E C O N O M I C S   B U L L E T I N

Collusion with secret price cuts: an experimental investigation

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Abstract

Theoretical work starting with Stigler (1964) suggests that collusion may be difficult to sustain in a repeated game with secret price cuts and demand uncertainty. Compared to equilibria in games of perfect information, trigger−strategy equilibria in this context result in lower payoffs because punishments occur along the equilibrium path. We tested the theory in a series of economic experiments. Consistent with the theory, treatments with imperfect information were less collusive than treatments with perfect information. However, in the imperfect−information treatments, players seemed to settle on the static Nash outcome rather than using trigger strategies. Players did resort to punishments for undercutting in perfect−information treatments, and this sometimes led to successful collusion afterward.

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1. Introduction

Stigler (1964) discussed the inherent difficulty in sustaining collusion in a repeated game in which the actions of a firm's rivals (say price or quantity choice) are unobservable. If industry conditions are uncertain, say demand is subject to unobservable negative shocks periodically, then a firm may not be able to distinguish a rival's undercutting from an negative demand shock. In Green and Porter's (1984) formal model involving repeated quantity competition, it was shown that firms can sustain some collusion with trigger-price strategies: firms remain in a collusive phase as long as price remains sufficiently high, entering a finitely-long punishment phase (involving the static Cournot outcome) if market price falls below a threshold. Abreu, Pierce, and Stachetti (1990) extended the analysis to consider optimal trigger strategies.

In this paper, we use experimental methods to shed light on the practical relevance of the theory. As Slade (1992) notes, "…it is important that players know in advance what constitutes a punishment and understand when they are being punished. When players cannot meet to discuss their strategies, complex rules, which are difficult to communicate, can be counter-productive."

Our paper is related to two strands of the empirical literature. One strand, including, for example, Porter (1983, 1985), Slade (1987, 1992), and Ellison (1994), tests models of dynamic competition using industry data. The other strand is the experimental literature on collusion in repeated duopoly markets. Mason and Phillips (1999) study the use of trigger strategies in a perfect-information setting, and find evidence supporting players' use of trigger strategies. There is also a series of papers in the literature studying repeated duopoly markets under imperfect information, for example, Dolbear et al. (1968), Benson and Feinberg (1988), Mason and Phillips (1997) and Cason and Mason (1999). The closest paper to ours is Holcomb and Nelson (1997), however our experimental design allows for clearer inferences on the effects of imperfect information and shocks. Furthermore, our design is closer to the familiar Green and Porter (1984) model.

2. Theory

In what follows we briefly summarize Tirole's (1988) discussion of the Green and Porter (1984) model. The stage game of the infinitely-repeated game has two firms, $i = 1,2$, simultaneously choosing prices $p_i \in [0, \infty)$. Firms produce a homogeneous product, splitting demand equally if they charge equal prices, the low-price firm obtaining all the demand if they charge unequal prices. The firms have a constant marginal and average cost of production c. Market demand is subject to fluctuations, equaling $D(p)$ with probability α and zero with probability $1-\alpha$.

2.1 Secret Price Cuts

First consider the infinitely-repeated version of the above stage game in which a firm does not observe its rival's past actions directly but can only draw inferences from the level of its own realized demand. Suppose firms play the following trigger strategy: begin by charging price p; if own demand is $D(p)/2$, continue charging p next period and repeat the process; if own demand drops to zero, enter a price war phase, charging *c* for *T* periods before returning to *p*. In equilibrium, no firm will undercut the collusive price *p*, yet there will still be price wars since firms' demands will be driven to zero by the exogenous demand shock.

2.2 Observable Price Cuts

Now consider a model that is in all ways identical except in one respect: a firm can observe its rival's past actions. This allows firms to avoid costly price wars in equilibrium since firms distinguish between zero demand due to an exogenous demand shock and zero demand due to rival undercutting. Price wars need only follow undercutting, which can be prevented in equilibrium by the threat of grim-strategy punishments (marginal cost pricing forever). The fact that firms must choose prices before the state of demand is realized makes the calculation of equilibrium nearly identical to the usual case of Bertrand competition without fluctuating demand. As usual, the monopoly outcome (or any other collusive price) is sustainable for $\delta \geq 1/2$; for lower values of δ, the unique equilibrium involves marginal cost pricing.

2.3 Comparison

The two cases, secret vs. observable price cuts, lead to quite different implications. With secret price cuts, price wars must occur in equilibrium, whereas they need not with observable price cuts. The minimum discount factor necessary to sustain collusion with secret price cuts, $\delta \geq 1/[2(1-\alpha)]$, is higher than with observable price cuts, $\delta \geq 1/2$. It can be easily shown that the present discounted value of the stream of maximally collusive profits is lower with secret than with observable price cuts.

