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Abstract

We report results from experiments on location and price competition by collective and individual players. A version of the Hotelling game is used with discrete location and pricing spaces. Theoretical predictions depend on the degree of players' attitude towards risk. Collective players' strategies are found to exhibit a stronger tendency towards agglomeration in the middle which is the prediction under the assumption of very strong risk aversion. However, the predicted positive relation between differentiation and price levels receives stronger support by collective player strategies than by individual behavior.

JEL classification: L13, C91.

Keywords: product-and-price competition, discontinuous games, mixed strategy equilibria, group decision-making, risk-aversion.

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1 Introduction

We compare the behaviour of collective and individual players with respect to product and price competition in a series of finitely repeated duopolies of the Hotelling (1929) type. In our theoretical framework, several assumptions of the well known model of horizontal differentiation are modified in order to obtain a more realistic and richer in predictions model than is usually possible in the standard continuous-strategy (*well behaved*) version. Specifically, we assume that both *pricing* and *product design* ("location" in the Hotelling tradition) are chosen from a discrete strategy space. The assumption of discrete (*integer*, *round*, "*..99*", *etc.*) pricing is inspired by the well known fact that some retail prices which can be considered as "*focal*" are much more likely to be used by firms than other, non *focal*, ones. An even more appealing modification of the standard framework is inspired by the fact that, among a continuum of product designs (or "locations"), in reality, only a finite subset may be feasible due to technological restrictions or due to consumers' tastes clustering on a finite number of *ideal* varieties (locations), because of fashion, imitation, collective identity, *etc.* As we will see, from a mathematical point of view, the resulting framework is less elegant and yields less clear cut results than its continuous version because, generally speaking, mixed strategies must be used, in order for an equilibrium solution to be obtained. However, the resulting mixed-strategy equilibria offer a broad variety of outcomes which depend on the agents' attitude towards *risk*. Therefore, contrary to the extreme principles of *minimum* and *maximum* differentiation obtained under different formulations of the disutiltiy suffered by consumers in the continuous strategy version, the modified model used here provides a spectrum of results depending on purely idiosyncratic aspects of human behaviour. Our "collective-*vs.*-individual" experimental design aims at capturing differences in behaviour which, given previous findings, may result from different positions adopted by groups and individuals making decisions in the presence of risk and strategic interaction.

The hypothesis of performance differences between groups and individuals presented with some problem-solving tasks has been rigorously tested in numerous occasions by psychologists[1] and economists [2]. Some studies seeking the origins of the aforementioned performance differences compare the frequency with which collective and individual decisions suffer from certain biases. Along this line, the recency bias [Ahlawat (1999)] seems to be more likely to appear in individual behaviour than in groups, whereas Sindelar (2001) finds that the hindsight bias is equally likely to be observed in groups as in individual behaviour. Economic theory has put forward several arguments favoring the superiority of collective decisions in comparison to individual ones. For example, the human fallibility approach[3] has been used to formalise the argument that groups, adopting the right organizational structure, make better decisions than do individuals because they aggregate individual, boundedly rational (fallible) views of the problem on which a decision has to be made. More recent work by Sudgen (2000), adopting an agency-theoretic approach, provides a profound analysis of the way in which individual preferences interact with and are reflected on team preferences. However, as far as decision making under uncertainty is concerned, Knight's (1921) work provides an early and extensive reference to the advantages of groups (organizations) over individual decision-makers.[4] More recent experimental and empirical studies have also tested for differences between collective and individual decision making in the presence of risk. Far from attempting an exhaustive review of the literature on this issue, we mention few pieces of work.

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[1] For example, it has been argued [Tindale and Larson (1992)] that some of the findings claiming superiority of group performance in comparison to performance by any individual or combination of individuals overestimate the "assembly bonus effect".

[2] Bone *et al.* (1999) find significant differences in the consistency of individual and group decision making, while experimental results reported by Bornstein and Yaniv (1998) support the hypothesis that groups are more rational players than individuals.

[3] Introduced by Sah and Stiglitz (1986). As shown by Koh (1994), the approach can be used to derive the conditions under which a 50% majority rule for collective decision making is optimal or close to the optimal one.

[4] Of course, Knight's work has gone far beyond a mere comparison between collective and individual behavior, inspiring the modern theory of the firm [Demsetz (1995)].

