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ENDOGENOUS TIMING IN DUOPOLY: EXPERIMENTAL EVIDENCE

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Endogenous timing in duopoly: Experimental evidence*

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Abstract

In this paper we experimentally investigate the extended game with observable delay of Hamilton and Slutsky (Games Econ. Beh., 1990). Firms bindingly announce a production period (one out of two periods) and then they produce in the announced sequence. Theory predicts simultaneous production in period one but we find that a substantial proportion of subjects choose the second period.

Keywords: Commitment, Endogenous timing, Experimental economics, Cournot, Stackelberg.

JEL classification numbers: C72, C92, D43

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1 Introduction

There is substantial interest in the theoretical literature on endogenous timing in games. This literature started with Saloner (1987), Hamilton and Slutsky (1990), and Robson (1990) and includes recent contributions by Amir and Grilo (1999), Matsumura (2002), Normann (2002) and van Damme and Hurkens (2004). The basic questions these models try to answer is simple but significant. When are firms likely to play either a simultaneous-move game or a sequential-move game? In models with endogenous sequencing, the order of output or price decisions is not exogenously specified. Instead, it is derived from firms' decisions in a timing game.

Several recent experiments have attempted to validate the theory empirically[1] but support for the theory was by and large not found. In these experiments, simultaneous-move Cournot outcomes are modal—in contrast to the prediction. Even when sequential moves occur, Stackelberg leaders produce less than predicted while followers produce more (see also Huck, Müller and Normann, 2001).

Why does theory perform rather poorly in experiments? The theory underlying the experiments predicts the emergence of Stackelberg equilibria and typically there exist two Stackelberg equilibria. This causes two problems. First, coordination problems occur in the experimental markets since either firm may emerge as the Stackelberg leader. Neither Stackelberg equilibrium is preferable to the other and subjects find it difficult to coordinate on one.[2] Second, it is difficult to see from a behavioral perspective why players should coordinate on an equilibrium with large payoff differences (as it is the case in a Stackelberg leader-follower outcome). It is well known that many subjects in experiments exhibit an aversion against disadvantageous inequality. Such inequality aversion might render the Stackelberg equilibria unappealing candidates for convergence in an experiment.

In this paper, we want to further explore the reasons for the failure of the theory by investigating a timing game with a unique and symmetric equilibrium. The basis of the experiments is

[1] Huck, Müller and Normann (2002) investigate Hamilton and Slutsky (1990)'s action commitment game. Müller's (2005) experiments are on Saloner's (1987) model, extended by Ellingsen (1995). Fonseca, Huck and Normann (2005) analyze endogenous timing with asymmetric cost, as modelled by van Damme and Hurkens (1999).

[2] Most of the theoretical literature has ignored the coordination problem firms face in a duopoly with endogenous timing. An exception are van Damme and Hurkens (1999, 2004) who analyze a timing game with cost differences between firms. In their models, a unique Stackelberg equilibrium with the efficient firm as the Stackelberg leader is selected. However, Fonseca, Huck and Normann (2005) still observe simultaneous play as the modal case in related experiments.

Hamilton and Slutsky's (1990) extended game with observable delay in a quantity-setting framework. The equilibrium of this extended timing game is in simultaneous moves and has equal quantities as firms have symmetric costs. Hence, in our experiments, neither coordination failure nor inequality aversion should hinder the predictive power of the theory. Our conjecture is that the theory will be confirmed in the new experiments. If symmetric outcomes fuelled by inequality aversion have been previously observed even though they were not predicted, then it seems likely that the theory will be vindicated if symmetric outcomes are predicted.

A second novelty is that we run experimental sessions both with randomly matched participants as well as with participants in fixed duopoly pairs. Previous experiments have simulated one-shot interaction (random matching) between participants since the endogenous timing models are based on static games. However, repeated interaction is always a possibility in the field. Since we want to investigate the behavioral forces supporting or contradicting the prediction of the timing game, it seems intriguing to analyze fixed matching as well. With fixed matching, collusion becomes a possibility and then the timing of duopoly decisions may have an entirely different nature (on which we elaborate in the next section). Further, firms should be better able to resolve coordination failure problems with fixed matching.

As with previous studies, our results do not fully support the theory. Many timing decisions are out of equilibrium. Subjects often delay their output decisions though producing early is the dominant strategy. This suggests that additional forces not captured in the endogenous timing models influence participants' decisions. In particular, we argue below that our results are consistent with recent findings of Tykocinski and Ruffle (2003). Their results suggest that subjects often have a preference to delay their decisions even when waiting does not provide any additional information.

