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7047
2018

May 2018

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Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
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Editors: Clemens Fuest, Oliver Falck, Jasmin Gröschl
www.cesifo-group.org/wp

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CESifo *Working Paper No. 7047*
Category 11: Industrial Organisation

An Experimental Analysis of the Complications in Colluding when Firms are Asymmetric

Abstract

I study an indefinitely repeated game where firms differ in size. Attempts to form cartels in such an environment, for example by rationing outputs in a manner linked to firm size differences, have generally struggled. Any successful cartel has to set production shares in a manner that ensures no firm will defect. But this can require allocating sellers disproportionate shares, which in turn makes these tacit agreements difficult to create and enforce. I analyze some experimental evidence in support of this last proposition.

JEL-Codes: D800, L150.

Keywords: asymmetric cartel, repeated game, experiments.

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May 3, 2018

1 Introduction

In the early days of the Great Depression, soft demand and the recent discovery of a large deposit in East Texas (the so-called "Black Giant") combined to push many firms to the brink of failure. This situation was complicated by the tension between larger firms, often referred to as *majors*, and smaller firms, often called *independents*. In particular, the majors struggled to rein in what they saw as "overproduction" on the part of the independents. Ultimately, the majors turned to the government for help; in response, the Texas Railroad Commission set up a quota system. Notably, these quotas were biased towards small producers (Cave and Salant, 1995, p. 98).[1] The difficulty suffered by majors in successfully restricting output was echoed in the 1980s, when the Organization of Petroleum Exporting Countries (OPEC) struggled to prop up oil prices. As new sources of supply entered the market, particularly from the North Sea, OPEC tried to promulgate a quota system. It is instructive to consider the pattern of quotas and production associated with the largest player – Saudi Arabia – and two smaller players – Iran and Venezuela. The Saudis were allocated a quota of 7,650 barrels per day (bpd) in 1982, and produced only 6,961 bpd. Iran and Venezuela were allocated quotas of 1,200 bpd and 1,500 bpd, respectively; they each over-produced, delivering outputs of 2,397 and 1,954 bpd, respectively. In response, OPEC adjusted the three countries' quotas for 1983, to 5,000 bpd for Saudi Arabia – which they again honored – and 2,400 bpd for Iran and 1,675 bpd for Venezuela, which they again violated.[2]

[1] The majors first looked to the Federal government for assistance; this resulted in passage of the "National Industrial Recovery Act". When this act was ruled to be unconstitutional, the majors hit on a scheme whereby each large firm would buy up output from smaller firms, remove it from the market (holding it in stockpile reserves), in order to prop up profits. This in turn lead to a challenge under the Sherman Antitrust Act, with an ultimate finding against the majors United States v. Socony-Vacuum Oil Co., 310 U.S. 150 (1940), reversing 105 F.2d 809 (7th Cir. 1939), reversing 23 F. Supp. 937 (W.D. Wisc. 1938)).

[2] Although Iran's over-production was minor – they produced 2,454 bpd – Venezuela's substantially exceeded their quota, producing 1,852 bpd. See Adelman (1995, Ch. 4) for discussion.

Many oligopoly markets have producers of different sizes. Examples of this phenomenon include soft drinks, where private-label soft drink producers are loath to cooperate with well-known branded sellers like Coke and Pepsi; similarly, private brand cereals generally undercut prices charged by Kellogg, General Mills, and Post. In both examples, private-label sellers have significantly smaller market shares than their better known counterparts. In the American steel industry, the major seller – U.S. Steel – promulgated a scheme that favored its smaller rivals for decades, allowing them increased market share (Adams and Mueller, 1982).

These examples all point to the difficulties associated with crafting a successful cooperative agreement to raise profits in asymmetric markets – where sellers differ in size, and that the smaller sellers are often the source of difficulties, demanding relatively larger shares or failing to honor any arrangements. Because any arrangement requires firms agree on the division of any gains, and because marginal output reductions yield different impacts on firms' relative profits, determining the distribution of these gains can be a thorny problem (Schmalensee, 1987).

One might imagine firms varying in size for a variety of reasons: they could have different assets, or they might have access to different technologies; in any event, they are likely to exhibit asymmetries in costs. My goal in this paper is to shed light on the behavior of heterogeneous firms, which I interpret as resulting from different marginal costs. To this end, I analyze data from an experimental analysis based on a relatively simple linear-quadratic payoff structure. I find that subject choices in the presence of heterogeneous costs are significantly closer to the (non-cooperative) Cournot/Nash equilibrium than are choices in a symmetric structure. Moreover, smaller sellers (*i.e.*, those with greater marginal costs) appear to be "tougher negotiators", in the sense that their observed market shares exceed those from the Cournot/Nash equilibrium. Indeed, the evidence from these experimental data shows that the small agent making output choices chooses outputs slightly above the Cournot/Nash level and the large agent chooses outputs below the Cournot/Nash level. In other words, it is the small producer that spoils the cooperative efforts of rivals.

