The Use of a Simple Decision Rule in Repeated Oligopoly Games

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Abstract

Much interest has been directed towards decision rules and conditions when firms make decisions converging to a non-cooperative Nash equilibrium in repeated oligopoly games. We explore the use of a simple decision rule where firms only need to have information about their own profits from the two previous periods. The principle of the decision rule is to choose a decision within a boundary of the decision that gave the highest profit in the two previous periods of the game. Simulations using the decision rule with different boundaries for both sequential and simultaneous decisions in the games are analysed. Furthermore, experiments with a Cournot game, where five firms make decisions simultaneously, show that by using the rule firms with only information about their own profits make decisions similar to firms who also have information about market demand and competitors. In conclusion, the simple decision rule can be used to compute optimal decisions and the rule can also be used as a benchmark for decisions made in repeated oligopoly games.

JEL Classification: C15;C72;C91;D82

Keywords: repeated oligopoly games, decision rules, private information, simulation, experiment

1. Introduction

Much interest has been directed towards decision rules and conditions when firms make decisions in repeated oligopoly games. One of the basic concepts when analyzing these markets is the non-cooperative equilibrium (Nash, 1951). The main questions are if the non-cooperative equilibrium gives good description of decisions made on the market and also how the decisions are made. An established way to study these questions is to use laboratory experiments with human subjects (Smith, 1994). Normally, the models of Cournot and Bertrand, and models of product differentiation are used in the experiments. The results from experiments show that firms need to make decisions for a number of periods before their decisions come close to equilibrium decisions. The results also show that there need to be three or more firms on the same market, for firms to make decisions similar to non-cooperative equilibrium decisions (Dufwenberg and Gneezy, 2000; Huck, Normann and Oechssler, 2004). Furthermore, the dispersion among decisions may vary; Garcia Gallego (1998) found for example that the individual decisions of firms with symmetric costs converged to the non-cooperative equilibrium, while Rassenti et al (2000) found convergence to the equilibrium of the total of the decisions of all firms with asymmetric costs, but wide dispersion among the decisions of the firms. The Bertrand-Edgeworth model has a mixed strategy equilibrium where decisions were dispersed as they fluctuated over time (Kruse et al 1994).

The information conditions on the market may influence the decisions firms make (Huck Normann and Oechssler, 2000). Furthermore, the information conditions determine what decision rules the firms can use, as some of the rules may need information about the demand on the market, costs or decisions of the other firms or profits of other firms, while other rules don't. The use of a number of different rules have been tested in experiments: Beating the opponents (Bosch-Domenech and Vriend, 2003), best reply (Rassenti et al, 2000; Huck, Normann and Oechssler, 1999), fictious play (Rassenti et al, 2000; Huck, 2002), gradient method (Kirman, 1995), imitation of other firms (Huck, Normann and Oechssler, 1999 and 2000), learning direction theory and hill-climbing (Nagel and Vriend, 1999) and least-square learning (Garcia Gallego, 1998). The general results from these studies were that these decision rules only partly were used.

In this study, we explore the use of a simple decision rule where firms only need to have information about their own decisions and profits from the two previous periods. The principle of the decision rule is arbitrary choosing decisions within a boundary of the decision that gave the highest profit in the two previous periods of the game. The firms do not even need to know what game they are playing (Oechssler and Schipper, 2003). The decision rule was inspired from several sources. First, from a stream of research where very little information is available for decision making (Kirman, 1995; Nagel and Vriend, 1999; Thorlund-Petersen, 1990). Second, from the stochastic optimization literature (Andradóttir, 1995; Zhigljavsky, 1991). Third, from the fast and frugal paradigm (Gigerenzer and Goldstein, 1996) where decision makers can perform well with only limited information and limited effort when decision making.

We will explore two versions of the decision rule, one where firms make decisions sequentially and one where the firms make decisions simultaneously. We analyze simulation results with different boundaries of adjustments of decisions for both versions of the decision rule. Furthermore, we use experiments with a Cournot game to compare decisions made with the decisions rule and only private information about profits, to decisions made by firms who also have information about market demand and competitors and do not have to use the decision rule (Rassenti et al 2000). We find that the simple decision rule where firms make decisions sequentially can be used to compute optimal decisions and that the rule where firms make decisions simultaneously can be used as a benchmark for decisions made in repeated oligopoly games. Hence, the decision rule makes decisions converge and approximate the non-cooperative equilibrium.

The remainder of the paper is structured as follows. In the next section, the decision rule and its use in models of competitions are described. Then, the simple decision rule is used in computer simulations and in experiments. Finally, conclusions are made on the use of the decision rule. Instructions for the experiment and description for how random numbers were generated are in Appendix.

2. The decision rule in models of competition

The idea behind the simple decision rule is that each firm only use information about its own decisions and own profits in the two previous periods, to make its next decision. The rule has the following steps.

Step 0. Each firm has an initial decision that is its current best decision and receives information about its profit.

Step 1. Each firm makes adjustments of its current best decisions and receives information about its profit.

Step 2. Each firm compares the two profits and selects the decision of the two that gave the highest profit as its current best decision.

Step 3. Steps 1 – 3 continue until a specified number of adjustments of the current best decision have been made.

Two of a number of possible versions of the decision rule is explored. The first version is sequential decision making, where only one firm makes decision at the time. The firm compares its profits before and after it has made its adjustment, while the other firms have their decisions unchanged. The firm repeats the decision of the two previous decisions that gave the highest profit, the current best decision, and then wait for the other firms to make their decisions. The second version is simultaneous decision making, where all firms make their decisions at the same time. The firms compare their profits before and after they have made their adjustments, and they select the decisions that give the highest profits as it current best decision. Then the firms make adjustments to their current best decisions. It should be pointed out that the current best decision serves only as a reference point for the next decision.

