

Bertrand competition with asymmetric costs: Experimental evidence*

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Abstract:

We provide supporting evidence from the laboratory for the Nash predictions of the homogeneous-good Bertrand model under asymmetric constant unit costs.

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1 Introduction

Many economic models of price competition in homogeneous goods markets are based on the prediction that equally efficient rivals will fiercely compete leading to zero profits, whilst a more efficient firm will just undercut the price offered by a less efficient rival. While several papers have studied the interaction of firms with symmetric costs in the laboratory (Bruttel, 2008; Dufwenberg and Gneezy, 2000 and 2002; Fouraker and Siegel, 1963), experimental evidence for the case of asymmetric firms is very scarce. Our paper aims at helping to fill this gap.

Dugar and Mitra (2011) is another paper to allow for asymmetric costs under price competition. We compare our result to theirs in the conclusion.

2 The Model

Consider a market with n firms which compete for selling exactly one unit, where $n = 2$ or 3 . The reservation price of the fictitious buyer is 100. The firm offering the lowest price in the market sells one unit, whilst the other firms sell zero units. If two (three) firms offer the lowest price, each of these firms sell half (a third of) a unit. Firm i has a constant marginal cost of production given by c_i , and there are no other costs. The profit of firm i in each round is given by $\Pi_i = \frac{(p_i - c_i)d_i}{N}$, where $p_i \in \{0, 1, 2, \dots, 100\}$ is the price chosen by firm i , N is the number of firms offering the lowest price in the market and $d_i = 1$ if p_i is the lowest price in the market and $d_i = 0$ otherwise.

In any market in which firm i has a strictly lower marginal cost than the others, we have that any Nash equilibrium (NE) not involving any weakly dominated strategies consists of firm i capturing the entire market by setting price equal to the second lowest marginal cost.¹ For the rest of the paper, we focus on these NE, unless otherwise mentioned.

More specifically, we focus on the following three markets (Cases 1-3).

¹See Blume (2003), Erlei (2002) and Kartik (2011) for theoretical clarifications. Although these papers assume a downward sloping demand function, unlike our model, their results carry over to our case.

Case 1: $n = 2$ and $c_1 = 10, c_2 = 20$.

Case 2: $n = 3$ and $c_1 = 10, c_2 = 20, c_3 = 30$.

Case 3: $n = 3$ and $c_1 = c_2 = 10, c_3 = 30$.

The pure strategy NE not involving any weakly dominated strategies for Cases 1-3, are as follows.²

Case 1: $(p_1^* = 20, p_2^* = 21)$

Case 2: $(p_1^* = 20, p_2^* = 21, p_3^* \in \{31, \dots, 100\})$

Case 3: $(p_1^* = p_2^* = 11, p_3^* \in \{31, \dots, 100\})$ and $(p_1^* = p_2^* = 12, p_3^* \in \{31, \dots, 100\})$

3 Design

Cases 1 and 2 were crucial to our study since in both these cases the two lowest cost firms are asymmetric. The main difference across Cases 1 and 2 is the total number of firms in each market. We included both these cases to check whether, in the presence of asymmetric costs, increasing the number of firms in a market increases competition in the laboratory, as concluded by earlier studies in different settings (for price competition, see Dufwenberg and Gneezy, 2000, and for quantity competition, see Huck et al., 2004). Case 3 served as a control, replicating the symmetric game, since competition between the two identical lowest cost firms determines the equilibrium.

At the beginning of each round, the computer determined whether a duopoly or triopoly would prevail. In the case that everyone would act in a triopoly, the computer decided whether Case 2 or Case 3 would apply to all markets in that round. Each subject was then randomly assigned to a group of either 2 or 3 participants and a cost in line with the prevalent Case. Within Cases 1 and 3, in each round, each subject was assigned one of two possible roles, that of the low- or the high-cost firm. Within Case 2, in each round, each

²The complete list of pure strategy NE are as follows.

Case 1: $\{(p_1^*, p_2^* = p_1^* + 1) : p_1^* \in \{11, 12, \dots, 20\}\}$

Case 2: $\{(p_1^*, p_2^* = p_1^* + 1, p_3^* \in \{p_1^* + 1, \dots, 100\}) : p_1^* \in \{11, 12, \dots, 20\}\}$

Case 3: $(p_1^* = p_2^* = 10, p_3^* \in \{11, \dots, 100\}), (p_1^* = p_2^* = 11, p_3^* \in \{12, \dots, 100\})$ and $(p_1^* = p_2^* = 12, p_3^* \in \{13, \dots, 100\})$

subject was assigned one of three possible roles, that of the low-, the middle, or the high-cost firm. Hence, depending on market size and cost structure, there were altogether 7 roles a subject could act in. The determination of market size and the role of each subject in each round was done quasi-randomly, so as to ensure that within each session, each subject was assigned each of the 7 roles for 8 rounds. Thus, each session consisted of 56 rounds. We ran 2 (7) sessions with 12 (18) subjects (150 subjects in total), all at the CentER laboratory at Tilburg University.