This outcome can not be explained by standard theoretical treatments, as those generally allocate a larger share of market output to the low-cost firm.[3] But this result is broadly consistent with other experimental papers. For example, while the Equity, Reciprocity and Competition (ERC) model coincides with the Cournt/Nash equilibrium in a symmetric structure, it may not do so with asymmetric costs because "the [low cost player] may choose a smaller output in order to boost relative payoff" (Bolton and Ockenfels, 2000, p. 181). The outcomes I observe from these experimental data have this flavor: while the typical higher-cost player's long-run output is close to its Cournot/Nash level, the typical lower-cost player's output is smaller than the Cournot/Nash level.[4] By contrast, behavior in the symmetric design is more in accord with the "win continue, lose reverse" model discussed by Huck et al. (2003) or the "trial and error" approach suggested by Huck et al. (1999) and Huck et al. (2004).[5]

The paper is organized as follows. Section 2 presents a theoretical framework for cooperative arrangements in the use of a common property resource. I suggest a two-phase strategy, based on a cooperative, or "carrot", action that delivers higher payoffs to parties; deviation from the carrot phase triggers a punishment, or "stick", regime. The ability of this strategy to deliver improvements, via reduced harvesting efforts, requires that two incentive constraints be satisfied –

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[3] See, for example, Schmalensee (1987, Table 1), which shows that the increased profit earned by the larger cost firm is smaller than would obtain under "proportional reduction" – in which case the firms' shares would correspond to the Cournot/Nash levels.

[4] It is also possible that it might take the high-cost player longer to figure out the potential gains from cutting output, as suggested by Friedman (1983). While I can not rule out this explanation, the econometric model I employ below is sufficiently flexible as to pick up evidence of tendencies in that direction, and the results I find do not point towards such.

[5] Shapiro (1980) provides an alternative conceptual approach that models convergence from an initially non-collusive situation to a collusive regime.

one for each player. I argue that the incentive constraint for the larger player is the more likely to bind, thereby requiring the arrangement to be disproportionately more favorable to the large player. In particular, such a regime would afford the large player a larger share than would obtain under a pro-rata sharing rule; this fact makes agreement less probable. I then investigate the empirical plausibility of these predictions, drawing on previously published experimental work. Section 3 offers a discussion of that experimental structure, while section 4 offers empirical results based on econometric analysis of the data. Section 5 offers discussion.

2 Modeling cooperation in an asymmetric industry

To flesh out the theoretical backdrop to the experimental design discussed below, I consider a homogeneous goods duopoly, with firms $i = 1,2$ that produce outputs q_i, patterned after Schmalensee (1987). Inverse market demand is $p = a - bQ$, where market output $Q = q_1 + q_2$. Firm i bears costs $c_i q_i$, *i.e.*, it faces constant marginal costs c_i. To fix ideas, I let firm 1 be the low-cost firm, and set $c_1 = 0$. In a symmetric structure $c_2 = 0$, while in an asymmetric structure $c_2 > 0$. It is well known that the Cournot/Nash equilibrium is such a setting entails outputs $q_i^N = \frac{a-2c_i+c_j}{3b}$ with profits $\pi_i^N = b\left(q_i^N\right)^2$. Both firms employ a discount factor δ to evaluate payoffs one period into the future. Mildly abusing notiation, I denote the output selected by firm $k = 1,2$ in period t as q_{kt}.

To support a cooperative regime (q_1^c, q_2^c) let us suppose the firms each play the grim strategy: firm i chooses q_i^c in period 1; in any subsequent period $t > 1$, i chooses $q_{it} = q_i^c$ if $q_{ks} = q_k^c, k = 1,2$ in all previous periods $s < t$, otherwise choose $q_{kt} = q_k^N$. With this strategy, there are two subgames of note: those where no player has deviated in any previous period, and those where one player has deviated in some previous period.[6] By design, the strategy dictates a best-reply to the rival's strategy in the latter type of subgame (*i.e.*, choosing the Cournot/Nash output is by definition a best-reply to the Cournot/Nash output), so the combination that obtains when both firms play the grim strategy induces a subgame-perfect Nash equilibrium when the strategy pair generates a Nash equilibrium. That in turn requires the present discount flow of profits associated with honoring the strategy, V_i^c, not be smaller than the present discounted flow of profits associated with defecting, V_i^d. The former is well known to be $V_i^c = \frac{\pi_i^c}{1-\delta}$. Since defection will trigger reversion to the Cournot/Nash equilibrium, and play will stay there forever after, the present discounted value of defection is easily seen to be $V_i^d = \pi_i^d + \frac{\delta}{1-\delta}\pi_i^N$, where π_i^d are the profits earned by selecting the one-shot best-reply to the rival firm's (cooperative) output. There are many combinations of outputs (q_1^c, q_2^c) that satisfy $V_i^c \geq V_i^d$; the boundary, where the firm is just willing to play the grim strategy, is defined by $V_i^c = V_i^d$. In the linear demand, constant marginal cost framework adopted here, this frontier is implicitly defined by a quadratic relation between q_i^c and q_j^c. I refer to this relatiOn as the "incentive constraint" in the subsequent discussion.

Figure 1 illustrates the general principle. Here, I plot the incentive constraints for each of the two players. Choices for the larger player are plotted on the $x-$axis, while choices for the smaller player are plotted on the $y-$axis. The incentive constraints intersect at two places: the one-shot Cournot/Nash equilibrium (the point farthest to the northeast) and the most cooperative outcome (the point farthest to the southwest). Also indicated in this diagram are combinations with the same ratio of outputs as in the Cournot/Nash equilibrium, represented by the dashed line labeled "pro-rata sharing". The key point is that the pro-rata sharing locus crosses the large

6 If both players defected in the previous period, the typical convention is to treat such a period as if no defection occurred (Fudenberg and Tirole, 1991).

players incentive constraint at a point well above the most cooperative regime, and so in general one might expect the large player to press for sharing rules that are seemingly disproportionately to its advantage. If, as seems intuitive, the smaller player insists on a more “equitable” sharing arrangement, it will be difficult to craft an agreement that exerts much influence on the levels of activity. In particular, it seems unlikely that a voluntary agreement will do much to reduce aggregate production.