Next, we specify the decisions rules with mathematical notation. The decisions are denoted $x_{i,t}$ where i is the number of a firm and t is the time period. The adjustments of decisions are denoted $\Delta_{i,t}$. The decisions of the other firms is denoted $x_{-i,t}$ where $-i$ denotes all firms, but not the firms studied. The profit for a firm i is denoted $\Pi_i(x_{i,t}, x_{-i,t})$ and it depends on the decisions of the firm $x_{i,t}$ and also on the decision of the other firms $x_{-i,t}$.

The decision rule selects the current best decision for firm i in period t, $x_{i,t}$, by comparing profits of decisions in the two previous periods $x_{i,t-2}$ and $x_{i,t-1}$, where $x_{i,t-1} = x_{i,t-2} + \Delta_{i,t-1}$. For sequential decision making with repetition of the current best decision, the decisions are determined by:

$$(1) \quad x_{i,t} = \begin{cases} x_{i,t-2} & \text{if } \Pi_i(x_{i,t-2} + \Delta_{i,t-1}, x_{-i,t-2}) \leq \Pi_i(x_{i,t-2}, x_{-i,t-2}) \\ x_{i,t-2} + \Delta_{i,t-1} & \text{if } \Pi_i(x_{i,t-2} + \Delta_{i,t-1}, x_{-i,t-2}) > \Pi_i(x_{i,t-2}, x_{-i,t-2}) \end{cases}$$

For simultaneous decision making with current best decisions as reference point for next decision, the decisions are determined by:

$$(2) \quad x_{i,t} = \begin{cases} x_{i,t-2} & \text{if } \Pi_i(x_{i,t-2} + \Delta_{i,t-1}, x_{-i,t-2} + \Delta_{-i,t-1}) \leq \Pi_i(x_{i,t-2}, x_{-i,t-2}) \\ x_{i,t-2} + \Delta_{i,t-1} & \text{if } \Pi_i(x_{i,t-2} + \Delta_{i,t-1}, x_{-i,t-2} + \Delta_{-i,t-1}) > \Pi_i(x_{i,t-2}, x_{-i,t-2}) \end{cases}$$

To prevent random walk, the profit has to be improved by the adjustment $\Delta_{i,t-1}$, else the current best decision will not be changed. Compared to learning direction theory and hill-climbing, the adjustments of decisions in the simple decision rule can be chosen arbitrarily as long as the current best decisions are selected from the decisions that gave the highest profit in the previous two periods.

We shall study how the simple decision rule can be used in the model of Cournot, two models of product differentiation quantity and price, and Bertrand-Edgeworth model (Vives, 1999). In the model of Cournot, firms make decisions on quantity, q. The demand parameters are here denoted a and b. The number of firms on the market, N. The decisions of the other firms, q_{-i}, is denoted with the mean quantity of the other firms, $\overline{q}_{-i}$. The inverse demand function is:

$$(3) \qquad p(q_i, \overline{q}_{-i}) = a - bq_i - b(N-1)\overline{q}_{-i}$$

With c_i as variable cost, the profit function is:

$$(4) \qquad \Pi(q_i, \overline{q}_{-i}) = \left(p_i(q, \overline{q}_{-i}) - c_i\right)q_i$$

The profit function (4) with the inverse demand function (3) can be written as $\Pi = Sq_i - Tq_i^2$, where $S = a - b(N-1)\overline{q}_{-i} - c_i$ and $T = b$. Variable substitution from q to x, with $q_i = Sx/T$ gives $\Pi = S^2 x(1-x)/T$. Collecting S and T to A, with $A = S^2/T$, gives in turn $\Pi = Ax(1-x)$. The profit function $Ax(1-x)$ is a quadratic function, which has its maximum value $A/4$ at $x = 1/2$. The best reply of a firm, i.e. the decision that give the maximum profit for a firm with respect to the decisions of the other firms, is $x = 1/2$ inserted in $q_i = Sx/T$, gives $q = S/(2T)$. We use function $Ax(1-x)$ to study the simple decision rule for sequential decision making. With A, S and T fixed, there is direct relationship between x and q_i, $x = q_i T/S$. For simplicity, we let x denote the decision in period $t-2$ and let $x+\Delta$ denote the adjustment of decision in period $t-1$. For decision x to be adjusted to $x+\Delta$ the following conditions apply:

(5) $\quad A(x+\Delta)(1-(x+\Delta)) > Ax(1-x)$

(6) $\quad \Delta(1-\Delta-2x) > 0$

A positive adjustment, $\Delta > 0$, give higher profit when $1-2x-\Delta > 0$. This can be written as $x + \Delta/2 < 1/2$. Correspondingly, a negative adjustment, $\Delta x < 0$, give higher profit when $1-2x-\Delta < 0$, that is when $x + \Delta/2 > 1/2$. As sequential decision making is defined, only adjustments will be valid if they fulfil this condition. However, with sufficiently many and small adjustments Δ, x will approach $1/2$.

Next, we specify the demand function for a model of product differentiation on quantity (Vives, 1999; Huck, Normann and Oechssler, 2000).

