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Economic Theory

Playing Cournot although they shouldn't

Endogenous timing in experimental duopolies with asymmetric cost

Miguel A. Fonseca[1], Steffen Huck[2], and Hans-Theo Normann[1]

[1] Economics Department, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK (e-mail: {m.fonseca,hans.normann}@rhul.ac.uk

[2] Department of Economics & ELSE, University College London, Gower Street, London WC1E 6BT, UK (e-mail: s.huck@ucl.ac.uk)

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Summary. In this note, we experimentally investigate the extended game with action commitment in a Cournot duopoly with asymmetric cost. Risk dominance considerations allow to select a unique equilibrium in which the low-cost firm is the Stackelberg leader. The data, however, do not support the theory as simultaneous-move play is modal. Average output choices are in line with the Cournot equilibrium. This suggests that Cournot is a much more robust predictor for competition in markets than theory suggests.

Keywords and Phrases: Commitment, Endogenous timing, Experimental economics, Risk dominance, Stackelberg.

JEL Classification Numbers: C72, C92, D43.

1 Introduction

Oligopoly models with endogenous timing have become popular to explain the emergence of Stackelberg leadership. The most frequently applied model is probably the action commitment game of Hamilton and Slutsky (1990). In that game, production can occur in one of two periods. In the first period, firms can either produce some quantity or decide to wait. If, and only if, they have decided to wait, they are informed about the other firm's first-period action and can then produce their output in the second period. Hamilton and Slutsky show that this game has

Correspondence to: H.-T. Normann

three subgame perfect equilibria of which only two are in undominated strategies. These two equilibria predict that one firm chooses a Stackelberg-leader quantity in the first period while the other firm waits and produces the Stackelberg-follower quantity in the second period.

While being an elegant theoretical justification for strategic asymmetries between firms, the model's prediction failed in a recent experimental study. Huck, Müller, and Normann (2002; hereafter HMN) implemented Hamilton and Slutsky's model one-to-one in an experimental market but Stackelberg leadership almost never emerged. Significantly, only 5.4% of all observations were in line with the predicted Stackelberg equilibria. Instead, there was a strong tendency toward symmetric outcomes. Roughly one half of all observations were either Cournot play, symmetric collusion, or punishments of Stackelberg behavior (where endogenous followers match high Stackelberg-leader quantities rather than playing best replies). Many observations had to be classified as coordination failures. Concluding from the data in HMN, it appears that Hamilton and Slutsky's prediction is by and large rejected.

Despite this evidence, HMN are cautious when drawing general conclusions from their data. They argue that the complete symmetry of firms in their experiment may have prevented coordination on one of the Stackelberg equilibria. This is van Damme and Hurkens' (1999) point. They provide a compelling theoretical argument to believe that Stackelberg leadership is more likely to emerge when firms have asymmetric costs. The key idea is that the asymmetry should help to overcome the indeterminacy of Hamilton and Slutsky's solution. Van Damme and Hurkens (1999) argue that, since early commitment implies taking a substantial risk, one should expect that the firm for which commitment is less risky should assume the role of leader. Following Harsanyi and Selten's (1988) risk dominance considerations[1], they show that this is the firm with lower costs. Hence, with asymmetric cost, a unique Stackelberg equilibrium survives the application of equilibrium refinements.

In this note, we implement the extended game with action commitment with asymmetric firms in a laboratory experiment. We do this by introducing a low-cost and a high-cost firm, matching van Damme and Hurkens' (1999) environment. Our results indicate that HMN's results are robust. Low cost firms are not able to use their cost advantage to become Stackelberg leaders. Again, many outcomes have both firms committing early and Cournot play is modal.