3 The Experimental Data

To evaluate the predictions of the model I above, I make use of experimental data from Mason et al. (1992), which contains details on the execution of the experiment. Here I restrict the discussion to details regarding the experimental designs.[7]

Subjects were placed in one of two market structures, each of which was based on linear demand and constant marginal costs. In both designs, $a = 4, b = \frac{1}{24}, c_1 = 0$. In the *symmetric* design, both players have marginal costs c_1, while in the *asymmetric* design the “large” firm has marginal costs c_1 and the “small” firm has marginal costs $c_2 = \frac{1}{2}$. The Cournot/Nash equilibrium outputs are then $q_1^N = q_2^N = 32$ in the symmetric design and $q_1^N = 36, q_2^N = 24$ in the asymmetric

[7] A copy of the experimental instructions is available in the appendix. Some key aspects of the experimental design are as follows: Subjects were recruited for a length of time 30 to 45 minutes greater than an experimental actually ran. After the instructions were read, a practice period was conducted. A monitor randomly chose the counterpart value while all subjects simultaneously selected their row value from a sample payoff table. Then, half of the subject pool was moved to another room. Each person was matched with an anonymous opponent in the other room. Subjects were told they would be paired with the same person for the duration of the experiment. In each market period the subjects wrote their choice on a record sheet and a colored piece of paper. These colored slips were then exchanged by a monitor, and earnings for the period were tabulated from the payoff table. They had many more record sheets and colored slips of paper than required for a session. Each subject was given a starting cash balance of $5.00 to cover potential losses, and was told that if their balance went to zero they would be discussed from the experiment with a $2.00 participation fee (the remaining participant would then be allowed to operate as an unfettered monopolist). Although it was feasible for a lost-cost player to dispatch a high-cost opponent without suffering losses, this never happened.

design. Profits were presented to subjects in the form of payoff tables which show the profit accruing from various output combinations. Subjects were told the experiment would run at least 35 periods, with a random termination rule (corresponding to a 20% chance that the experiment would be stopped) applied at the end of each period starting with period 35. Thus, the design mimics a repeated game with discount factor 0.8.

I use data from six experimental sessions. In three sessions based on the symmetric design, a total of 38 subjects (19 pairs) made choices for between 35 and 46 periods. In three asymmetric sessions, a total of 50 subjects (25 pairs) made choices for between for 36 to 46 periods. These data then induce an unbalanced panel; to avoid the potential for overly large influence on the results by subject pairs who were particularly fast at making decisions, or lucky in terms of the sequence of random termination actions, I restrict attention to the first 35 periods in the econometric analysis discussed below.

A visual summary of the experimental data is provided in Figures 2–4. Figure 2 shows the average choices made by subjects in the symmetric design, which I refer to as "LL." The Figure includes two reference levels of note: 32, the Cournot/Nash equilibrium level, and 24, the joint profit maximizing choice, Average choices tend to lie between these two reference levels, though closer to the Cournot/Nash output. Figure 3 compares average market choices in the two designs. To facilitate comparison, I plot the choices as fractions of the market Cournot/Nash equilibrium levels. The average market choices for the symmetric design are shown by the solid line, while the average choices for the asymmetric design are shown by the dashed line. On balance, the symmetric choices are a smaller fraction of the Cournot/Nash equilibrium output. Figure 4 explores this latter pattern at the individual player level. Here, I plot the average choices for L (low cost) players as the solid line, with the average choices for H (high cost) players as the dashed line. The panel on the left shows the levels of choices, while the panel on the right shows these choices as fractions of the respective Cournot/Nash equilibrium choices. That H player choices are smaller than L player choices, as depicted in the left panel, is to be expected in light of the cost disparity. But the interesting feature here is that H player choices are a larger fraction of the Cournot/Nash equilibrium choice, on average, than are the L player choices. This pattern is at odds with the theoretical design articulated above, and indeed earlier conceptual analyses; this disparity merits deeper investigation, a task I undertake with a formal econometric analysis in the next section.

4 Econometric Analysis

The econometric model I employ treats the database as a pooled cross-section/time series sample. In this vein, I analyze choices made in each period for each of the subjects in a particular design, and analyze systematic differences in behavior to asymmetries in subjects' payoff functions.

I assume that an individual's choice in period t is related to the rival's choice in period t - 1, via a dynamic reaction function; this framework is similar to the empirical model discussed in Huck et al. (1999, eq. (4)). Because human subjects are likely to be boundedly rational, I allow for noise in this relation. Moreover, as there is a potential for learning or signaling (Mason and Phillips, 2001), the noise affecting the dynamic reaction function is likely to be serially correlated. Correspondingly, I allow the disturbance to follow an autoregressive process; in that way, the dynamic strategies can be rewritten as including *N* lags:

$$q_{it} = \varphi_{i0} + \Sigma_{n=1}^{N} \mu_{nh} q_{i,t-n} + \Sigma_{n=1}^{N} \nu_{nh} q_{j,t-n} + \omega_{kt} + \eta_{it}, \qquad (1)$$

where q_{it} is player i's period t choice, j is $i's$ rival, k indexes the players' subject pair, $h = L$ (respectively, H) if player i is low (respectively, high) cost, and I allow for individual-specific fixed effects (via φ_{i0}) and pair-specific variance (*i.e.*, random effects, via ω^2_{kt}). The individual-specific residual, η_{it}, is assumed to be white noise. I assume there is no cross-equation covariance between subject pairs. In the results reported below, I allow for $N = 3$ lags; with that structure the residuals display no serial correlation.[8]

I estimate the parameters in eq. (1) using random effects, including pair-specific dummy variables, while imposing robust standard errors (equivalently, clustering at the subject pair level). This approach yields consistent, asymptotically efficient estimates (Fomby et al., 1988).