The identity of each subject remained anonymous to the other participants in all rounds. All subjects were informed about the number of firms and the costs of all firms in their own market. All subjects then chose a price from the set $\{0,1,2,\dots,100\}$. At the end of each round, each subject was shown the costs and prices of all firms in his/her own market only, and his/her own profit.

At the beginning of the experiment, every participant received 30 “Points” as an initial endowment to cover possible losses.³ The total earnings at the end of the experiment equaled the sum of Points a subject earned in each round plus 30. For every 15 Points, the subject received 1 Euro in cash.⁴

The aim was to design an environment most conducive to reaching the Nash equilibrium. Earlier research has indicated that it takes more than one round to allow Bertrand predictions to be realized in the laboratory (see for example, Bruttel, 2008, and Dufwenberg and Gneezy, 2002). In order to give the predictions of the one-shot game a chance to be realized in the laboratory whilst, at the same time, allowing the subjects to accumulate some experience during the course of the session, a random-matching protocol was used (as used by Dufwenberg and Gneezy, 2000, 2002; Dufwenberg et al, 2007), whereby in successive rounds each subject faces different rival(s) chosen randomly. A second condition facilitating convergence to Nash equilibrium concerns the set of information provided to the subjects.

³Losses (usually minor) occurred in, respectively, 5.6%, 2.8%, 0.4% of the observations in Case 1, 2 and 3.

⁴The instructions are available in the Appendix at:
<https://sites.google.com/site/araychaudhurihome/research>.

If, after each round, each subject can observe the prices in other markets, this creates a possibility to signal the willingness to collude on the part of individual subjects by repeatedly choosing prices higher than the NE level (see Bruttel, 2008; Dufwenberg and Gneezy, 2002; Isaac and Walker, 1985; Ockenfels and Selten, 2005). Therefore, at the end of each round, each subject was shown the costs and prices of all firms in his/her own market only. This is also in line with the finding of Huck *et al.* (2000) that providing full information about the rivals' actions within the same market leads to more competition.

4 Results

For brevity, we focus only on the results pertaining to the market price (defined as the lowest of the prices posted by the firms in a given market).⁵ Figure 1 shows the evolution of the average market price across all sessions separately for each Case. Note that the variable “adjusted period” only counts (in chronological order) those rounds where the Case in question was played within each session.

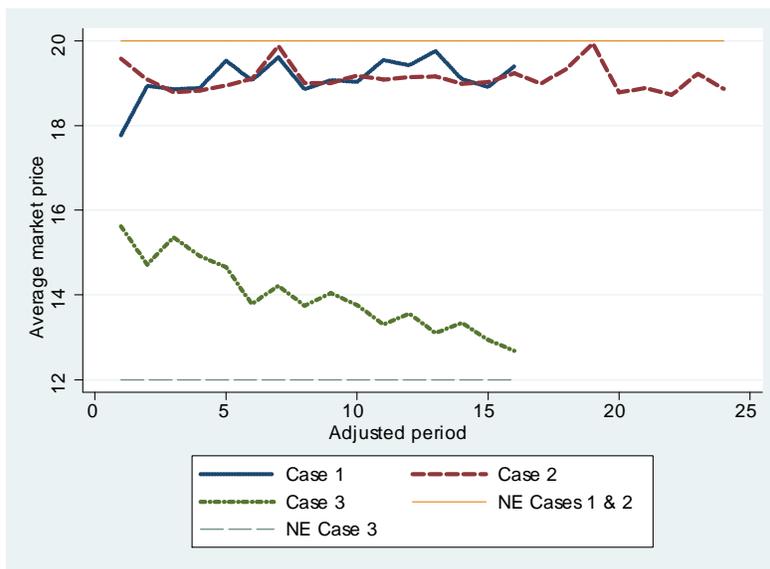


Figure 1: Average Market Price across all sessions

⁵Results pertaining to the prices posted by the higher cost firms are available upon request.

As illustrated by Figure 1, in the asymmetric markets (Cases 1 and 2), the average market price is very close to 20 (the NE not involving any weakly dominated strategies) consistently from the first to the last adjusted period.⁶ Moreover, such a pattern has been observed in each of the sessions.

In the symmetric market (Case 3), in the beginning of each session, the market price is higher than in the NE and converges toward the NE over time, in line with Bruttel (2008) and Dufwenberg and Gneezy (2002).