2 The model

Following van Damme and Hurkens (1999), we study a Cournot duopoly market with linear demand

$$p(q_1 + q_2) = \max\{30 - q_1 - q_2, 0\}, \tag{1}$$

[1] The risk dominance concept is by Harsanyi and Selten (1988). It relies on quantifying the risk associated with each Nash equilibrium of a game. In simple 2×2 games, this can be done by computing the (Nash) product of deviation losses. The risk dominant Nash equilibrium will be the one whose product of deviation losses is the greatest (see van Damme and Hurkens, 1999, and Section 2 below).

and asymmetric linear cost functions

$$C_1(q_1) = 6q_1, \tag{2}$$

$$C_2(q_2) = 8q_2. \tag{3}$$

Hamilton and Slutsky's (1990) extended game with action commitment modifies the standard duopoly model by allowing for two production periods before the market clears. Firms can choose their quantities from a set $\mathcal{Q}$ in one of the two periods, $t = 1, 2$. Let W indicate the decision to wait until period 2. Then, in period 1, firms choose from the set $\mathcal{Q} \cup \{W\}$. If, and only if, they decide to wait, they choose a quantity in $\mathcal{Q}$ in the second period after being informed about the other firm's first-period choice. In the experiment, we let subjects choose their quantities from the finite set $\mathcal{Q} = \{3, 4, 5, ..., 14, 15\}$. The complete payoff matrix given to the subjects is reproduced in the appendix.[2]

What are the predictions for this game? Following Hamilton and Slutsky (1990), we eliminate weakly dominated strategies. We analyze the truncation of the extended game in which profits for the wait strategy, W, are derived using standard best-replies in period 2. In this truncated game we find that, for firm 1, the strategies 3 and 4 are strictly dominated by 5, and 14 and 15 are strictly dominated by 13. Also, strategies 5, 6, 7, 8 and 9 are weakly dominated by W. For firm 2, strategy 3 is strictly dominated by 4, strategies 11, 12, 13, 14 and 15 are strictly dominated by 10, and strategies 4, 5, 6, and 7 are weakly dominated by W. Thus, we can focus on the 4×5 game depicted in Table 1. It is easy to verify that this 4×5 game has two pure strategy[3] subgame perfect equilibria in weakly undominated strategies. In the first equilibrium, firm 1 commits to an output of 13 in $t = 1$ and firm 2 waits and produces its best reply (i.e., an output of 5) in $t = 2$. In the second equilibrium, firm 2 commits to an output of 10 in $t = 1$ and firm 1 waits and produces its best reply (i.e., an output of 7) in $t = 2$. The simultaneous-move Cournot equilibrium has firm 1 producing 9 units of output and firm 2 producing 7 units of output. Note that this equilibrium is in weakly dominated strategies.

Van Damme and Hurkens (1999) apply Harsanyi and Selten's (1988) risk dominance considerations to select among the two Stackelberg equilibria. If we reduce the game further and consider a game in which each player can choose only the two equilibrium strategies, $\{13, W\}$ and $\{10, W\}$, we get the 2×2 game constituted by the four cells in the lower right corner of the matrix in the Table 1. While we still obtain the two Stackelberg outcomes as strict equilibria, it is straightforward to determine the risk-dominant equilibrium in the reduced 2×2 game. Moreover, van Damme and Hurkens (1999) show that this is a reliable procedure in this version the action commitment game.[4] In the equilibrium with firm 2 as the Stackelberg leader, the product of deviation losses is $(50 - 42) * (49 - 13) = 288$, while in the equilibrium with firm 1 as the Stackelberg leader, the product of deviation losses

[2] The table was derived using equations (1) to (3). In order to guarantee uniqueness of best replies, the payoffs of 14 out of 225 cells were altered (substraction of 1 payoff point).

[3] Like van Damme and Hurkens (1999), we do not consider mixed strategies. Mixed strategies may however play a role. See van Damme and Hurkens (1999) and HMN.

[4] In general, this procedure may select solutions that are not risk-dominant in the overall game. See van Damme and Hurkens (1999).

Table 1. Truncation of the extended game

		low-cost firm				
		10	11	12	13	W
high-cost-firm	8	60 32	55 24	48 16	39 8	64 48
	9	50 27	44 18	36 9	26 0	56 45
	10	40 20	33 10	24 0	13 −10	49 50
	W	80 36	77 30	84 25	85 20	72 42

is $(85 - 72) * (20 + 10) = 390$. The product of deviation losses is larger in the equilibrium where the efficient firm 1 leads. Therefore, risk considerations allow the conclusion that the efficient firm will emerge as the Stackelberg leader.

