1$, the market price is less competitive than the symmetric collusive outcome. Positive values of ρ are therefore interpreted as cooperative/ collusive observations. Table 5 reports the average ρ for each treatment over the whole game, the p-value associated with the Mann-Whitney test, and the conclusion of the test.

Table 5: ρ (Whole Game)

		$C25$	$S25$	p-value	Conclusion
1)	Avg. ρ	0.1180	0.2763	0.0505	$H_a : C25 < S25$

		$C33$	$S33$	p-value	Conclusion
2)	Avg. ρ	0.1534	0.2593	0.2773	$H_0 : C33 = S33$

		$C50$	$S50$	p-value	Conclusion
3)	Avg. ρ	0.2749	0.2004	0.0436	$H_0 : C50 > S50$

Again, we do not see a consistent ranking of complements and substitute treatments. Substitutes is more cooperative when the absolute slope of the two treatments is $\frac{1}{4}$, there is no significant difference when the absolute slope of the two treatments is $\frac{1}{3}$, and when the absolute slope of the two treatments is $\frac{1}{2}$ we have that the complements treatment is more collusive. Some of these differences may be based on initial starting positions of groups. This early adjustment can be misinterpreted as collusion when subjects are just learning how to play the game. If we eliminate the first 10 rounds, all significant differences in the degree of cooperation disappear. Table 6 presents these comparisons.

Table 6: ρ (Last 10 Rounds)

		$C25$	$S25$	p-value	Conclusion
1)	Avg. ρ	0.0651	0.1687	0.1405	$H_0 : C25 = S25$

		$C33$	$S33$	p-value	Conclusion
2)	Avg. ρ	0.1497	0.3176	0.179	$H_0 : C50 = S50$

		$C50$	$S50$	p-value	Conclusion
3)	Avg. ρ	0.1832	0.1091	0.2658	$H_0 : C50 = S50$

Consequently, after adjusting for initial learning, we find very little evidence that tacit collusion is fostered by games of strategic complements or strategic substitutes.

Finally, we are also interested in whether the slope of the reaction functions impacts tacit collusion within a particular strategic setting. In other words, are groups more likely to collude if they participate in C25 or C33, C25 or C50, etc. A casual look at the average ρ in tables 5 and 6 seems to suggest that in the complements treatments subjects are more likely to collude as the slope of the reaction curve gets larger. No such pattern is obvious in the substitutes' treatments. At the individual level Mann-Whitney test comparing ρ between the C25 and C33 treatment are not significant.[18] However, the test comparing ρ between the C25 and C50 treatment is weakly significant at the 0.0768 in favor of higher ρ in the C50 treatment. Thus, there is some evidence in the complements case that when reaction slopes are closer to zero collusion may be more difficult. For the substitutes case, we cannot reject the null hypothesis of equality of distribution for any of the pair wise comparisons.

4.3 Pricing Dynamics

We use regression analysis to analyze the price-setting dynamics of our firms. We treat the data as a panel and employ both fixed and random effects estimation to control for unobserved individual heterogeneity. Standard errors are clustered at the pair level. Following Potters and Suetens (2009) and

[18] The corresponding $p-$value is 0.3391.

AFH we estimate the model

$$\Delta p_{it} = \alpha_i + \beta \Delta p_{j(t-1)} + \epsilon_{it}$$

for each of the six treatments using first differences in price to estimate how firm i reacts to a previous price change by firm j. Table 7 presents the results from this regression.[19] The coefficient for the complement treatments are in the first row of data (marked with a (C)). The coefficients for the substitute treatments are in the second row (marked with a (S)).

Table 7: Regression Results $\Delta p_{it} = \alpha_i + \beta \Delta p_{j(t-1)} + \epsilon_{it}$

	$\frac{1}{4}$ Slope		$\frac{1}{3}$ Slope		$\frac{1}{2}$ Slope	
	FE	RE	FE	RE	FE	RE
$\Delta p^C_{j(t-1)}$	0.164***	0.164***	0.0898	0.0964	0.165***	0.165***
$\Delta p^S_{j(t-1)}$	0.025	0.026	0.128*	.128*	0.07	0.069