2 Model and predictions

In Hamilton and Slutsky's (1990) extended game with observable delay two firms can produce in one of two possible periods (period 1 or 2). A pure strategy for firm $i = 1, 2$ is a choice of a production period $t_i \in \{1, 2\}$ and a set of functions $\tau_i : \{(1,1), (1,2),\ (2,1) \times R^+, (2,2)\} \rightarrow R^+$ which is firm i's quantity choice as a function of production periods, (t_1, t_2), and the output of firm $j \neq i$ when firm i is the Stackelberg follower. Given the decisions to produce in period 1 or 2, firms will not mix over outputs.

In the experiments we used the following linear inverse demand function

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

where q_i denotes firm i's output. Linear costs of production in both periods were given by

$$C_i(q_i) = 6q_i, \qquad i = 1, 2. \tag{2}$$

Profits are denoted by $\Pi_i = p(q_1 + q_2)q_i - 6q_i$.

Consider the predictions in the static game first. We start with the second stage. In the subgame with $t_1 = 1$ and $t_2 = 1$, firms play the simultaneous-move Cournot equilibrium in period 1 with $q_i = 8$ and resulting in payoffs of $\Pi_i = 64$ $(i = 1, 2)$. The same holds in the subgame with $t_1 = 2$ and $t_2 = 2$. In the subgame with $t_1 = 1$ and $t_2 = 2$, firms play the Stackelberg equilibrium with firm 1 choosing $q_1^L = 12$ in period 1 whereas firm 2, the Stackelberg follower, chooses $q_2^F = 6$ in period 2. This implies payoffs of $\Pi_1^L = 72$ and $\Pi_2^F = 36$. Outputs and payoffs for the subgame with $t_1 = 2$ and $t_2 = 1$ are $q_2^L = 12, q_1^F = 6$ and $\Pi_2^L = 72$ and $\Pi_1^F = 36$. Then we go back to the first stage. From $\Pi_i^L = 72 > \Pi_i = 64$ (if $t_j = 2$) and $\Pi_i = 64 > \Pi_i^F = 36$ (if $t_j = 1$), choosing period 1 is a dominant strategy and thus we have $t_1 = t_2 = 1$ in the unique subgame perfect equilibrium.

With repeated interaction in the fixed matching sessions, it is well known that collusion can occur (Selten and Stoecker, 1986). It is easy to verify that $q_i = 6$ is the symmetric joint-profit maximizing strategy which results in payoffs of $\Pi_i = 72$ $(i = 1, 2)$. Given both firms collude, the timing decisions are immaterial. However, if there is some uncertainty about the other players' willingness to collude, timing decisions may play an important role. For example, producing at $t_i = 2$ may resolve the uncertainty whether the other player colludes, and at $t_i = 2$ non-colluding rivals may also be punished. Producing at $t_i = 1$ provides an opportunity to signal collusive intents. Note that if these incentives for moving first or second materialize, they would be rather different from those in the static endogenous timing models.

3 Experimental design and procedures

The experimental markets were designed so as to implement the extended game with observable delay one-to-one. The game was repeated over 30 rounds in order to allow for learning both with random and fixed matching.

A minor difference to the game as formally stated above is that subjects had to choose their quantities from a truncated and discretized strategy space, yielding a standard payoff bi-matrix.

Subjects had to choose integer quantities between 3 and 15.[3]

In both treatments, subjects got individual feedback about what happened in their market at the end of each round. That is, the computer screen[4] showed the production period, the quantity, and the profit of both duopolists. In sessions with random matching (henceforth RANDOM), subjects were rematched by the computer at the beginning of each round. We conducted five sessions with ten participants each. The two sessions with fixed matching (henceforth FIXED) had ten participants as well, so there were five fixed duopoly pairs in each session. Treatments were conducted in an identical way, except for the matching scheme.

The experiments were conducted at Royal Holloway, University of London, in spring and summer 2002. Altogether 70 subjects participated in the experiment. They were students from various departments, many from fields other than economics or business administration.

In the instructions (see Appendix A) subjects were told that they would act as a firm which, together with another firm, serves one market, and that in each round both were to choose when and how much to produce. After having read the instructions, participants could privately ask questions.

Before the first round was started subjects were asked to answer two control questions (which were checked) in order to make sure that everybody had full understanding of the payoff table.