Moreover, by comparing Cases 1 and 2, we observe that allowing an additional firm with a higher marginal cost than firms 1 and 2 to exist in the market does not affect the average market price. This is in contrast to previous results pertaining to the symmetric case which show that increasing the number of firms increases competition in the laboratory (for price competition, see Dufwenberg and Gneezy, 2000, and for quantity competition see Huck *et al.* 2004). These papers also imply that collusion is very likely to occur in symmetric duopolies. Within our setting, however, we observe that two firms are enough to have markets converge to the NE when we incorporate cost asymmetry, as shown by our results for Case 1.

The above results are supported by Table 1 which shows OLS regression results of the market price under different specifications. In determining the statistical significance of variables, robust errors are used to account for possible heteroskedasticity. Let p denote the average market price across sessions.

In model (1) in Table 1, we regress market prices on case dummies, where Case 1, Case 2 and Case 3, respectively, take on the value of 1 in those rounds in which the corresponding case is played, and 0 otherwise.

As per column 1, the average market price in Cases 1, 2 and 3 are 19.11, 19.11 and 13.98 respectively. In regression (2) in Table 1, we repeat the analysis of regression (1), this time also controlling for time effects by including the variable “Period” which denotes the number

⁶The average market price is in fact closer to 19 than to 20. This may be due to the fact that by setting price at 19 instead of 20, firm 1 reduces the risk of having to share profits with firm 2. This might have led subjects to set price at 19 more often than at 20 when playing within Cases 1 or 2 in the laboratory.

of the round. There is a tendency for prices to fall with experience. However, as shown by regression (3), this effect is driven by Case 3.

In regression (3) of Table 1, we repeat the analysis of regression (1), this time checking for whether the time effect varies across the Cases by including interaction terms of the “Period” variable and the Case dummies. We find that the coefficients of the interaction terms for Cases 1 and 2 are very close to zero, whereas that for Case 3 is significantly larger (in absolute value) and negative. This is because, as we noted earlier, in asymmetric markets subjects are observed to play the NE strategy right from the start of each session so that experience does not play a role. In regression (4) of Table 1, we repeat the analysis of regression (2), this time replacing the “Period” variable with the “Adjusted period” variable. The results are similar to those obtained in regression (2).

In regression (5) of Table 1, we repeat the analysis of regression (3), this time replacing the interaction terms of the “Period” variable and the Case dummies with the interaction terms of the “Adjusted Period” variable and the Case dummies. The results are similar to those obtained in regression (3).

In order to control for possible session size effects, we repeated the analysis in regression (1), this time including a size dummy which took the value of 1 (0) if the number of participants in a given session was 12 (18). We ran another regression interacting the size dummy with the case dummies. Moreover, in order to control for order effects, two different parameter sets were used to generate the quasi-random assignment of cases to rounds in different sessions. We repeated the analysis in regression (1), this time including a dummy for the parameter set. We ran another regression interacting the parameter set dummy with the case dummies. We did not find any size or order effects.⁷

⁷The details of this analysis are available in the Appendix at:
<https://sites.google.com/site/araychaudhurihome/research>.

	(1)	(2)	(3)	(4)	(5)
Case 1	19.11*** (0.286)	19.30*** (0.296)	18.72*** (0.237)	19.27*** (0.300)	18.67*** (0.242)
Case 2	19.11*** (0.221)	19.32*** (0.253)	19.17*** (0.286)	19.35*** (0.271)	19.17*** (0.285)
Case 3	13.98*** (0.552)	14.20*** (0.582)	15.46*** (0.701)	14.14*** (0.577)	15.45*** (0.699)
Period		-0.01* (0.004)			
Period×Case 1			0.01** (0.005)		
Period×Case 2			0.00 (0.004)		
Period×Case 3			-0.05*** (0.007)		
Adj-Period				-0.02* (0.010)	
Adj-Period×Case 1					0.05** (0.015)
Adj-Period×Case 2					0.00 (0.009)
Adj-Period×Case 3					-0.17*** (0.025)
N	3,200	3,200	3,200	3,200	3,200
R^2	0.976	0.976	0.976	0.976	0.976

Notes: Robust standard errors are in parentheses. ** and *** indicate significance at the 5% and 1% level, respectively.

Table 1: Regression results

5 Conclusion

We report results of an experimental test of the Bertrand model under asymmetric costs. There exist many applications of this model, the main prediction of which (based on the notion of Nash equilibrium in undominated strategies) is that a more efficient firm will set price at the marginal cost of a less efficient rival. In light of our results, this is indeed a reliable model to apply to various contexts.

Dugar and Mitra (2011) find that, unless the size of asymmetry is much larger than in our study, more efficient firms set price significantly higher than the rival's marginal cost. However, when comparing our results to theirs, one must take into consideration that there exist significant differences across the design choices in the two studies. For example, Dugar and Mitra (2011) have between-subject designs with fixed-roles (where within each session the role of a subject is fixed to either the high-cost type or the low-cost type), whereas we have a within-subject design with random assignment of costs across rounds.

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