Iselin (1991) finds no difference between collective predictions of an uncertain event (bankruptcy) and composite (average) predictions by individual subjects. The failure is attributed to the fact that, in the experiments reported by the author, groups have failed to benefit from expert members' opinions. Elliot and McKee (1995) find that collective decisions outperform individual ones provided that some risk sharing among group members and across risks takes place and that individual perceptions of risk are successfully communicated to the rest of the group. Finally, Prather and Middleton (2002), using real-world financial data, find clear evidence in favor of the hypothesis that teams make better decisions than individuals. However, such differences in risk attitudes by individual and collective players have not been studied so far in the context of strategic market interaction. In fact, Sabater-Grande and Georgantzís (2002) is the only paper -to our knowledge- explicitly introducing an individual subject's risk attitude as an explanatory variable of behaviour in a strategic (deterministic and stochastic) setting. In such contexts, the role of collective decision making remains an unexplored phenomenon. Although the experiments whose results are reported here do not explicitly account for risk aversion, the theoretical framework used offers a range of theoretical predictions, which depend on the assumption concerning the subjects' attitudes towards risk. Therefore, our analysis combines, on one hand, a design for strategic interaction in repeated market experiments with competition in both long run (product differentiation or location) and short run (price) variables and, on the other hand, a test for intrinsic differences between individual and group decision making in the presence of risk.

Product and price competition have been broadly studied by economists. However, while numerous theoretical models have been used to explain a large number of phenomena related with pricing and product differentiation[5], empirical work aimed

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[5] An exhaustive list of such phenomena falls out of the scope of this paper. As representative examples, we mention minimal differentiation and variety clustering [like in Hotelling (1929) and Eaton and Lipsey (1975)], maximal differentiation [like in D'Aspremont *et al.* (1979)], predation [Judd (1985)] and multiproduct activity [Aron (1993)] or the lack of it [Martínez-Giralt and Neven (1988)], *etc.*

at formally testing theoretical predictions represents only a very small part of the literature. This lack of systematic empirical testing of product differentiation theory is often explained as a result of the difficulties faced by economists to successfully represent the product differentiation variable by proxies based on real world data[6]. Even when empirical work accounts for product differentiation, the latter is treated as an explanatory variable of other economic phenomena. Therefore, in a strict sense, product differentiation theory remains an empirically unexplored field of our discipline.

Like in the case of many other phenomena for which real world data leave little space for empirically testing economic theories, product differentiation models have been tested in the laboratory. Brown-Kruse and Schenk (2000), Collins and Sherstyuk (2000), and Huck et al. (2000), study experimental spatial markets with 2, 3 and 4 firms, respectively. However, all three articles report experiments with individual subjects whose only decision variable is location. That is, like in earlier work by Brown-Kruse *et al.* (1993), prices were taken to be exogenously given. Minimal product differentiation predicted by theory as the non-cooperative equilibrium for the framework used in Brown-Kruse *et al.* (1993) and Brown-Kruse and Schenk (2000), as well as 'intermediate'[7] differentiation predicted as the collusive outcome of the framework when communication among subjects is allowed were given support by their experimental results. The assumption of non-price competition in the experimental studies of spatial competition reviewed above, makes the results

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[6] Along this line, an assumption which seems to be broadly accepted by economists is that RD expenses are a good proxy for vertical product differentiation and advertising levels can be used as a proxy for horizontal differentiation. For a critical review of some of these assumptions and other similar ones, see Greenaway (1984).

[7] We use this term to refer to a product differentiation that lies between minimal (both firms locate in the middle of the segment) and maximal (each firm occupies one of the two extremes of the line) differentiation. In fact, the degree of product differentiation which corresponds to the joint profit-maximising solution is shown to require the firms to locate on the quartiles of the segment.

obtained directly applicable to the voting literature[8]. However, it fails to address a standard intuition which has motivated most of the theoretical work on the economics of product differentiation. Namely, that a firm may want to differentiate its product from products sold by rival firms in order to relax price competition. Our aim in this paper is to experimentally test the predictions of a location-and-price competition model of horizontal product differentiation.

Our theoretical model highlights the importance of using discrete variables as the strategic space of players. An important feature which emerges as a determinant factor of observed behaviour is a subject's attitude towards risk. Finally, unlike the framework adopted in the aforementioned experiments on product differentiation, our framework allows for incomplete market coverage, which is, though, observed in a much smaller number of occasions than would have predicted under low degrees of risk aversion.