Results from this regression analysis are collected in Table 1. Here I display parameter estimates for the asymmetric structure in regression 1 (the second column) and for the symmetric structure regression 2 in (the third column). To economize on space, I denote the explanatory variables in regression 2 as x_{nL} and $y_{nL}, n = 1, 2, 3$ (though all subjects in that treatment were type L). In both regressions, subjects tend to respond positively to their own past choices and negatively to their rival's past choices. In addition, in the asymmetric design subjects with the high marginal cost, *i.e.*, subjects playing the role of high cost firms, choose markedly smaller values than do low cost subjects.

Once consistent and efficient estimates of the parameters are obtained, one can develop estimates of the carrot by considering the deterministic analogues to eq. (1). If agents choose the steady state values, q^*_L and q^*_H, for several consecutive periods this gives a system of two equations

[8] The approach I took here was to collect the residuals e_{it} and then regress residuals at time t on residuals from time $t-1$; *i.e.*, $e_{it} = \rho e_{it-1} + u_{it}$. Observing a statistically important parameter estimate $\hat{\rho}$ indicates the presence of serial correlation. In the variant with $N = 3$ the parameter estimate $\hat{\rho}$ was not statistically significant ($\hat{\rho} = .178$; t-statistic = 1.44). I also estimated a variant of equation 1 with $N = 2$ lags; the residuals from that regression did display serial correlation ($\hat{\rho} = .196$; t-statistic = 7.99). I conclude from this exercise that the appropriate version of equation 1 has $N = 3$.

in two unknowns:

$$q_L^* = \varphi_{0L} + \mu_{1L} q_L^* + \mu_{2L} q_L^* + \mu_{3L} q_L^* + \nu_{1L} q_H^* + \nu_{2L} q_H^* + \nu_{3L} q_H^*, \tag{2}$$

$$q_H^* = \varphi_{0H} + \mu_{1H} q_H^* + \mu_{2H} q_H^* + \mu_{3L} q_H^* + \nu_{1H} q_L^* + \nu_{2H} q_L^* + \nu_{3L} q_L^*, \tag{3}$$

where φ_{0L} (respectively, φ_{0H}) refers to the average value of φ_{0i} across all L (respectively, H) subjects. Define $\tilde{\mu} = \mu_1 + \mu_2 + \mu_3$ and $\tilde{\nu} = \nu_1 + \nu_2 + \nu_3$. Solving the system of equations (2)–(3) yields:

$$q_L^* = \frac{(1-\tilde{\mu})\varphi_{0L} + \tilde{\nu}\varphi_{0H}}{(1-\tilde{\mu_L})(1-\tilde{\mu_H}) - \tilde{\nu}^2}, \tag{4}$$

$$q_H^* = \frac{\tilde{\nu}\varphi_{0L} + (1-\tilde{\mu})\varphi_{0H}}{(1-\tilde{\mu_L})(1-\tilde{\mu_H}) - \tilde{\nu}^2}. \tag{5}$$

Inserting the estimates for the relevant parameters (taken from Table 1) into eqs. (4)–(5) then yields maximum likelihood estimates of the underlying equilibrium values.[9] Here, the resultant values are $q_L^* = 33.21$ and $q_H^* = 24.51$ for the asymmetric structure. These outputs are close to the one-shot Nash combination, indicating that subjects in the asymmetric structure were unable to effect much of a reduction in output. Moreover, most of the burden is carried by the larger player, as q_L^* is almost three units below player L's Nash choice, while q_H^* is slightly larger than H's Nash choice.

A similar approach may be used to estimate the carrot output in the symmetric structure.

[9] See Fomby et al. (1988) for details. Dynamic stability requires that all of the μ and ν parameters, as well as $1-\tilde{\mu}_h$ and $1-\tilde{\nu}_h, h = L, H$, are also less than one in magnitude – which they are here. This is a substantive concern, for dynamic stability allows one to interpret the carrot choices derived in eqs.eqs. (4)–(5) as equilibrium choices. Covariance information from the maximum likelihood estimates of the a's and b's can similarly be used to construct consistent estimates of the covariance structure for the steady state values (Fomby et al., 1988, Corollary 4.2.2).

Here, however, the regression equation is

$$q_{it} = \varphi_{i0} + \Sigma_{n=1}^{N} \mu_n q_{i,t-n} + \Sigma_{n=1}^{N} \nu_n q_{j,t-n} + \omega_{kt} + \eta_{it}, \tag{6}$$

as all agents are type L. Accordingly, the steady state choice for subjects in the symmetric design is

$$q_L^* = \frac{\varphi_0}{1 - \tilde{\mu} - \tilde{\nu}}, \tag{7}$$

where as above $\tilde{\mu} = \mu_1 + \mu_2 + \mu_3$ and $\tilde{\nu} = \nu_1 + \nu_2 + \nu_3$, and where φ_0 refers to the average value of φ_{0i} across all subjects. Using the parameter values from Table 1, one obtains $q_L^{**} = 29.22$. Comparing this estimate against the estimate for q_L^*, I conclude that subjects in the symmetric structure were more successful at reducing output.

A clear implication of these results is that, at least in these experimental markets, it is difficult for the low-cost player to induce the high-cost player to act cooperatively. This result comports to the predictions from the theoretical analysis above.