3 Experimental design and procedures

Subjects received written instructions, the payoff matrix reproduced in the Appendix and a game log in which they would record both decisions and payoffs in each round. Subjects were given an identification number, through which they would conduct their decisions and that was known only to them. The experiments were run with pen and paper. In all sessions, ten subjects participated. There were five high-cost firms and five low-cost firms, and subjects acted as either a high or a low cost firm for the entire experiment.

In the main treatment, we studied the markets with endogenous timing as described in Section 2. In a control treatment we studied the simple simultaneous-move Cournot market with the same cost and demand parameters.[5] In both treatments, subjects were randomly rematched in every round and this was commonly known. For each treatment we conducted three sessions. In all, 60 subjects participated. There were 20 rounds in each experiment. Three rounds were randomly selected and profits from these rounds paid off using an exchange rate of two British pence for one experimental profit unit. Average payments were £ 8.30 (including a show-up fee).

4 Results

We start with our main question. Do the efficient firms emerge as endogenous Stackelberg leaders? Out of 300 observations,[6] the low-cost firm emerged as a Stackelberg leader 94 times. In 53 cases the high-cost firms became a Stackelberg

[5] The only Cournot duopoly experiment with asymmetric cost in the literature we are aware of is Mason et al. (1992). They observe that cost asymmetries reduce attempts to collude.

[6] Recall that we have three sessions with five duopolies playing 20 periods.

Table 2. Average quantities

Firms' cost:		in $t = 1$	Follower in $t = 2$	Cournot in $t = 2$	Cournot treatment
	output	8.99	8.21	8.83	8.58
low	std. dev.	1.95	1.35	1.36	1.36
	# obs.	201	53	46	300
	output	8.26	7.14	7.22	7.25
high	std. dev.	1.81	1.85	1.60	1.58
	# obs.	160	94	46	300

leader. In 107 cases simultaneous play in $t = 1$ occurred. Simultaneous play in $t = 2$ occurred in the remaining 46 cases. Put it a different way, the low-cost firms committed themselves in $t = 1$ in 201 cases while high-cost firms committed themselves early in 160 cases.

The data support the van Damme-Hurkens prediction only in that low-cost firms committed themselves more often in $t = 1$. However, this difference is not significant at standard levels.[7] Moreover, there is no noticeable time trend towards the risk-dominant equilibrium since timing choices in the first and second half of the experiment is virtually identical.[8] Finally, the percentage of Stackelberg leader-follower outcomes with either the low or the high cost firm moving first (49%) is only slightly higher than in the symmetric-cost setup in HMN (46.51%). It appears that adding cost asymmetries changed the timing decisions only moderately. Simultaneous play still emerged in the majority of cases and Cournot-Nash play in period $t = 1$ was the most frequently observed outcome. Regarding the timing decisions, by and large, the theory is rejected.

The output decisions of firms are not in favor of Stackelberg either. In Table 2 we report average outputs of both treatments for efficient and inefficient firms. For the endogenous timing treatment, we report quantities produced in $t = 1$ and $t = 2$ separately, and we further distinguish between output produced by explicit followers and output produced by simultaneously moving firms in $t = 2$. When committing themselves in $t = 1$, the efficient firms produce an average output of 8.99 which is remarkably close to the Cournot prediction of 9 and substantially smaller than the Stackelberg leader prediction, 13. This value is also very close to the simultaneous-move Cournot outcome in $t = 2$ and the Cournot control treatment.[9] We already noted that high-cost firms often commit in $t = 1$. When

[7] Ignoring possible dependencies among observations within sessions, we count each subject as one observation. Mann-Whitney's U statistic is 77 which fails to yield significant differences for $n_1 = n_2 = 15$.

[8] Over the second half of the experiment, the following timing outcomes were observed. Simultaneous play in $t = 1$: 53 cases. Low-cost firm Stackelberg leadership: 48 cases. High-cost firm Stackelberg leadership: 28 cases. Simultaneous play in $t = 2$: 21 cases. As is immediate from the data above, behavior in the first half is very similar.