The experiment we design has three essential characteristics: (a) it is a two-stage location and price game with two sellers, (b) there is a small (discrete) number of possible location and price choices which leads to high risk in subject's decision making, and (c) the design allows to compare individual and group decision making. As we will see in Section 4, the repetition of the two stage location-then-price competition game asks for an experimental design which solves the problem of representing short- (pricing) and long-term (product design or location) decisions in an efficient way.

Despite important differences between our framework and the Hotelling (1929) model, behaviour by the majority of our subjects support the principle of minimum product differentiation and almost competitive price levels. But, this is only the most frequent result. Several other situations with intermediate degrees of differentiation and higher prices are also obtained. Groups are less successful than are

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[8] Since Downs' (1957) work, non-price competition by competitors choosing locations on a closed linear segment along which a population of consumers (voters) are uniformly distributed is often adopted by theoretical political scientists to model electoral competition between political parties. For a more detailed review of this literature see Collins and Sherstyuk (2000).

individual players in adopting product differentiation strategies, but once differentiation has been achieved, groups are more successful in establishing higher prices than individuals are.

The remaining part of the paper is organised in the following way: Section 2 offers a detailed description of the theoretical framework and the experimental design with a brief discussion of theoretical problems and considerations which should be taken into account in order to explain our experimental subjects' behaviour. In Section 3, the experimental design and results are discussed. Section 4 concludes. In the Appendix we present the tables which summarise the Nash equilibria in the pricing subgames.

2 Theoretical Framework and Experimental Design

2.1 Basic Model and Parameters

Let two firms, A and B, play a two-stage game. In the first stage, firm $i \in \{A, B\}$ chooses a location $L_i \in \{1, 2, ...n\}$ (we set $n = 7$) among n equally spaced points along a unit-length linear segment, as shown in Figure 1. In the second stage, after the location choices are known by both firms, each firm chooses a price $P_i \in \{0, 1, 2, ...P^{\max}\}$ (given the assumptions stated below, $P^{\max} = 10$).[9] In each stage, decisions are simultaneously made by the two firms, whose aim is to maximise individual profits. Firms sell their product to n consumers, each one located on each one of the equally spaced points on the linear segment.

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[9] As we will see in the experimental design section, we have made the game last for 25 periods. In periods 1, 5, 10, 15, 20, and 25, both the location and the pricing decision are taken. In the rest of the periods, the subgame has only one stage, the pricing one, location remains fixed until the next location and price decision period. As the repetition of the game is finite, the equilibrium we obtain for the one shot game can easily be adapted in order to describe the equilibrium of the whole supergame.

Insert Fig. 1 about here

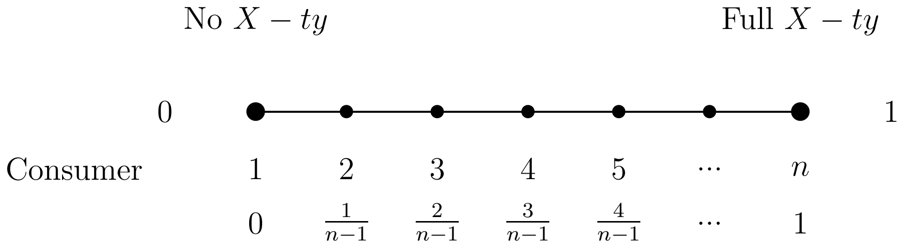

Figure 1: Linear city with discrete locations.

A consumer $j \in \{1, 2, 3...n\}$ buys a maximum of *one* unit of the product from firm $i \in \{A, B\}$ in order to maximise a utility given by:

$$U_{ji} = \max\{10 - p_i - t \cdot x_{ji}, 0\},$$

where x_{ji} is the 'distance' on the product characteristics space between j's ideal variety and the one actually offered by firm i, and t (here, $t = 6$) is a unit-transportation cost parameter (disutility suffered per unit of "distance" on the product characteristics space). The decision of the consumer to purchase the good from i implies that $U_{ji} \geq U_{jk}$,with $k \neq i$. In fact, if $U_{ji} = U_{jk}$ holds, the consumer will randomly (with a probability of 1/2 for each firm) choose one of the two firms. This turns out to be an important difference from the continuous-strategy version of the model. In fact, a discrete consumer location framework is also used by Collins and Sherstyuk (2000), but their number of consumer locations is much larger than ours (100 against 7), so that, in our framework, the possibility of a 'draw' on a consumer location is far more important for a firm's profits. This, together with the fact that, in the experiments reported here, 'draws' are solved in a probabilistic -rather than a deterministic- way (by tossing a coin) exposes our subjects to a far more significant risk than that faced by Collins and Sherstyuk's (2000)[10] subjects. Therefore, consumers cannot be treated as zero-mass particles of a population whose individual ideal varieties