3. Experimental Approach

Our experimental approach involves a discrete version of the game from Section 2. Two players in a market simultaneously choose one of three prices: a “collusive” price *C*, an “undercutting” price *U*, and a “punishment” price *P*. The resulting payoffs from this symmetric game are given in Table 1. By adding a third action (*P*), undercutting and punishment can potentially be distinguished, whereas they are convoluted in cruder, two-action setups. In the continuous-price model in Section II, too, undercutting is logically distinct from punishment: the undercutting price is only slightly lower than the collusive price, whereas the punishment price equals marginal cost.

We conducted two experimental sessions (each lasting about one and a half hours) with undergraduate participants from American University. Eight students participated in each session. Students were randomly grouped into duopoly markets (they did not know the identity of their rival) and given instructions for the initial treatment. There were no demand shocks and rival choices were revealed after each period. The participants were told that the game would be played for eight periods with certainty; thereafter a die would be rolled to determine whether the game would continue for an additional period, with a 2/3 probability of continuing. The rolling of the die allowed the game to have an uncertain ending, effectively simulating a supergame with discount factor $\delta = 2/3$ in the treatment's latter stages. (See Feinberg and Husted (1993) for experiments on varying discount factors in a repeated duopoly setting.) The same two participants played together for the duration of the treatment.

Following the end of Treatment 1 in both sessions, new instructions (for Treatment 2 in one session and Treatment 3 in the other) were given out, market pairings were reassigned---still unknown to participants---and the same stage game was played with certainty for 18 periods, with continuation beyond that point with a 2/3 probability determined by throw of a die. Again, the pairings were maintained for the duration of the treatment. In Treatments 2 and 3, participants were only informed about their own payoffs after each period but not about rival's actions. Also, in both treatments negative demand shocks giving zero payoffs regardless of choices made were imposed in periods 10 and 16. Participants were instructed at the outset that there would be such shocks roughly 10 to 15 percent of the time but not which periods they would occur.

In Treatment 2, participants were told immediately after periods 10 and 16 that a negative shock occurred (referred to as "revealed" demand shocks). Given that participants were informed of their own profits and whether or not a negative demand shock occurred, in principle each had enough information to deduce whether or not its rival had deviated from the collusive outcome. In Treatment 3, participants were never informed about the occurrence of the shock (referred to as "secret" demand shocks). Hence, it was impossible for them to distinguish undercutting by a rival from an adverse demand shock since both would give the player zero profit. Of course if a player were to repeatedly earn zero profit after choosing *C*, it might begin to believe that it was increasingly unlikely to be due to random demand shocks, but rather due to undercutting.

Treatment 1, involving full information and no demand shocks, was meant to initiate participants in the structure and logic of the basic game. The formal test of the theory comes from a comparison of Treatments 2 and 3. In moving from Treatment 2 to 3, the amount of information players have about demand, and by inference the information they have about their rival's past actions, is reduced.

First consider the case of revealed demand shocks. For our parameters, it can be shown that only one period of reversion ($T = 1$, in essence a "tit for tat" strategy) is required to sustain collusion, though obviously a grim strategy (involving the threat of reversion until the end of the game) would also be successful in sustaining collusion. Next, consider the case of secret demand shocks. Here, again, it turns out that only one period of reversion is required to sustain collusion with trigger strategies, whether the trigger strategies employ (*U*,*U*) or (*P*,*P*) reversion.

4. Results and Interpretation

The results for Treatments 2 and 3 are presented in Tables 2 and 3. Combining the results for Treatment 1 (the benchmark treatment with full information about rival's past actions and no demand shocks) from both sessions (not reported here, but available from the authors), an argument can be made that there was some convergence to the collusive outcome in about half of the markets; in addition, *C* was played by market participants 62 percent of the time.

In Treatment 2 (the treatment with revealed demand shocks), the results for which are reported in Table 2, there was little decline in the ability to collude. There is a fair degree of convergence to the collusive outcome in three of the four markets. *C* was chosen 68 percent of the time, the exact fraction for these players in Treatment 1. Thus we conclude that merely adding the demand shock, but still allowing players to infer rival's past actions by informing them of the demand shock after it occurred, did not reduce players' ability to collude.

In Treatment 3 (the treatment with secret demand shocks), the results for which are reported in Table 3, there was a sharp decline in the ability to collude. There appears to have been convergence to (*U*,*U*) in all four markets. *C* was chosen only 21 percent of the time, a 31 percent reduction from Treatment 1 for these same players. Thus we conclude that secret price cuts combined with secret demand shocks substantially reduces players' ability to collude, perhaps even beyond what theory would predict.

A comparison of payoffs reinforces this conclusion. In the second session, moving from Treatment 1 to Treatment 3, caused average per-period, per-player payoffs to decline from 39.5 cents to 25.8 cents, a decline of a third. In the first session, moving from Treatment 1 to Treatment 2 caused virtually no change in per-period, per-player payoffs (the decline was from 54.5 cents to 54.4 cents to be exact). Though the participants in the second session appear to be less cooperative on average than those in the first session, considering the within-session variation purges any participant-specific effects.