[9] In our Cournot treatment, we do not observe industry output averaging above the equilibrium prediction as it was the case in Mason et al. (1992).

doing so, they choose on average 8.26 which is above the Cournot equilibrium of 7 but again smaller than the Stackelberg leader prediction, 10.

Let us illustrate first-period behavior of the low-cost firms a bit further. Table 3 shows absolute frequencies (across all sessions) of first-period quantities chosen by low-cost firms. First of all, recall that the quantities 3, 4, 14 and 15 are strictly dominated actions in the 2-stage quantity commitment game. According to Table 3 these quantities are rarely chosen in the first period. Nevertheless, first-period choices are quite dispersed over the interval from 6 to 13. Outputs of 8, 9 and 10 emerge as modal actions, yielding average output choices which are according to the Cournot equilibrium. The Stackelberg leader action, 13, was modal among the outputs larger than 10 but it was chosen in only 16 out of 201 cases (7.9 %). Again, this does not support the Stackelberg prediction.

Table 3 also shows predicted best replies ($BR^h(q^l)$) and actual follower behavior ($q^h, t = 2$) of high-cost firms. Roughly, high-cost firms' average replies are in line with the prediction. Only for the quantity choices 12 and 13 there is a moderate tendency to produce more than predicted. This is in contrast to the results in HMN and Huck, Müller, and Normann (2001). In those papers there was a strong tendency of followers to overproduce whenever the Stackelberg leader produced more than the Cournot output. Huck, Müller, and Normann (2001) show that this overproduction is in line with aversion against disadvantageous inequality. Here it appears that the exogenously imposed asymmetry of cost functions reduces inequality aversion.[10]

Table 3. Distribution of first-period choices, best replies and actual average replies in period 2

$q^l, t = 1$	3	4	5	6	7	8	9	10	11	12	13	14	15
# obs.	1	2	2	8	20	53	42	45	6	4	16	1	1
$BR^h(q^l)$	10	9	9	8	8	7	7	6	6	5	5	4	4
$q^h, t = 2$	10.00	9.00	9.00	7.20	8.00	7.15	7.00	6.56	6.00	7.00	7.57	4.00	4.00
std. dev.	0.00	0.00	0.00	2.39	0.00	0.78	0.00	2.28	0.00	2.16	4.72	0.00	0.00
# obs.	1	2	2	5	8	26	18	16	2	4	7	1	1

5 Conclusion

In this note, we experimentally investigate Hamilton and Slutsky's (1990) extended game with action commitment in a duopoly with asymmetric cost. Van Damme and Hurkens (1999) apply Harsanyi and Selten's (1988) risk dominance considerations to select a unique equilibrium solution in this game which has the low-cost firm emerging as the Stackelberg leader. The data, however, do not support the theory.

[10] This effect is similar to an effect in "mini ultimatum games" where the equal split is replaced by an almost equal split. If the latter favors the proposer responders' willingness to accept the unfair offer increases significantly. See Güth, Huck, and Müller (2001).

Regarding the timing decisions, Cournot-Nash play is modal. Also, output decisions are on average according to the Cournot equilibrium. This confirms results obtained in Huck, Müller, and Normann (2002). In their study, firms were perfectly symmetric which caused coordination problems that could caused the failure of the theory. In the light of our new data, it seems, however, that Cournot is a much more robust predictor of competition in markets than suggested by the endogenous timing literature.[11]

Why does the theory by and large fail in our study? One possible explanation is that subjects do not gain much from delaying their output decisions. Consider the cases in which both firms commit early. If we compare actual profits to the profits which would have been realized if subjects had delayed and played a best reply, a moderate increase of 12.5% results, implying an increase in monetary payments of £ 0.35. This suggests that Harrison's (1989) flat-maximum critique might apply. If firms do not gain much by delaying, this could prevent sequential-move outcomes from emerging more frequently and give rise to Cournot outcomes. However, the flat-maximum critique generally applies to Cournot games with linear demand and cost which induce quadratic profit functions. But, despite the flatness of the payoff function, behaviour typically converges very close to Cournot equilibria (when the matching is random or at least three firms compete); see, for example, Huck, Normann, and Oechssler (2003) who survey experimental Cournot data.[12]