The monetary payment was computed by using an exchange rate of 300 "points" for one pound sterling and adding a flat payment of £4.[5] Subjects' average earnings were £13.02 ($19.53 at the time) including the flat payment. The sessions lasted about 60 to 90 minutes.

4 Experimental results

We report the results of treatments RANDOM and FIXED separately. When discussing the results, we often refer to third 1 (rounds 1-10), third 2 (rounds 11-20), and third 3 (last ten rounds).

4.1 Random matching

Table 1 shows the evolution of the relative frequency of t=1 choices over time. In RANDOM the relative frequency of t=1 decisions increases from 57% to 72% (from third 1 to third 3). This is

[3] We used the same matrix as in Huck, Müller and Normann (2001).

[4] We are grateful to Urs Fischbacher for letting us use his software toolbox "z-Tree" (Fischbacher, 1999).

[5] This payment was made since subjects could have made losses in the game.

	third 1	third 2	third 3
RANDOM	57	69	72
FIXED	50	51	53

Table 1: Relative frequency of period 1 choices

		third 1 $t=1$	third 1 $t=2$	third 2 $t=1$	third 2 $t=2$	third 3 $t=1$	third 3 $t=2$
RANDOM	$t=1$	9.0, 9.0	10.6, 7.8	9.0, 9.0	10.3, 8.9	8.7, 8.7	9.3, 9.0
	$t=2$	7.8, 10.6	8.3, 8.3	8.9, 10.3	9.1, 9.1	9.0, 9.3	8.5, 8.5
FIXED	$t=1$	9.0, 9.0	9.2, 8.4	9.4, 9.4	9.0, 8.0	9.7, 9.7	8.5, 7.7
	$t=2$	8.4, 9.2	9.0, 9.0	8.0, 9.0	9.2, 9.2	7.7, 8.5	7.6, 7.6

Table 2: Average individual quantities in the subgames over time

a clear trend towards equilibrium timing behavior. However, the relative frequency of t=1 choices is still below the equilibrium prediction of 100% towards the end of the experiment. Moreover the increase slows down considerably from third 2 to third 3.

Since we have random matching, the relative frequency of timing decisions immediately imply the relative frequencies of the timing outcomes. The equilibrium prediction with both firms choosing t=1, occurs with only 55% (third 3). Simultaneous play in t=2 occurs with 10% and sequential play with the remaining 35% (third 3). Since t=1 choices increase over time, the relative frequency of the subgame where both firms choose t=1 increases whereas the frequency of the other two subgames decreases.

Once firms have made their timing choices, they know in which sequence they choose their outputs. How do firms behave in the subgames? Table 2 shows average individual quantities across thirds contingent on the timing decisions. In RANDOM, we observe that after a short learning phase (third 1) the t_1=t_2=1 and t_1=t_2=2 subgames are virtually identical. They are also close to the Cournot prediction. However, in the asymmetric subgame, attempts to exploit a first-mover advantage by choosing a higher than Cournot quantity of 8 is punished by followers.[6] Note, for

[6] Interestingly, the fraction of subjects (9) who choose to delay 22 times or more are more competitive Stackelberg

instance, that the best response to a first mover's quantity of 10 and 9 is 7 and 8 respectively. Moreover, first-movers' output is smaller than predicted (12 units).

As a consequence, both Stackelberg leaders' and followers' payoffs are smaller than the payoffs in the two simultaneous subgames[7]. In fact, the payoffs in the Cournot subgame in t=1 are higher than in any other subgame.[8] This provides an incentive for the subjects to avoid the sequential-move subgame by coordinating on the t=1 Cournot subgame, thus avoiding to choose production in $t = 2$. Note also that, over time, Stackelberg leaders become less competitive and Stackelberg followers less punitive such that payoff differences become less extreme and, thus, the incentive to avoid the sequential-move game gets weaker. This might explain why the increase of t=1 choices gets slower over time. We also note that subjects choosing period 1 earn on average higher payoffs over time than subjects choosing period 2.[9] The profit figures are 51.6 and 47.3 (third 1), 48.9 and 41.6 (third 2), and 54.4 and 49.9 (third 3) after t=1 and t=2 choices respectively.