An interesting issue regards the use of the punishment action *P* and the response it engenders in rivals. Players did resort to the punishment action, if only sparingly (30 times out of a possible 472 choices, i.e., six percent of the time). Most of the time *P* was chosen by a firm that had chosen *C* and had been undercut by a rival in the prior period (23 out of 30, i.e., 77 percent of the time). This suggests students understood the use of the punishment strategy, consistent with theory. Typically, players reverted to *P* for only one period and then returned to *C*, though there was one case where a player carried out the punishment *P* for two periods and one case for three periods. When *P* is chosen by a player to punish a rival who has chosen *U* while the player had chosen *C*, the rival responds by changing his/her action to *C* 47 percent of the time.

On the effects of the demand shocks, the observed shocks in Treatment 2 caused only one out of 16 actions (six percent) to change; as predicted, observable exogenous shocks should not lead to a breakdown in collusion. The shocks in Treatment 3 also did not lead to a breakdown in collusion but perhaps for a different reason: there was so little collusion to begin with in periods preceding the shock -- *C* had been chosen prior to the shock in only two of the 16 cases.

5. Conclusion

Demand uncertainty alone had little effect on players' ability to collude. Just as they were in the treatment with no demand shocks, trigger strategies were used in the treatment with revealed demand shocks, often having the effect of making the rival play more collusively afterward.

The combination of secret demand shocks with secret price cuts was essential to impair collusion. Theory suggests this should be the case: demand uncertainty is only important if it masks rival's secret deviations. What was surprising from our experiments was the extent to which the combination of secret demand shocks and secret price cuts impaired players' ability to collude. Despite parameters allowing collusion to be sustainable with trigger strategies requiring only one period of punishment, our results suggest that the combination of secret demand shocks and imperfect information about rival pricing may prevent players from sustaining collusion at all.

Table 1. Profit Table (in cents)

		Other's choices		
		Collusive price (C)	Undercutting price (U)	Punishment price (P)
	Collusive price (C)	75	0	0
Your Choices	Undercutting price (U)	100	25	0
	Punishment Price (P)	0	0	0

Table 2: Results for First Session, Treatment 2

		Period																				
Market	Player	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
A	1.1	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*
	1.8	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*
B	1.2	*C*	*U*	*U*	*P*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*
	1.5	*U*	*U*	*C*	*C*	*U*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*
C	1.3	*C*	*C*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
	1.6	*U*	*C*	*C*	*U*	*C*	*P*	*C*	*U*	*U*	*U*	*U*	*P*	*C*	*C*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
D	1.4	*U*	*U*	*C*	*C*	*P*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*U*	*U*	*U*	*U*
	1.7	*U*	*C*	*P*	*U*	*U*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*U*	*U*	*C*	*C*	*U*

Notes: Treatment 2 involves demand shocks about which players are informed after they occur and no information about rival's past actions (but a rival's actions can be inferred given information about demand shocks) . Demand shocks occurred in shaded periods (10 and 16). *C* stands for "Collusive price", *U* for "Undercutting price", and *P* for "Punishment price". Game lasted until period 18 with certainty; die roll resulted in three additional periods, 19 through 21. In the naming convention for the players, the number before the decimal represents the session and the number after the decimal represents the the particular player.

Table 3: Results for Second Session, Treatment 3

Player	Period 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2.1	*C*	*C*	*C*	*C*	*C*	*C*	*C*	*U*	*U*	*U*	*U*	*C*	*U*	*C*	*P*	*P*	*U*	*P*	*U*
2.8	*C*	*U*	*U*	*U*	*C*	*U*	*U*	*U*	*U*	*U*	*C*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
2.2	*C*	*C*	*U*	*C*	*U*	*U*	*U*	*P*	*C*	*P*	*U*	*U*	*U*	*U*	*C*	*U*	*U*	*U*	*U*
2.5	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*C*	*U*	*C*	*U*	*U*	*U*	*C*	*U*	*C*	*U*	*U*	*U*
2.3	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*P*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
2.6	*C*	*C*	*U*	*C*	*C*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
2.4	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*	*U*
2.7	*C*	*C*	*P*	*C*	*P*	*C*	*P*	*C*	*U*	*U*	*C*	*U*	*P*	*C*	*U*	*U*	*C*	*U*	*U*

Notes: Treatment 3 involves secret, random demand shocks and no information about rival's past actions. Demand shocks occurred in shaded periods (10 and 16). C stands for "Collusive price", U for "Undercutting price", and P for "Punishment price". Game lasted until period 18 with certainty; die roll resulted in one additional period, 19. In the naming convention for the players, the number before the decimal represents the session and the number after the decimal represents the particular player.

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