5 Discussion

This paper highlights the importance of asymmetry in compromising cooperative voluntary behavior in common property resource use (Scherer and Ross, 1990). Both the analytics, and experimental evidence, point to small sellers as the root cause of these difficulties. While a cooperative regime would require tilting extraction in the direction of the larger firm, small sellers resist. This intransigence ultimately undercuts the ability to form an arrangement that limits harvesting.

There is some disagreement in the literature as to whether the difficulty for parties to construct voluntary cooperative arrangements, such as field unitization, warrants some form of government intervention. Libecap and Wiggins (1985) take the position that difficulties in forming voluntary unitization agreements may reflect the importance of asymmetric information. To the extent this explanation carries weight it would argue against government intervention, for example by mandating unitization agreements. By contrast, Weaver (1986) offers arguments in support of government imposed unitization arrangements. It is interesting to note that two of the arguments she offers are: that "profitable obstructionism" can easily undermine voluntary unitization, and the importance of "mistrust of the majors" (Weaver, 1986, p. 101). Placed in the context of my analysis, these features point to the likely difficulty of forming an arrangement that will preclude opportunism, particularly if such an arrangement is perceived to disproportionately favor the larger firm.

One explanation for the results articulated above is that subjects' utility is based on both the payoffs they receive and the payoffs their rival receives. For example, if subjects bear disutility when there is disparity in payoffs, then subject i's utility can be expressed as

$$U_i(\pi_i, \pi_j) = \pi_i + \gamma|\pi_i - \pi_j|.$$

Denoting the low-cost player as subject 1, and the high-cost player as subject 2, and assuming $\pi_1 > \pi_2$, the two subjects' utilities can be written as

$$U_1 = (1-\gamma)\pi_1 + \gamma\pi_2;$$

$$U_2 = (1+\gamma)\pi_2 - \gamma\pi_1.$$

Grafting such a scenario onto the linear-quadratic framework introduced above, the one-shot Nash equilibrium would be

$$\tilde{q}_1^* = \frac{a + c - \gamma(a - c)}{3 - 4\gamma^2)b}; \tag{8}$$

$$\tilde{q}_2^* = \frac{a - 2c + a\gamma}{3 - 4\gamma^2)b}. \tag{9}$$

It is easy to see that this pushes the Nash equilibrium towards a smaller (respectively, higher) output for the low-cost (respectively, high-cost) player. It also induces a similar effect on the quasi-cooperative player.

An alternative explanation for the experimental outcome I describe in this paper is that small sellers are less patient, *i.e.* they use a smaller discount factor. As in the previous adaptation, this change will induce the high-cost (respectively, low-cost) player to select a larger (respectively, smaller) output in the quasi-cooperative arrangement than is predicted in the model with a common discount factor.

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6 APPENDIX: EXPERIMENTAL INSTRUCTIONS

This is an experiment in the economics of market decision making. The National Science Foundation and other funding agencies have provided funds for the conduct of this research. The instructions are simple. If you follow them carefully and make good decisions you may earn a CONSIDERABLE AMOUNT OF MONEY which will be PAID TO YOU IN CASH at the end of the experiment.

In this experiment you will be paired at random with one other person known to you as ”the other participant”. The identity of this person will not be revealed during the experiment, nor will this person know who you are.

Over several market periods each of you will choose at the same time values of X in a table. The two selected values of X will then be used to determine the payments made to you and the other participant.

Both of you will be selecting X from tables consisting of rows and columns. The values YOU may select are written down on the left hand side of the table and are row values. You will always pick a row value. Treat the values selected by the other participant as column values. The intersection of the row and column value determines your earnings for that period. Earnings are recorded in a fictitious currency called tokens. At the end of the experiment tokens are converted into cash at the exchange rate of 1000 tokens= $1.00.

As mentioned, all earnings will be paid to you in cash at the end of the experiment. At the beginning of the experiment you will be given an initial balance of 3,000 tokens ($3.00). Earnings will be added and losses will be subtracted from this balance. If your balance should go to zero or become negative, you will be excused from the experiment and paid a participation fee of $5.00.

This fee will be paid to everyone and cannot be influenced by what happens during the session. In the event the other participant's balance becomes zero or negative, he or she will be excused from the experiment and for the duration of the experiment your column value will be fixed at zero.

A sample payment table is provided below. Down the left side of this table you may select values from 0 to 20. The other participant also selects values from 0 to 20, which become column values to you. For example, if you pick 8 and the other participant picks 10, then at the intersection of row 8 and column 10 the entry 376 represents your earnings in tokens. Or, you might have picked 15 and the other persons might have chosen 19. At the intersection of row 15 and column 19 your earnings would be -33, and you would take a loss.

During each market period you will be asked to keep a record of all choices and earnings. There is a sample record sheet at the end of these instructions. It is filled in for two market periods labeled Sl and S2. You will be given several record sheets with many more market periods than you will need in the experiment. Everyone will receive a beginning balance of 3000 tokens as shown in the first period of row 2. In row 3 you record your choice of X. Suppose you choose 8, as discussed above, this value is entered on row 3 and also written on a red or blue slip of paper with the market period shown. The color of your payment table is the same as the color of the paper on which you write your choices. Once you have made a choice, an experimenter will take your choice and then deliver to you on a different colored slip of paper your counterpart's choice. You can then complete entries (4) - (6), recording the value selected by the other participant (4), and your earnings from the payment table (5). Since the other participant picked 10 in this example, your earnings in row 5 are 376. Your balance in row (6) is the sum of entries on row (2) and (5) or 3376.