(8) $\quad p(q_i, \overline{q}_{-i}) = a - bq_i - q(N-1)\overline{q}_{-i}$

However, the profit function is the same after variable substitution, i.e. $Ax(1-x)$, as in the Cournot model. The difference compared to Cournot is variable S, where $S = a - q(N-1)\overline{q}_{-i} - c_i$.

A model of product differentiation on price is (Garcia Gallego 1998; Huck, Normann and Oechssler, 2000).

(9) $q_i(p_i, \overline{p}_{-i}) = a - bp_i + g(N-1)\overline{p}_{-i}$

The profit function with price as decision variable is:

(10) $\Pi(p_i, \overline{p}_{-i}) = (p_i - c_i)q_i(p, \overline{p}_{-i})$

Profit function (10) with demand function (9) is also quadratic. However, the profit function for price includes components of costs, here denoted c_i. Using variable substitution with S and T, the profit function for price is $\Pi = Sp_i - Tp_i^2 - Sc_i$. For the model on product differentiation – price $S = a + g(N-1)\overline{p}_{-i} - c_i$ and $T = b$. The price can be represented with x which gives the following profit $\Pi = Ax(1-x) - Sc_i$. This function also has it's maximum value at $x = 1/2$, but the maximum profit $A/4$ is reduced with Sc_i.

Finally, we define Bertrand-Edgeworth game as follows for two competing firms, i, j with capacity constraints $k_1 = k_2 = k \leq a$ (Levitan and Shubik, 1972; Kruse et al, 1994):

(11) $$q_i(p_i, p_j) = \begin{cases} a - bp_i & p_i < p_j \\ 1/2(a - bp_i) & p_i = p_j \\ a - k_j - bp_i & p_i > p_j \end{cases}$$

For the Bertrand-Edgeworth model this means $S = a + bc$, $S = (a + bc)/2$ or $S = a + bc + k_j$ and $T = b$. Variable substitution gives the same profit function as for product differentiation on price. The optimal decisions depend on k, when cost are zero, i.e. $c_i = 0$, if $k = a$ then $p^* = 0$, if $a/3 < k < a$ the prices fluctuate, if $0 < k \leq a/3$ then $p^* = a - 2k$.

The models of Cournot and product differentiation have one unique equilibrium each. In the Bertrand-Edgeworth model, the equilibrium depends on capacity constraints and the equilibrium could also be mixed equilibrium. For sequential decision making, the effect of an adjustment of a decision is evaluated while the other firms on the same market do not make any decisions. This decision making coincide with the definition of Nash-equilibrium, where the profit of a firm cannot be improved by only adjusting its decision. For simultaneous decision making, the adjustment of a decision can not be completely evaluated since the other firms may adjust their decision at the same time. This means that the effect of adjustments of decisions only can be determined approximately.

3. Results

3.1 Computer simulations

We use computer simulations for the two versions of the simple decision rule in the models of competition. First, the results of the Cournot model are presented, then the use of the decision rule in two models of product differentiation (on quantity and on price) is discussed, and finally the results of the Bertrand-Edgeworth model is presented.

In the simulations, adjustments of decisions, Δ, were generated with random numbers, u, uniformly randomized between 0 and 1, i.e. $0 \leq u \leq 1$ (see appendix). The boundary of the adjustment of a decision is denoted, D, and the adjustment is determined by $\Delta = 2D(u - 1/2)$. The boundary of adjustment was held fixed within the same simulation, and the boundary was the same for all firms on the market. Simulations were made with both versions of the decision rule, sequential and simultaneous, with different boundaries of adjustment, where x, was either quantity or price.

We use the Cournot model in Rassenti et al (2000) to illustrate simulation results and in the next section we use data from their experiments that were played for 75 periods. The parameters used in (3) were $a = 540$ and $b = 1$, and there were five firms competing on the same market with asymmetric costs $c_1 = 6, c_2 = 18, c_3 = 30, c_4 = 42, c_5 = 54$. The optimal quantities were respectively $q_1^* = 109, q_2^* = 97, q_3^* = 85, q_4^* = 73, q_5^* = 61$. Simulations were made with the adjustments of quantity decisions. The boundary of adjustment was $D = 30$. Figure 1 shows one single simulation run of sequential decision making where it takes about as many as 250 periods for the decisions of the five firms to reach their respectively individual non-cooperative equilibrium levels, $q*$. The vertical lines in the figure show adjustments of decisions.