Our first observation is that regardless of treatment the coefficient on $\Delta p_{j(t-1)}$ is positive. Thus, a change in price by firm j is always followed by a change in price by firm i in the same direction. While this is consistent with how players are expected to act in the strategic complements treatments, it runs contrary to our expectations for the strategic substitutes treatments. However, the significance levels in the substitute case are either not significant or weakly significant. In particular, when the reaction curve slopes are $\frac{1}{4}$ and $\frac{1}{2}$ the coefficient on $\Delta p_{j(t-1)}$ is significant at the .01 level for strategic complements treatments. For these two slope values in the strategic substitutes treatment the coefficient, while positive, is very small but is not statistically significant at any of the standard levels. These results are flipped for the $\frac{1}{3}$ slope treatment. Comparing the complements and substitutes treatments, the coefficient on $\Delta p_{j(t-1)}$ is larger and significant in the strategic substitutes treatment.

While these results agree with the directional prediction of the best response dynamic for the complement treatments, they does not seem as apt

[19] *, **, *** indicates significance at .10, .05, and .01 levels, respectively.

to explain pricing in the substitutes treatments. The model may be incorrectly specified. For the model to be correctly specified we must include all variables that will have an impact on a firm's decision to change price. A simple alternative learning model is that a firm adjusts his price at time t as a function of $\Delta p_{j(t-1)}$ and the change in his own profit in the previous period (i.e., $\Delta\pi_{i(t-1)} = \pi_{i(t-1)} - \pi_{i(t-2)}$). Our second model is therefore

$$\Delta p_{it} = \alpha_i + \beta\Delta p_{j(t-1)} + \delta\Delta\pi_{i(t-1)} + \epsilon_{it}.$$

The estimated coefficients are presented in Table 8.[20]

Table 8: Regression Results $\Delta p_{it} = \alpha_i + \beta\Delta p_{j(t-1)} + \delta\Delta\pi_{i(t-1)} + \epsilon_{it}$

	$\frac{1}{4}$ Slope		$\frac{1}{3}$ Slope		$\frac{1}{2}$ Slope	
	FE	RE	FE	RE	FE	RE
$\Delta p^C_{j(t-1)}$	-.099*	-.098*	-.197	-.184	0.041	0.042
$\Delta\pi^C_{i(t-1)}$	.221***	.221***	.314***	.309***	.143**	.142**
$\Delta p^S_{j(t-1)}$	-.640***	-.631***	-.313	-.304*	-.34**	-.34**
$\Delta\pi^S_{i(t-1)}$	-.641***	-.633***	-.225***	-.221***	-.34**	-.34***

In the complements treatment, the coefficients on $\Delta p_{j(t-1)}$ are for the most part insignificant and with the exception of the $\frac{1}{2}$ treatment the coefficients are negative. The coefficients on $\Delta\pi_{i(t-1)}$ are positive and significant at the .01 level across all treatments and slope values, indicating that a positive change in one's profit in the previous period leads to a positive change in one's current price. In the strategic substitutes treatment the coefficient on the lagged change in the other firm's price is negative and mostly significant. This is consistent with the theory. A difference with the complements treatment is that the coefficient on $\Delta\pi_{i(t-1)}$ is negative and highly significant for all slope values, indicating that a positive change in one's profit in the previous period leads to a decrease in price in the current period.

[20] *, **, *** indicates significance at .10, .05, and .01 levels, respectively.

5 Conclusion

We conducted a duopoly market experiment utilizing six different treatments to investigate whether tacit collusion is fostered in games with strategic complements. When comparing duopoly pricing games of strategic complement and strategic substitute treatments with the same absolute slope, there is little evidence that either strategic setting is more collusive . At an aggregate level we observe that behavior approaches the Nash equilibrium in all of the treatments – i.e., the average distance approaches zero as time increases. The treatments C25 and S25 are nearly identical at the aggregate level. The treatments C33 and S33 also have similar convergence rates. We also find weak evidence in the strategic complements case that tacit collusion is facilitated in treatments with slopes further from zero. In particular, subjects in the C50 treatment had higher ρ values than subjects in the C25 treatment. This is consistent with the theory in as much that incentives to deviate from a collusive agreement are much stronger in the C25 treatment.