This balance is carried to the top of the next column in period S2. In period S2, the sample record sheet shows your choice of 15 while the other person chooses 19. By looking at the intersection of row 15 and column 19, it can be verified that you earn -33. Thus your balance in this market period falls to 3343 tokens.

Are there any questions about this procedure?

SUMMARY

1. Each period you must select a value for X from the table. Your choice is always a row value.

2. Your earnings from the table will depend on the value you choose and what the other person chooses.

3. The payment you receive can be found at the intersection of the row value you choose and column value chosen by the other participant in the table.

4. Record your choices and those of the other participant on a record sheet write down your earnings and keep a record of your total balance as shown on the record sheet.

At this time we will do a practice trial with the Sample Payment Table. Choose a value of X between 0 and 20 and record it on the Sample Record Sheet for period S3. One of the experimenters will act as the other participant, and randomly choose the other participant's value for X. Based on your choice and that of the other participant, determine your earnings from the Sample payment Table and fill out the record sheet for the third sample period. One of the experimenters will come to check your record sheet. If you have any questions on how to fill out the sample record sheet or how to calculate earnings, the experimenter can answer your questions.

SAMPLE PAYMENT TABLE

VALUE SELECTED BY THE OTHER PARTICIPANT

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
1	426	453	414	376	337	299	260	222	183	145	107	68	30	-9	-47	-86	-124	-163	-201	-240	-278
2	906	513	473	433	394	354	314	274	234	194	154	114	74	34	-6	-46	-86	-126	-166	-206	-246
3	926	571	530	488	447	405	364	323	281	240	198	157	115	74	33	-9	-50	-92	-133	-175	-216
4	946	626	583	540	497	454	411	368	325	283	240	197	154	111	68	25	-18	-61	-104	-146	-189
5	961	678	633	589	544	500	456	411	367	323	278	234	189	145	101	56	12	-33	-77	-121	-166
6	976	726	681	635	589	543	497	451	405	360	314	268	222	176	130	84	39	-7	-53	-99	-145
7	985	772	725	678	630	583	536	488	441	394	346	299	252	204	157	110	62	15	-33	-80	-127
8	994	815	766	718	669	620	571	522	473	425	376	327	278	229	181	132	83	34	-15	-64	-112
9	997	855	805	754	704	654	604	553	503	453	402	352	302	252	201	151	101	50	00	-50	-101
10	1000	892	840	789	737	685	633	581	530	478	426	374	323	271	219	167	115	64	12	-40	-92
11	997	926	873	820	766	713	660	607	553	500	447	394	340	287	234	181	127	74	21	-33	-86
12	994	957	902	848	793	738	683	629	574	519	465	410	355	300	246	191	136	81	27	-28	-83
13	985	985	929	873	817	760	704	648	592	536	479	423	367	311	254	198	142	96	30	-27	-83
14	976	1010	953	895	837	780	722	664	606	549	491	433	376	318	260	203	145	87	30	-28	-86
15	961	1033	973	914	855	796	737	678	618	559	500	441	382	323	263	204	145	86	27	-33	-92
16	946	1052	991	931	870	809	749	688	627	567	506	445	385	324	263	203	142	81	21	-40	-101
17	926	1068	1006	944	882	820	757	695	633	571	509	447	385	323	260	198	136	74	12	-50	-112
18	906	1081	1018	954	891	827	763	700	636	573	509	445	382	318	254	191	127	64	00	-64	-127
19	879	1092	1027	962	896	831	766	701	636	571	506	411	376	311	246	181	115	50	-15	-80	-145
20	852	1099	1033	966	899	833	766	700	633	567	500	433	367	300	234	167	101	34	-33	-99	-166

Figure 1: Asymmetric Incentives to Cooperate.