It is instructive to compare these results to those reported in Huck, Müller and Normann, 2002 (henceforth HMN). Their experimental design is identical to ours but the one major difference is the timing game. HMN used Hamilton and Slutsky's (1990) extended game with action commitment. In this game, a firm can move first only by committing to an output. When doing so, the firm does not know what its competitor is doing. By waiting until the second period, a firm can observe the other firm's first period action. Theory predicts the emergence of Stackelberg equilibria.[10]

The surprising insight from the comparison to HMN is that results differ only marginally—though predictions based on subgame perfectness oppose each other. In HMN, the relative frequency of t=1 decisions is 56%, 65% and 62% across thirds. These numbers are very close to ours in the first two thirds and only somewhat smaller towards the end of the experiment. Note that in our experiment firms have a strict incentive to choose t=1 (they can only lose by choosing t=2) while,

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followers than the overall average.

[7] Significant at the 5% level using a Wilcoxon signed ranks test, where each observation corresponds to the average profits across players from a session.

[8] The difference between Cournot in period 1 and Stackelberg leader and Stackelberg follower, respectively, is significant at the 5% and 10% level, respectively, using a one-tailed Wilcoxon signed ranks test. The difference between the two Cournot outcomes is not testable, due to an insufficient number of observations.

[9] This is, however, not significantly different at any conventional level of significance (two-tailed Wilcoxon signed ranks test).

[10] More precisely, there exist two Stackelberg equilibria and one first-period Cournot equilibrium, but only the two Stackelberg equilibria are in undominated strategies.

in the extended game with action commitment, firms have a weak incentive to delay (as they can play a best reply to whatever the rival firm did in t=1). Nevertheless, aggregate t=1 choices are rather similar in both studies.

The similarity of market outcomes in both experiments is also illustrated by a look at the frequency of Cournot outcomes (that is, both firms choosing quantity 8, regardless of the timing decisions). In Random we find 16.0% and in HMN 14.4% Cournot outcomes. Another telling statistic is the ratio of market shares. We calculate the number $s := \max\{q_1, q_2\}/\min\{q_1, q_2\}$ for each individual market and for each round. The average s for the markets in HMN is 1.27 (standard deviation 0.36) and 1.33 (standard deviation 0.48) in Random. Thus, the ratio of market shares in the current study (in which symmetric Cournot outcomes are predicted) is not smaller than in the previous experiment where asymmetric Stackelberg outcomes are predicted.

4.2 Fixed matching

Let us now consider treatment Fixed. Table 1 above also shows the evolution of the relative frequency of period-1 choices in Fixed. In contrast to Random, period-1 choices stay roughly constant at a level of 50%. The frequency of timing outcomes is not immediate from Table 1 as they depend on individual duopoly pairs. We find that the frequency of the predicted t_1=t_2=1 subgame increases from 17% to 32% (from third 1 to third 3). Surprisingly, the frequency of the t_1=t_2=2 subgame increases, too, from 17% to 26%. As in treatment Random, the frequency of the sequential subgame decreases from 66% to 42%, but it is modal in all thirds.

Table 2 reports average quantities. With the exception of the t=1 Cournot subgame, outputs are generally smaller compared to Random, indicating a tendency to collude. We note that output produced in the first-period simultaneous subgame is always slightly higher than the Cournot quantity of 8. Whilst the Cournot output in t=1 appears to be larger in Fixed,[11] we observe that average outputs in the sequential subgame, as well as in the t=2 Cournot subgame are smaller in the Fixed treatment (and also smaller than the predicted output of 8.) Third, both Stackelberg leaders and followers in treatment Fixed are less competitive than those in treatment Random[12] but they do not appear to collude (on average). This implies that in treatment Fixed there is less of an incentive to avoid the sequential subgame by choosing t=1.

[11] This difference is not significant (one-tailed Mann-Whitney U test).

[12] This is significant at the 1% level regarding the Stackelberg followers, but not regarding the Stackelberg leaders (one-tailed Mann-Whitney U test).

As expected from the lower quantities, profits are generally higher in Fixed. More precisely, average profits after choosing period 1 and period 2, respectively, are 50.8 and 49.4 (third 1), 50.1 and 49.3 (third 2), and 50.3 and 60.3 (third 3), respectively. Hence, timing decisions do not seem to affect profits very much in the first two thirds but towards the end of the experiment subjects seem to coordinate more effectively in the t_1=t_2=2 subgame. The fact that the frequency of both simultaneous subgames rises over time can by and large be explained by observing that some pairs tend to coordinate on t=1 whereas others tend to coordinate on t=2. Recall that production costs are the same in both periods.