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[10] In that work, the authors assume that 10 units are demanded at each location and, in the case in which a 'draw' occurs, 5 units are purchased with certainty from each of the two firms involved.

are distributed according to a continuous distribution function along the relevant product characteristics space. Rather, they are treated as individuals (or, generally speaking, clusters of individuals) with unit demand for the product supplied by the manufacturers.

2.2 Benchmark Solutions

A number of theoretical results indicate the possibility of non existence of equilibrium in economic games with discontinuous payoff functions. A famous example is the proof by D'Aspremont *et al.* (1979) concerning non existence of a pure-strategy equilibrium in the price-setting stage of the Hotelling (1929) model of product differentiation. It can be easily verified that, in our framework, the stage price-setting game will, in general fail to have a pure-strategy equilibrium. Despite the fact that both the price-setting as well as the location-then-price competition games are repeated a finite number of periods, the non existence of pure strategy equilibria in some of the price-setting subgames is not necessarily translated into non-existence of a pure-strategy equilibrium of the supergame considered. In our framework, in which not only payoffs but, also, action spaces are discontinuous and (thus) discontinuity points do not satisfy the property of a negligible probability (Dasgupta and Maskin (1986a, 1986b)) or, even the weaker version of the property required by Simon (1987)[11], a mixed strategy equilibrium may also fail to exist. However, it can be shown[12] that, in the special case used here, backward induction by substitution of subgames with their corresponding mixed strategy equilibria in prices leads to a pure strategy equilibrium for the supergame, in both prices and locations.

In this section, together with the aforementioned equilibrium, we propose and discuss some more combinations of location and pricing strategies that can be

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[11] The author requires that only some (even one) of the discontinuity points satisfies the negligible probability property.

[12] Detailed calculations, assuming a very low degree of risk aversion, are provided in the Appendix.

thought of as globally optimal solutions. Although these are not predicted as equilibria of the model, they offer a useful benchmark for the analysis of globally ideal behaviour. As can be observed from the comments in the lines below, not even the optimal strategies can be obtained without specific assumptions concerning players' attitude towards uncertainty.

2.2.1 Tacit Collusion

A *global maximum* in the two firms' joint profit is obtained with firms locating on locations 2 and 6 and prices $(P_i, P_k) = (8, 9)$, for $(i, k) = (A, B)$. Then, all consumers are served and the joint profit is given by $8 \cdot 4 + 9 \cdot 3 = 32 + 27 = 59$. A main problem associated with this solution as a predictor of play by subjects acting individually and in the lack of any communication and tacit coordination is asymmetry. It is very unlikely that one of two *ex ante* symmetric (and probably inequity averse) players will accept the role of the low-profit player (the one whose price is 9 earns 27 monetary units against 32 earned by the other firm), especially when side payments are not allowed. A more complex coordination mechanism could be used by firms in order to change roles over subsequent periods as a profit-sharing device, but this, given our experimental results seems a rather unrealistic scenario.

A *symmetric* joint profit-maximising solution is obtained if firms (who are now assumed to restrict their strategy profiles to those with symmetric prices) choose the same locations, but set a price $P = 8$. Joint profits are, now, given by $8 \cdot 7 = 56$. A problem which is associated with this solution is that each firm's expected demand is 3.5 which is the result of a 'draw' on the *central* consumer location. This implies that each firm's *ex post* profits will be either $8 \cdot 4 = 32$ or $8 \cdot 3 = 24$ (each firm's expected profits are, then, given by 28).

A *risk-averse* joint profit-maximising solution could be the symmetric strategy profile $P = 9$. Then, given firm locations 2 and 6, the consumer in the middle (location 4) will prefer not to buy the good at all. Firms earn certain profits of $9 \cdot 3 = 27$ monetary units each (joint profits are 54). This strategy would be chosen by tacitly colluding firms if they were sufficiently risk averse to prefer a certain payoff that is one unit less than an expected gain implying a 50% probability of earning three units less than the certain payoff guarantees.