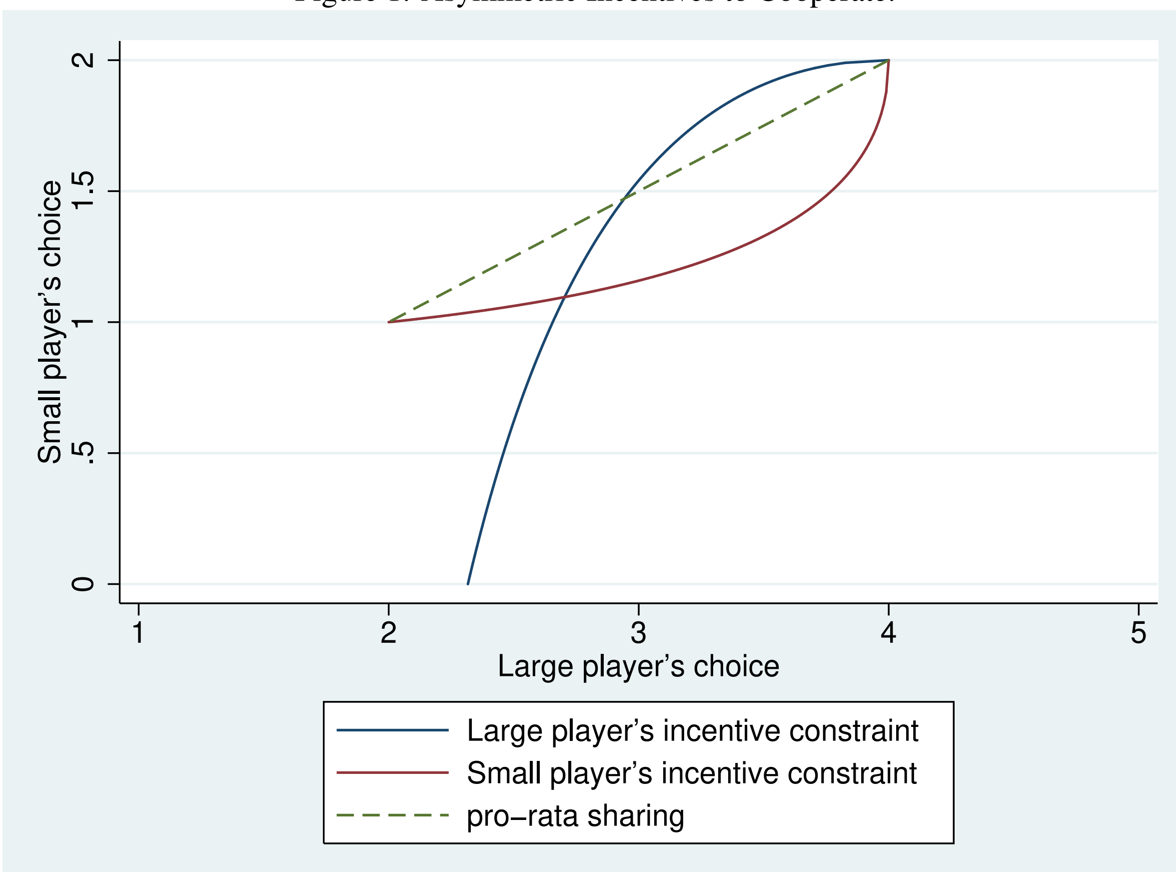

Figure 2: Experimental results: symmetric firms.

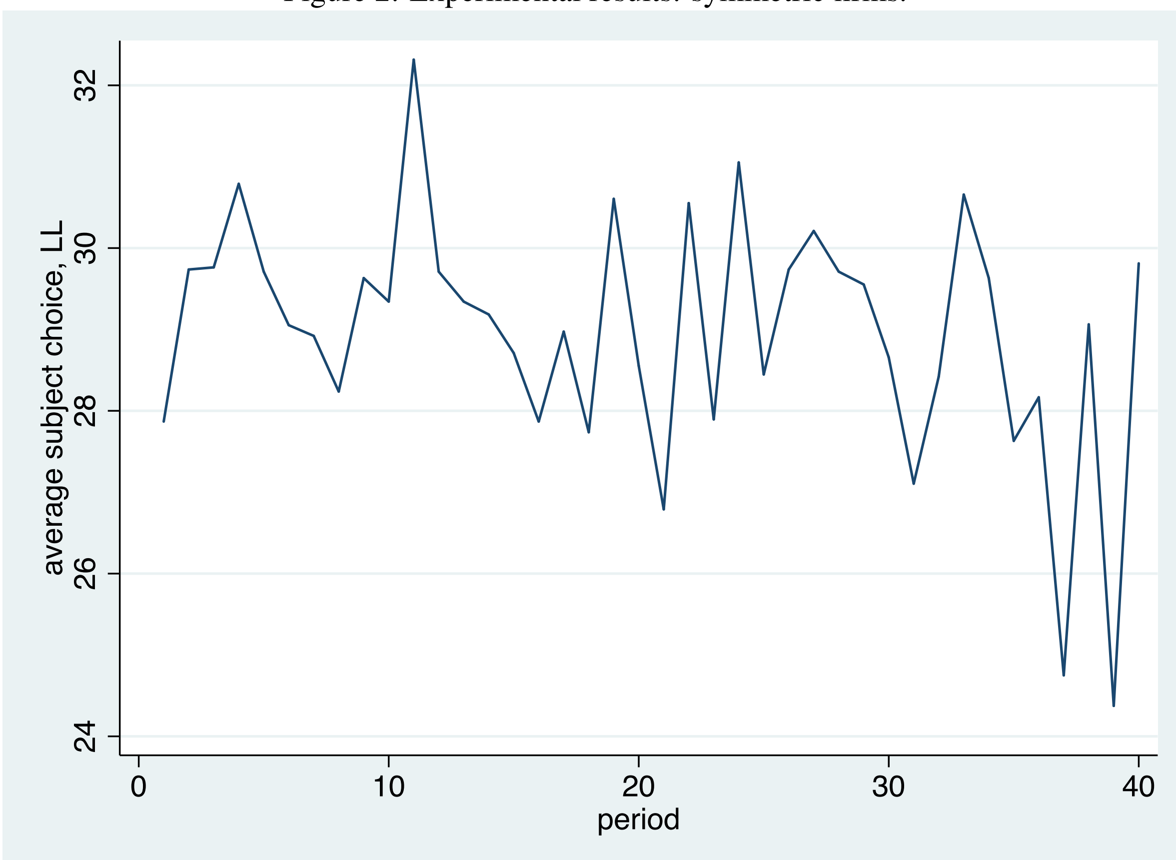

Figure 3: Experimental results: symmetric vs. asymmetric markets.