5 Discussion

Hamilton and Slutsky's (1990) extended game with observable delay has a unique and symmetric subgame perfect equilibrium in which both players choose to produce in the first period, implying symmetric Cournot quantities. In this paper we report on an experimental test of this prediction. We run the game both with a random and a fixed matching scheme. With random-matching, we find that timing choices move in the right direction but they do not converge to the predicted level as nearly one third of all subjects still chooses to delay toward the end of the experiment. With a fixed-matching scheme we find that the subgame perfect equilibrium has no predictive power with regard to timing choices as throughout the experiment only half of the timing observations are period one choices. The differences in timing choices in the two treatments can to some extent be explained by the differences observed in the asymmetric subgames. In the treatment with random matching more competitive behavior in the asymmetric subgames provides an incentive to avoid it by choosing to produce early. This is not the case in the treatment with fixed matching as here the behavior in the asymmetric subgames is less competitive.

The finding that timing choices do not converge to the predicted level suggests that there must be preferences that cause subjects to delay their decisions. Recently, Tykocinski and Ruffle (2003) documented that such preferences exist. Their study is about "reasonable reasons for waiting". Experimental subjects had to choose between two options in a certain scenario and an uncertain scenario. It turned out that subjects often prefer to delay their decisions even when waiting does not provide any additional information at all.

While it is difficult to compare these individual decision experiments to our strategic context, one can draw parallels. Our results indicate that subjects sometimes prefer to wait even when doing so puts them at a strategic disadvantage. When choosing period two, our subjects can find out which action the rival firm has chosen, provided this rival chose the first period. Even though they become the Stackelberg follower in this case, they prefer to wait, perhaps to resolve the strategic uncertainty about the other player's action. Once subjects are more familiar with the experimental environment, this preference to wait is getting weaker in the random-matching treatment. Nevertheless many subjects still delay towards the end of the experiment.

With fixed matching, these considerations may be less relevant since subjects face less ambiguity regarding choices of their opponent. As argued above, timing choices may not reflect the incentives suggested by non-cooperative game theory. Instead, timing choices may turn out to be an instrument to support collusion. While we observe only little collusion in our experiments, our results suggest that timing decisions do not affect profits by very much with fixed matching (except towards the end of the experiment).

We found that our results with random matching are similar in many respects to those in Huck, Müller and Normann (2002) where, however, Stackelberg equilibria are predicted. Generally, previous work[13] found that endogenous timing models predicting asymmetric outcomes are of limited behavioral relevance due to coordination failure and inequality aversion. The results in this study show that there are forces sufficiently strong to prevent play from converging to a unique equilibrium of an endogenous timing model even if the equilibrium is symmetric.

References

[1] Amir, R. and I. Grilo (1999): Stackelberg versus Cournot Equilibrium, *Games and Economic Behavior* 26, 1-21.

[2] Ellingson, T. (1995): On Flexibility in Oligopoly, *Economics Letters* 48, 83-89.

[3] Fischbacher, U. (1999): Z-Tree, Zurich Toolbox for Readymade Economic Experiments, *Working paper Nr. 21*, Institute for Empirical Research in Economics, University of Zurich.

[4] Fonseca, M., S. Huck, and H.-T. Normann (2005): Playing Cournot Although They Shouldn't: Endogenous Timing in Experimental Duopolies with Asymmetric Cost, *Economic Theory* 25, 669-677.

[13] See Huck, Müller and Normann (2002), Müller (2005) and Fonseca, Huck and Normann (2005).

[5] Hamilton, J.H., and S.M. Slutsky (1990): Endogenous Timing in Duopoly Games: Stackelberg or Cournot Equilibria, *Games and Economic Behavior* 2, 29-46.

[6] Holt, C.H. (1985): An Experimental Test of the Consistent–Conjectures Hypothesis, *American Economic Review* 75, 314-325.

[7] Huck, S., W. Müller, and H.-T. Normann (2001): Stackelberg beats Cournot - On Collusion and Efficiency in Experimental Markets, *Economic Journal* 111, 749-765.

[8] Huck, S., W. Müller, and H.-T. Normann (2002): To Commit or not to Commit: Endogenous Timing in Experimental Duopoly Markets, *Games and Economic Behavior* 38, 240-264.

[9] Matsumura, T. (2002): Market Instability in a Stackelberg Duopoly, *Journal of Economics* 75, 199-210.

[10] Müller, W. (2005): Allowing for two Production Periods in the Cournot Duopoly: Experimental Evidence, *Journal of Economic Behavior and Organization*, forthcoming.

[11] Normann, H.-T. (2002): Endogenous Timing with Observable Delay and with Incomplete Information, *Games and Economic Behavior* 39, 282-291.

[12] Robson, A.J. (1990): Stackelberg and Marshall, *American Economic Review* 80, 69-82.