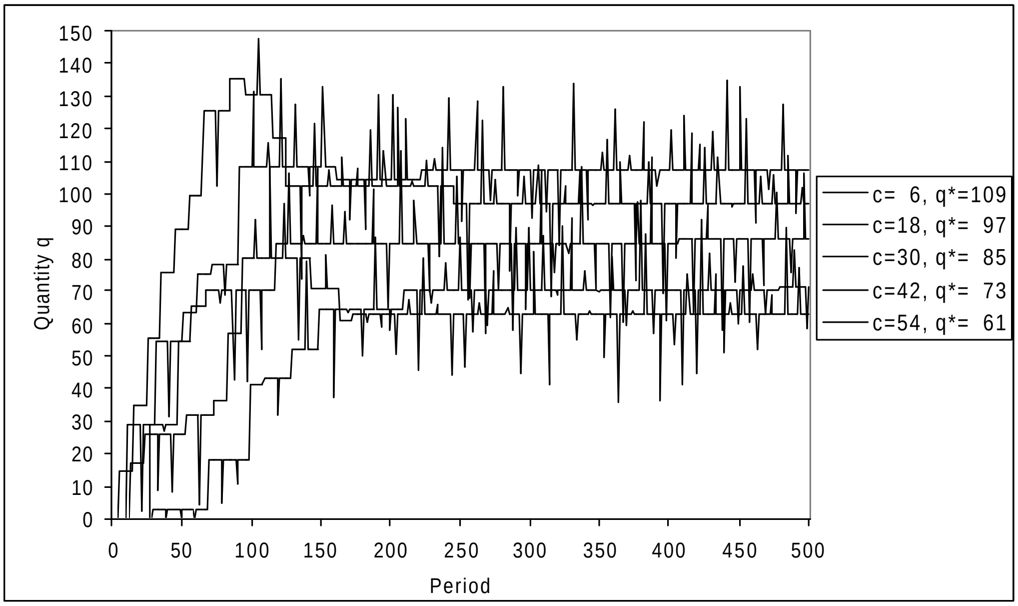


Figure 1. Sequential decision making in the Cournot model, quantity decisions of individual firms.

Figure 2 shows 100 runs of simulations of simultaneous decision making and total quantities for one to five firms competing on the same market where all firms had the symmetric cost $c = 30$. The mean total quantities approximate total non-cooperative quantities, $Q*$, for respectively number of firms on the same market, but there are fluctuations over time. Simulations of five firms with symmetric costs give similar total quantity as when costs are asymmetric (Table 3 below shows means and standard deviations).

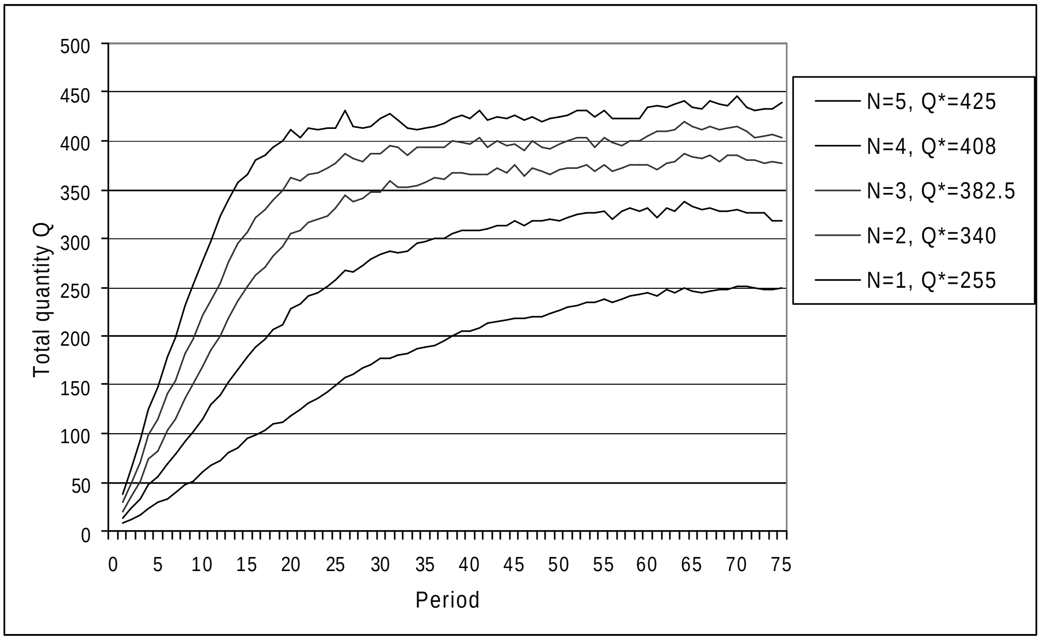


Figure 2. Simultaneous decision making in the Cournot model, total quantity decisions of firms.

In simultaneous decision making, decisions reach non-cooperatives decision much faster than in sequential decision making, for five firms 25 periods compared to 250 periods, respectively.

We use 100 runs of simulations to explore the simple decision rule with different boundaries in the models of competition. The start decisions are zero for all simulations presented, but we obtained similar result when altering the start decisions. The mean decisions are presented after the decisions approximate non-cooperatives decisions, here measured with mean decisions in 10 periods [t, t+9] = [t+10,t+19] and mean of 100 decisions [t, t+100].

For the Cournot model we use parameters $a = 1$, $b = 1$, and symmetric costs $c_i = .1$. The non-cooperative decisions for 1, 2, 3, 4, 5 firms are respectively .450, .300, .225, .180 and .150. Three different boundaries were used $D = .01,.05,.10$.

Table 1. Sequential and simultaneous decision making in the Cournot model.

	Number of firms				
	1	2	3	4	5
Non-cooperative	.450	.300	.225	.180	.150
Boundaries					
Sequential					
D=.10	.450	.300	.225	.180	.150
D=.05	.450	.300	.225	.180	.150
D=.01	.450	.300	.225	.180	.150
Simultaneous					
D=.10	.450	.297	.228	.186	.159
D=.05	.448	.291	.222	.179	.150
D=.01	.449	.284	.215	.170	.142

Table 1 shows that the mean decisions from sequential decision making do not differ much from non-cooperative decisions and the boundaries of adjustments do not matter much. For simultaneous decision making, the boundaries of adjustment matter more. For small adjustments the mean decisions are slightly below the non-cooperative decisions and for large adjustments the mean decisions are slightly above the non-cooperative decisions.

In the models of product differentiation, corresponding results were obtained for simulations of the decision rule. However, a main difference was for simultaneous decision making in the model of price, where the decisions on price were above the non-cooperative prices for all three boundaries of adjustments $D = .01, .05, .10$.