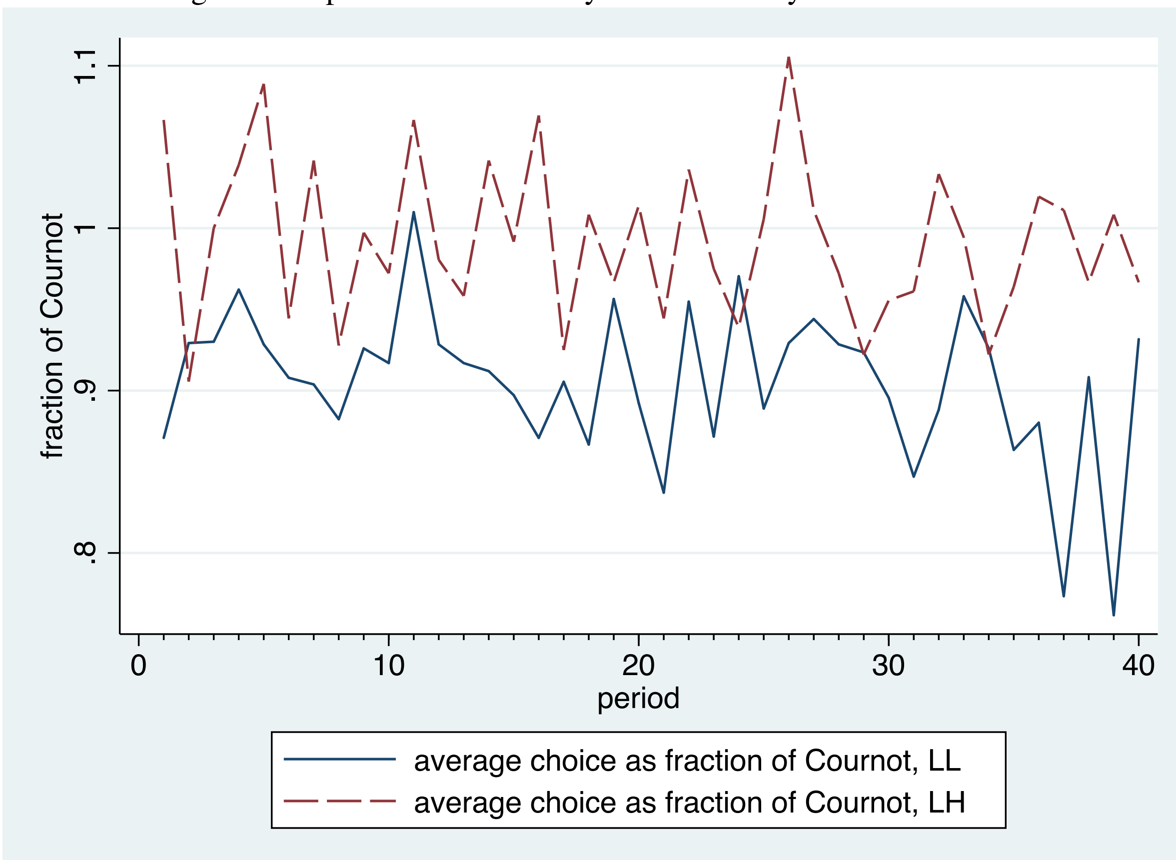

Figure 4: Experimental results: asymmetric firms.

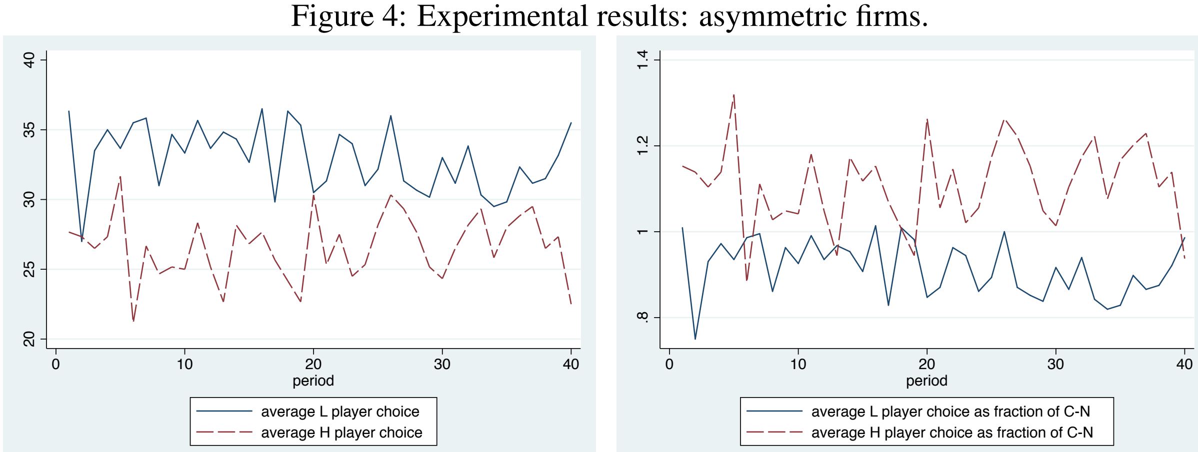

Table 1: Random Effects Regression Results: Asymmetric vs. Symmetric Experimental Designs.

	asymmetric	symmetric
xlL	-0.264***	-0.327***
	(0.069)	(0.074)
xl2L	0.151	0.026
	(0.107)	(0.072)
xl3L	-0.040	-0.131***
	(0.050)	(0.030)
ylL	0.253**	0.210***
	(0.099)	(0.060)
yl2L	-0.033	-0.022
	(0.070)	(0.040)
yl3L	0.075	0.103**
	(0.066)	(0.046)
xlH	-0.050	
	(0.055)	
xl2H	0.100	
	(0.141)	
xl3H	-0.059	
	(0.064)	
ylH	0.182***	
	(0.065)	
yl2H	-0.141***	
	(0.048)	
yl3H	0.029	
	(0.048)	
constant	21.064***	42.757***
	(4.233)	(4.300)
Q_{L*}	33.21	29.22
	(1.986)	(0.945)
Q_{H*}	24.51	—
	(4.312)	
N	1600	1216
R^2	0.5375	0.4350

All regressions include individual-specific dummy variables
Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$