[13] Saloner, G. (1987): Cournot Duopoly with Two Production Periods, *Journal of Economic Theory* 42, 183-187.

[14] Selten, R. and R. Stoecker (1986): End behavior in Finite Prisoner's Dilemma Supergames, *Journal of Economic Behavior and Organization.* 7, 47-70.

[15] Tykocinski, O.E. and B.J. Ruffle (2003): Reasonable Reasons for Waiting, *Journal of Behavioral Decision Making* 16, 1-11.

[16] van Damme, E. and S. Hurkens (1999): Endogenous Stackelberg Leadership, *Games and Economic Behavior* 28, 105-129.

[17] van Damme, E. and S. Hurkens (2004): Endogenous Price Leadership, *Games and Economic Behavior* 47, 404-420.

A Instructions (not for publication)

Welcome to our experiment! Please read these instructions carefully! Do not talk to your neighbours and keep quiet during the entire experiment. If you have any questions, please give us a sign. We will answer your question privately.

In our experiment you can earn different amounts of money, depending on your behaviour and that of other participants matched with you. All participants read identical instructions.

You have the role of a firm which produces the same product as a second firm in the market. First you have to decide, at which time you want to produce. Afterwards, you decide on the quantity you want to produce.

Regarding the time when to produce, you can choose either the first or the second production period. As the other firm has the same choice, there are four possibilities. Both first, both second, you first and the other firm second, and you second and the other firm first. In all cases, you will be informed about the timing decision of the other firm before choosing your quantity.

The quantity decisions are made in the sequence resulting from the timing decisions. If both firms choose first or both choose second, quantity decisions are made simultaneously. In those cases, you and the other firm have to make the quantity decisions not knowing what the other one chooses. If you choose first and the other firm second, then the other firm will learn your quantity decision before making its own decision. Likewise, if you choose second and the other firm first, then you will learn the other firm's output decision before making your own decision.

Note that the profit in each round depends only on the chosen quantities, not on the choice of production periods. In the attached payoff table, you can see the resulting profits of both firms for all possible choices of quantity. The table reads as follows: At the head of a row the quantity of your firm is indicated, at the head of a column the quantity of the other firm is stated. In the cell at which row and column intersect, your profit is noted in the lower left and the other firm's profit is stated in the upper right. All profits are expressed in a fictional currency, which we call "Points".

The experiment lasts 30 rounds. After each round, you will be informed about the quantity choice of the other firm, your profit and the other firm's profit.

You do not know with which participant you serve the market. You will be randomly matched with a participant each round. This random move is done by the computer.

Anonymity is kept among participants and instructors, as your decisions will only be identified with a code number. You will discreetly receive your payment at the end of the experiment.

Concerning the payment note the following. At the end of the experiment, your earnings in Points determine your payment in pounds sterling. For every 300 Points you will receive 1 £. In addition to this payment, you will receive the show-up fee of 4 £ independently of your earnings during the thirty rounds.

B Payoff table (not for publication)

Quant.	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
3	54 54	68 51	80 48	90 45	98 42	104 39	108 36	109 33	11 30
4	51 68	64 64	75 60	84 56	91 52	96 48	99 44	100 40	9 36
5	48 80	60 75	70 70	78 65	84 60	88 55	89 50	90 45	8 40
6	45 90	56 84	65 78	72 72	77 66	80 60	81 54	80 48	7 41
7	42 98	52 91	60 84	66 77	70 70	72 63	71 55	70 49	6 42
8	39 104	48 96	55 88	60 80	63 72	64 64	63 56	60 48	5 40
9	36 108	44 99	50 89	54 81	55 71	56 63	54 54	50 45	4 36
10	33 109	40 100	45 90	48 80	49 70	48 60	45 50	40 40	3 30
11	30 110	36 99	40 88	41 77	42 66	40 55	36 44	30 33	2 22
12	27 108	32 96	35 84	36 72	35 60	32 48	27 36	20 24	1 12
13	24 104	28 91	29 78	30 65	28 52	24 39	18 26	10 13	0 0
14	21 98	24 84	25 70	24 56	21 42	16 28	9 14	0 0	-1 -11
15	18 90	19 75	20 60	18 45	14 30	8 15	0 0	-15 -10	-3 -22

The head of the row represents one firm's quantity and the head of the column represents the quantity of the other firm. Inside the box at which row and column intersect, one firm's profit matching this combination of quantities stands up to the left and the other firm's profit stands down to the right.