Figure 3 shows one simulation run each for sequential and simultaneous decision making, where two firms are competing in the Bertrand-Edgeworth model with $a = 1$, $b = 1$, and symmetric costs $c_i = .0$ and with capacity constraints $k = .5$ over 500 periods.

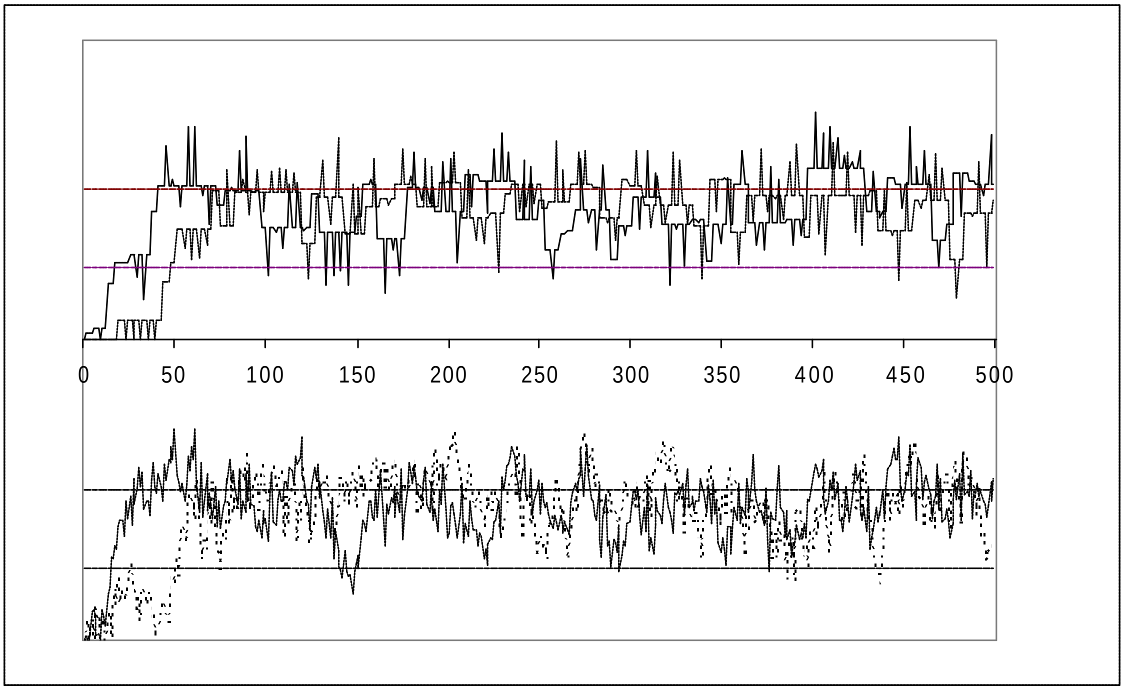


Figure 3. Sequential (above) and simultaneous decision making (below) in the Bertrand-Edgeworth model, individual duopoly decision on decisions. Horizontal lines are at p=.12 and p=.25.

Table 2 shows that the mean decisions of sequential decision making do not differ much from non-cooperative decisions. When $k \leq 3$ the decisions are similar, when $k \geq 4$ the decisions are within non-cooperative maximum and minimum fluctuations. The mean decisions of simultaneous decisions are generally higher than non-cooperative maximum decisions. When $k \geq 4$ and adjustment boundary $D = .10$, and when $k \geq 8$ and $D = .05,.01$ the decision rule does not converge to non-cooperative decisions.

Table 2. Sequential and simultaneous decision making in Bertrand-Edgeworth model, optimal maximum, minimum and mean prices from non-equilibrium decisions.

	Capacity constraint, k, as fraction of demand a									
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1
Non-coop - max	.80	.60	.40	.30	.25	.20	.15	.10	.05	.00
Non-coop - min	.80	.60	.40	.22	.12	.06	.03	.01	.00	.00
Sequential										
D=.10	.80	.60	.40	.27	.21	.15	.11	.07	.04	.02
D=.05	.80	.60	.40	.28	.22	.17	.12	.08	.03	.01
D=.01	.80	.60	.40	.29	.24	.19	.14	.09	.05	.04
Simultaneous										
D=.10	.87	.68	.53	.39	.35	.33	.34	.35	.36	.37
D=.05	.80	.60	.43	.29	.23	.18	.14	.12	.13	.15
D=.01	.79	.60	.42	.29	.24	.19	.15	.15	.15	.17

To sum up, the simulations show that sequential decision making with the simple decision rule reaches the individual non-cooperative decisions slower, but precise, compared to simultaneous decision making which approximates the non-cooperative aggregate decisions with substantial dispersion among decisions.

3.2 Experiments

Experiments were conducted where human subjects had only information about their own decisions and their own profits, and where they were enforced to use of the simple decision rule. The purposes of the experiments was to study how human subjects compare to the computer simulations using the rule, and also how decisions with the rule compare to human subjects not enforced to use the decisions rule and with more information available. The comparisons are limited to the Cournot model and the simple decision rule with simultaneous decision making.

The same parameters as Rassenti et al (2000) were used, hereafter called Rassenti, so comparisons could be made between the decisions with the decision rule to the data from their experiment[1]. In their experiment five firms competed on the same markets over 75 periods. The firms had information about the demand function and they received information about the individual decisions and the profits of the other firms on the market. The costs were asymmetric and private.