It seems promising to investigate whether the support for endogenous Stackelberg leadership increases in variants of the timing model with a stronger incentive to move second. For example, in models proposed by Mailath (1993) and Daughety and Reinganum (1994), one firm is informed about the state of demand while the other one is not. Here, the uninformed firm is predicted to become the endogenous Stackelberg follower (see, however, Normann, 1997). This is an intuitive hypothesis which might be confirmed in experiments. The uninformed firm gains by moving second as it can learn about the state of demand by observing the informed first mover's action. Pal (1991) proposed a model with symmetric firms where production costs are lower in the second period. Again, it seems conceivable that such a setup could support Stackelberg-like outcomes to occur in experiments since the follower can save significant costs by moving second.

Appendix

A Instructions to participants (Endogenous timing treatment)

Welcome to our experiment! Please read these instructions carefully and if you have any questions, please raise your hand and we will be glad to clarify them. Also, please do not talk during the experiment; if you need help, please raise your hand.

In this experiment you will play the role of a firm. This firm is in a market with another firm. In this market, there are 2 time periods. You will have to choose in

[11] For recent theoretical papers *in favor* of Cournot outcomes in endogenous timing models, see Matsumura (1999) and Normann (2002).

[12] There is typically some collusion in duopolies where subjects play in fixed pairs.

which period to produce, and how much of your good you want to produce. Note that your profits do not depend on when you produce, but on how much you and the other firm produces. The more profits you make, the more money you will earn.

In the first period, you can either produce a quantity between 3 and 15 or you can choose to wait. If you choose to produce, you will not be able to know what the other firm is doing. If you choose to wait, you will have to make your production choice in the second period. You will also know whether the other firm has chosen to wait or what has he produced. To help you in your choice, there will be a table provided to you that gives the profit levels for every possible choice you and the other firm produce.

The payoff matrix works as follows: the quantity your firm produces is indicated at the head of each row. Your profits and the profits of the other firm will then be in the cells that correspond to your choice and the choice of the other firm. Your profits will be the large numbers written on the bottom left hand corner of each cell in italic. The profits are not measured in real money. Your earnings will be converted to £ later on in the experiment.

You will be given an experimental log. In each round, you will write down your decisions on the experimental log. After you have written your decision, it will be randomly matched with another firm. After the matching, you will be told of what the other firm has chosen to do and you will register the decisions of the firm in your experimental log. If necessary, the second period of the round will take place and then you will have to register your profits in the appropriate column of the log. The experiment will consist of 20 rounds. Please raise your hand after you have written your decision, so the co-ordinator can record it.

Your anonymity will be kept throughout the experiment. To ensure this, you will be given an ID code, through which you will make your decisions and receive your payoff.

Concerning the payment, you will receive a participation prize of £ 5 and you will receive an extra payment that consists in the pound sterling equivalent of the payoff of any 3 rounds of the experiment that will be randomly selected. One unit of our currency is worth 2 pence.

B Instructions (Cournot)

Welcome to our experiment! Please read these instructions carefully and if you have any questions, please raise your hand and we will be glad to clarify them. Also, please do not talk during the experiment; if you need help, please raise your hand.

In this experiment you will play the role of a firm. This firm is in a market with another firm. You will have to choose how much of your good you want to produce. The more profits you make, the more money you will earn.

To help you in your choice, there will be a table provided to you that gives the profit levels for every possible choice you and the other firm produce. The payoff matrix works as follows: the quantity your firm produces is indicated at the head of each row. Your profits and the profits of the other firm will then be in the cells that correspond to your choice and the choice of the other firm. Your profits will be the large numbers written in italic on the bottom left hand corner of each cell.

The profits are not measured in real money. Your earnings will be converted to £ later on in the experiment. You will be given an experimental log. In each round, you will write down your decisions on the experimental log. After you have written your decision, it will be randomly matched with another firm. After the matching, you will be told of what the other firm has chosen to do and you will register the decisions of the firm in your experimental log. Then you will have to register your profits in the appropriate column of the log. The experiment will consist of 20 rounds. Please raise your hand after you have written your decision, so the co-ordinator can record it.

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