Our main conclusions differ from AFH who do not compare treatments with the same strategic incentives. Interestingly, if one compares the C25 and S50 treatments from our experiment (i.e., the parameters used in the AFH design), the results are very similar to the ones reported by AFH. In particular, Figure 4 plots the average prices for the C25 and S50 treatments. Despite both time series converging toward the Nash equilibrium, the S50 treatment appears closer to the collusive outcome price throughout the experiment. At the individual level if we compare the two treatments via ρ over the whole game Mann-Whitney confirm this observation. The average ρ for the $C25$ treatment is 0.1180 compared to the 0.2004 in the $S50$ treatment the associated p-value is 0.0605 in favor of $C25 < S50$. This is is consistent with the findings of the AFH study. However, as we have argued, this result is not robust when similar sloped complements and substitutes treatments are compared.

References

[1] Amir, R. (2005). "Supermodularity and Complementarity in Economics: an Elementary Survey." *Southern Economic Journal*, 71(3), p. 636-660.

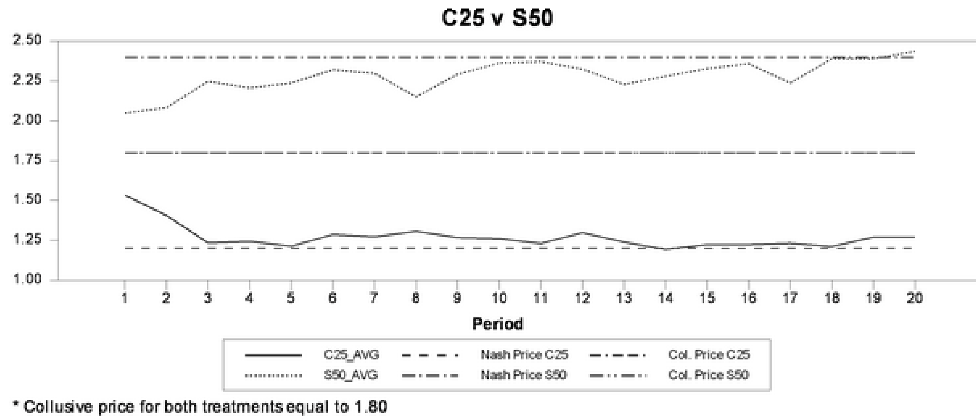


Figure 4: Average Prices for C25 and S50 Treatments

[2] Bülow, J., Geanakoplos, J., and Klemperer, P. (1985). "Multimarket Oligopoly: Strategic Substitutes and Strategic Complements." Journal of Political Economy, 93, p. 488-511.

[3] Anderson, L., Freeborn, B., and Holt, C. (2010), "Tacit Collusion in Price-Setting Duopoly Markets: Experimental Evidence," *Southern Economic Journal*, 76(3): 577-591.

[4] Chen, Y. and Gazzale, R. (2004). "When does Learning in Games Generate Convergence to Nash Equilibria? The Role of Supermodularity in an Experimental Setting." *American Economic Review*, 94, p.1505-35.

[5] Cox, J. and Walker, M. (1998). "Learning to Play Cournot Duopoly Strategies." *Journal of Economic Behavior and Organization*, 36, p.141-161.

[6] Dufwenberg, M., and Gneezy, U. (2000). "Price Competition and Market Concentration: An Experimental Study." *International Journal of Industrial Organization*, 18, p.7-22.

[7] Engel, C. (2007). "How much Collusion: A Meta-Analysis of Oligopoly Experiments." *Journal of Competition Law and Economics*, 3, p. 491-549.

[8] Holt, C. (1995). "Industrial Organization: A Survey of Laboratory Research. In Handbook of Experimental Economics, ed. John Kagel and Al Roth. Princeton, NJ: Princeton University Press, pp. 349-443.

[9] Milgrom, P. and Roberts, J., (1991). "Adaptive and Sophisticated Learning in Normal Form Games." *Games and Economic Behavior.*

[10] Potters, J. and Suetens, S. (2009). Cooperation in Experimental Games of Strategic Complements and Substitutes." *Review of Economic Studies.*

[11] Siegel, C. and Castellan, J. (1956) Nonparametric Statistics for Behavioral Sciences. McGraw-Hill, Inc. Second Edition.

[12] Suetens, S. and Potters, J. (2007). "Bertrand colludes more than Cournot." *Experimental Economics.* 10: 71-77

[13] Van Essen, M. (2010). "Information Complexity, Punishment, and Stability in Two Nash Efficient Lindahl Mechanisms." University of Alabama Working Paper.

[14] Van Essen, M., Lazzati, N. and Walker, M. (2011). "Out-of-Equilibrium Performance of Three Lindahl Mechanisms: An Experiment," forthcoming at *Games and Economic Behavior.*