Two experiment were conducted, here called Experiment A and B, with altogether 40 participants (20 + 20) using the decision rule (see Appendix). The participants were instructed that they would receive limited information during the experiments, and that they were to use a simple decision rule. The participants were informed that they were to make decisions on the number of units of an unspecified product they would sell on a market. They were to know that few products for sale would yield a high price, and many products for sale would yield a low price. However, they were not to know the demand function, the price, decisions or profits of the other firms, nor the number of firms on the market or how many periods they would play. Compared to Rassenti, the participants in our experiments were enforced to use the decision rule. The experiments were conducted on computers where the decision rule was

[1] I thank Rassenti et al (2000) for providing data from their experiments. Treatment 75-SHOW markets NN1, NN3, NN6, NN18 were used for comparisons. Market NN5 was not used as there were negative profits in a number of periods.

programmed so the participants had to use it when making their decisions. On computer screens, each firm could just see its own decisions and profits for the previous two periods. The boundary of adjustment was $(D = 30)$. The current best decision, i.e., the decision which gave the highest profit out of the two previous decisions, was put in the middle of 61 decisions. If the current best decision was 31 or higher the firm could choose between 61 decisions alternatives. If the current best decision was lower that 30 the firm could choose between 0 and the current best decision plus 30.

In Experiment A, there were four sessions where five firms competing on the same market, but they all had to use the decision rule and they only received information about their own decisions and own profits. Experiment B was designed to make comparisons between firms making decisions in Rassenti and firms making decisions with decision rule on the "same market". The decisions from Rassenti were used, but the decisions of one of the five firms were excluded from the total quantity in the market. Instead, each of the 20 firms in experiment B played the part of an excluded firm in Rassenti. The price was determined with the total quantity of four of the firms in Rassenti plus the decisions the participants made by using the decision rule. The participants in Experiment B tried to make their best replies to the decisions from Rassenti by using the decision rule. The comparison between firms in Rassenti and Experiment B is only indirect, as the firms in Rassenti could not take into account the decisions of the firm using the decision rule in Experiment B. However, the comparison gives some indications of what may happen when firms having much more information available compete with firms only using the simple decision.

In Rassenti, the participants had 50 seconds to make their decisions. In Experiment A and B the participants made decisions in their own pace, and they used a mean of about 20-25 seconds. The rewards in Experiment A and B were similar to Rassenti, with a mean earning of $14. We will make comparisons between decisions on quantity of: 100 runs of simulation and 20 firms in each Experiment A, Rassenti and Experiment B in 75 periods.

Figure 4 shows that the mean total quantities were above 400 from period 25 to period 75 in Simulation, Rassenti and Experiment A, while they were below 400 in all periods in Experiment B. The mean total quantities increased fastest to 400 in Rassenti. The total non-cooperative quantity is 425 for the five firms. About 77% of all decisions in Rassenti followed the criteria of the simple decision rule. The mean absolute adjustment for Simulation, Experiment A, Rassenti, and Experiment B were in order 18, 12, 24, 9, and the percentages of unadjusted decisions between one period and the next were for Experiment A, Rassenti, and Experiment B in order for 12%, 26%, 7%.

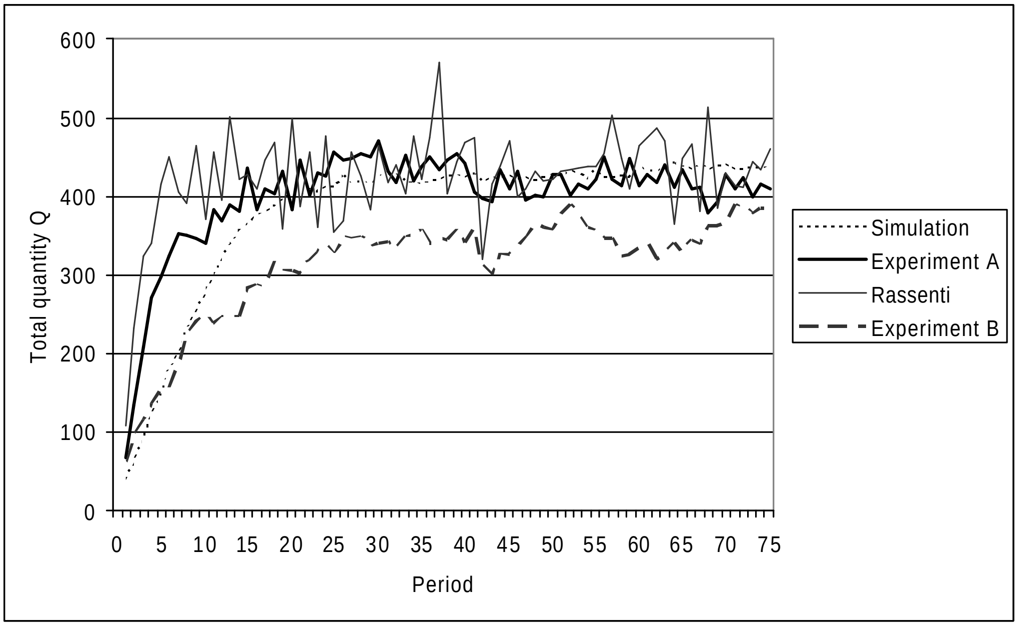


Figure 4. Mean total quantity in 75 periods of 100 runs of Simulation, and of 20 firms for respectively Experiment A, Rassenti and Experiment B.

Table 3. Mean total quantity and coefficient of variance (standard deviation divided by mean total quantity), in all 75 periods, the first third, the middle third and the last third of the 75 periods.

	All periods		First third		Middle third		Last third	
	$\overline{Q}$	$s/\overline{Q}$	$\overline{Q}$	$s/\overline{Q}$	$\overline{Q}$	$s/\overline{Q}$	$\overline{Q}$	$s/\overline{Q}$
Simulation	382	.30	290	.45	422	.13	433	.12
Experiment A								
1	388	.18	335	.30	417	.04	410	.04
2	386	.22	377	.28	428	.17	353	.12
3	399	.17	363	.25	415	.09	420	.12
4	428	.23	336	.35	460	.07	487	.09
Rassenti								
NN1	399	.17	378	.25	411	.15	409	.07
NN3	445	.24	412	.33	439	.19	483	.15
NN6	445	.23	416	.26	476	.27	442	.10
NN18	406	.18	381	.24	406	.12	432	.15
Experiment B								
1/NN1	404	.21	334	.33	425	.07	453	.10
2/NN3	220	.25	165	.26	259	.13	234	.17
3/NN6	265	.26	203	.35	277	.17	316	.10
4/NN18	363	.29	257	.44	412	.10	420	.13

Table 3 shows that the mean total quantities varied between markets within Experiment A, Rassenti and Experiment B respectively. The quantity decisions were significantly higher in Rassenti compared to Experiment in the first third (t=2.555, df=998, p<.02), however, there was no significant difference in quantity decisions in the middle and last third between

Rassenti and Experiment A. Table 3 shows that dispersion (measured with the coefficient of variance) among decisions decreased from the first to the middle and then to the last third. The dispersion among decisions was about the same for Experiment A and Rassenti.

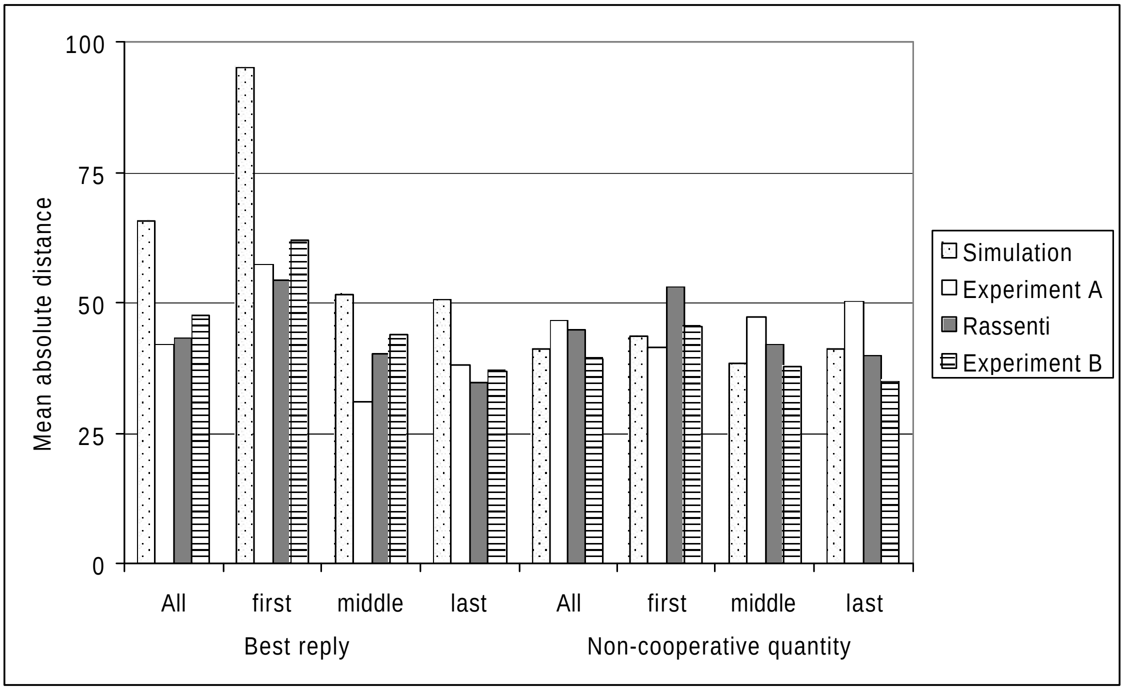


Figure 5. Mean absolute distance to best reply and mean absolute distance to non-cooperative quantity for All decisions, and for the first third, the middle third and the last third of 75 periods, for 100 runs of Simulation, and 20 firms each in Experiment A, Rassenti and Experiment B.

Figure 5 shows that mean absolute distance between decision to best reply and to non-cooperative quantity were about the same for Simulation, Experiment A, Rassenti and Experiment B. The main exception is the first third for Simulation where mean absolute distance to best reply was 95. There were no significant differences between Rassenti and Experiment A for absolute distances to best reply and to non-cooperative decisions. Despite decisions in Experiment B were lower than other decisions, the absolute distance to best reply and to non-cooperative decisions was not significantly larger in the last third. To sum up, decisions in Simulation, Experiment A and B with the simple decision rule were similar to Rassenti.

4 Conclusions

When decisions are made simultaneously in models of competition with the use of the simple rule described and with arbitrary choosing of decisions, aggregate decisions of competing firms converge to approximate the non-cooperative equilibrium. Since the decision rule only requires private information about profits in two previous periods, and this information usually is available, and when the rule may at least implicitly be used to a certain extent by firms, aggregate non-cooperative outcomes could be expected. Arbitrary decisions with the decision rule can serve as a benchmark for how decisions are made in future experiments.

It can be argued that the models of competitions studied here are simple, perhaps too simple to represent real markets, and that decision making with the simple decision rule may be valid in only for simple markets. It can also be argued that the simple decision rule performs relatively well when costs are asymmetric and when firms can not learn from each others decisions. It should however be pointed out that the models of competition used in this study are the same models normally studied. Furthermore, it is not clear that decisions are usually are imitated in these models. Also, imitation may lead to more competitive decisions where firms make less profit than when making non-cooperative decisions.

Simulation of sequential decision making with the decision rule lead to convergence to individual non-cooperative decisions. Although, the decisions rule was only used in these relatively simple models of competition, the rule may be useful for determining optimal decisions in more complex models. Furthermore, there are a number of alterations, refinements and extensions to the decision rule described. For example, a complete proof of convergence and studying of mixes between sequential and simultaneous decision making would be of interest. The decision parameter for the decision rule is the boundary of adjustment, it was held fixed in the simulations and in the experiment, but it can be further explored. Also, comparisons between the use of the simple decision rule and the use of the decision rules mentioned in the introduction, and other rules, would be of interest.

Finally, we can ask the question, would the simple decision rule be good for firms to use for their decision making? The answer may depend on the model of competition and what boundaries of adjustments to use. Some firms may actually benefit from using the decision rule, while other firms may make better decisions by using the available information about the market demand and competitors.

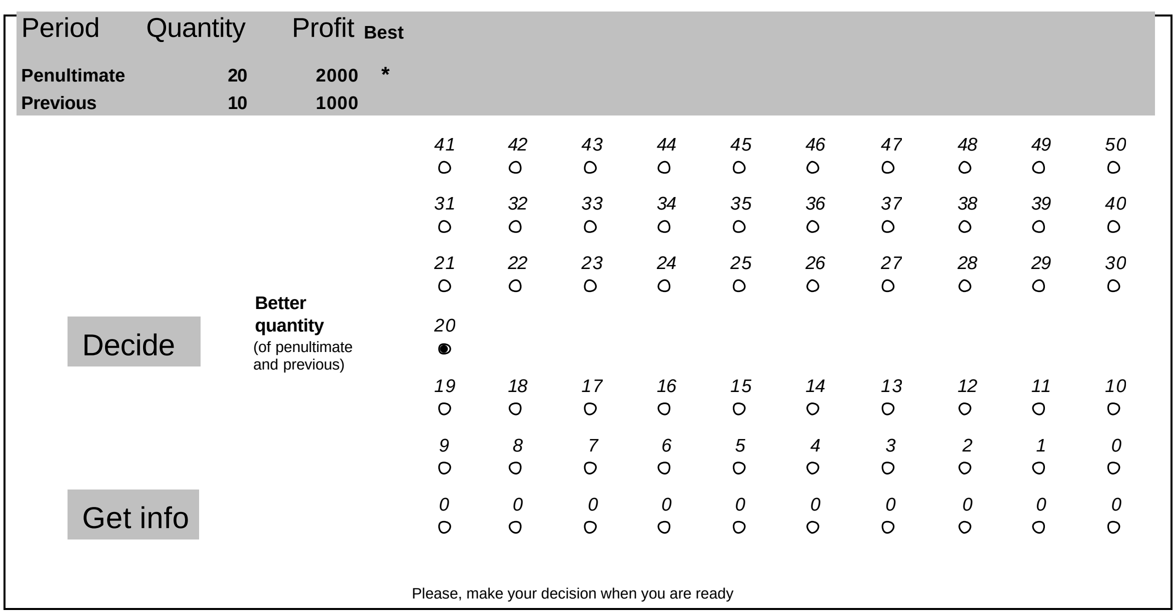
Appendix

Instructions for experiment

Welcome to the experiment! This experiment tests if good decisions can be made by using a simple decision rule. The rule requires very little information and therefore you will receive very little information when you use the rule.

You are a firm competing with an unspecified number of other firms who produce and sell products on the same market for an unspecified number of time periods. The decisions of the other firms affect the profit you make. However, you will not have any information about the other firms. This is part of the experiment. You will make decisions on quantities your firm will sell and you will observe the profits for your two previous decisions. The decisions of your two previous decisions which gave most profit will be your current best decision. The decision rule puts the current best decision in the middle of 61 possible alternatives for your next decision. If your current best decision is less than 30, you will have alternatives from 0 to your current best decision plus 30. You will make a number of decisions, but you will not exactly know how many. The instructor will tell when the experiment is ended. Your objective is to make as much profit as possible during the experiment. Your reward is calculated as a portion of your total earnings ($0 - $20). Good luck!

Step 1. Press "Get info" to update information.
Step 2. Select any of the 61 decision alternatives.
Step 3. Press the "Decide" button.
Step 4. Wait until you hear "Next period" then go to 1.



Computer screen from the application, showing 20 as current best decision and decisions alternatives from 0-50.

Random numbers

The random generator used for the randomization of adjustments of decisions is the multiplicative congruential generator (MCG) introduced by Lehmer. A sequence of random numbers $U_1, U_2, \ldots$ is defined by the algorithm: $U_t = aU_{t-1} \bmod m$. The multiplier, a, is 16807 and m is $2^{31} - 1$. The seeds, U_0, are the same as described in Law & Kelton (2000, p 429). The random numbers U_t generated are then divided by m, to give normalized random numbers in the interval $0 \le u \le 1$, with more than 10 decimals. The random number generated from this seed is in turn used to generate the next random number, and so on.

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