A final remark concerns the optimality of multi-location (-plant) operation. It can be easily checked that locating both plants in the middle of the segment can at most yield (for the optimal price $P = 7$) 49 monetary units of profit, which is far below the multi-location optima above.

2.2.2 Non-cooperative Equilibria

It can be checked that none of the solutions discussed above can be sustained as an equilibrium of the game, given that individual deviations from them are profitable. When we calculate the subgame perfect Nash equilibrium in prices and locations for the supergame considered we obtain[13]:

Locations	Prices	Expected Demands	Expected Profits
(2, 6)	(7, 7)	(3'5, 3'5)	(24'5, 24'5)

Table 1: Location and price equilibrium of the supergame.

In the calculation of the equilibrium of the game we have assumed a very low degree of risk aversion, according to which only in the case of equality between a certain and an expected payoff subjects prefer the certain outcome. However, our results indicate that subjects' risk aversion may be much stronger than that. An alternative solution in which strong risk aversion is assumed can be sketched in the following lines.

From textbook game theory, we know that *maximin play* by a subject faced with strategic uncertainty does not only fail to give a Nash equilibrium of a non-cooperative game, but, in the case of nonzero-sum games, may be an irrational strategy. However, we can imagine that a very risk averse player may want to guarantee a minimum payoff independently from the other players' strategies. Ignoring

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[13] In the Appendix we provide the tables which summarise the mixed and pure strategy price equilibria for each location combination, and also the payoff matrix with the equilibrium prices for each location combination.

the other player's rationality may lead a subject to treat strategic and non strategic uncertainty in the same way. In that case, strong risk aversion may be interpreted as an extreme fear that the worst outcome will emerge, including the case of an opponent who is irrational enough to pursue minimum rival payoffs rather than own utility maximisation. We will use the *maximin strategy* $(L_i, P_i) = (4, 1)$ as a benchmark (and extreme) prediction for behaviour by strongly risk averse players.

It is straightforward that intermediate degrees of risk aversion will lead to outcomes which range between the Subgame Perfect Equilibrium calculated above under the assumption of very weak risk aversion and the *maximin* benchmark prediction. This observation is compatible with a similar result in the experiments by Collins and Sherstyuk (2000) with exogenous prices, whose theoretical foundation is Osborne's (1993) proof that the characterisation of mixed strategy equilibria may vary according to assumptions concerning a player's attitude towards uncertainty.[14]

We can summarise the predictions corresponding to the theoretical solutions above in the following way.

Theoretical predictions:

1) *The joint profit-maximising and the low risk-aversion players' non-cooperative equilibrium locations are given by* $(L_i, L_k) = (2, 6)$*. The prediction for the corresponding prices ranges from* 7 *to* 9*, depending on the intensity of price competition (or collusion), and the degree of players' risk and inequity aversion.*

2) *However, more central locations leading to lower prices (more intense price competition) are expected in the case of stronger risk aversion, up to the extreme case of* maximin play *by strongly risk averse players choosing the central location* $L_i = 4$ *and the minimum positive price* $P_i = 1$.

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[14] In fact, in Harsanyi (1967), it is argued that a mixed strategy equilibrium can, under certain circumstances, be viewed as a pure strategy equilibrium in a game of incomplete information.

2.3 Experimental Design

Each experimental session consists of 25 periods. The experimental design is such that the two stage (location-then-price competition) game is modified in order to gain in realism by introducing series of periods during which firms can only modify their prices, taking product design as given. In periods 1, 5, 10, 15, 20, and 25, both location and pricing decisions are taken. In the rest of the periods, location is kept fixed and price is the only decision variable. As the repetition of the game is finite, the equilibrium we obtain for the one shot game can be used in order to describe the equilibrium of the whole supergame. The last (25th) period of the session is a 'location period', so a location-price sequence is played only. We have opted for this strategy as a way to isolate possible end-game behaviour in both location and price strategies.

Two treatments were organised in 18 experimental sessions each. In the basic treatment (BT), the two players were individual subjects, whereas in the collective treatment (CT) each player consisted of a group of 7-8 subjects. So, we have had 36 individual subjects playing in the basic treatment, and 36 collective subjects playing in the collective treatment. No individual subject participated in more than one experimental session.

Subjects were Economics students from three Universities (Universitat Jaume I in Castellón, University of Valencia and University of Zaragoza). Collective players were students (and groups were formed by classmates) of the undergraduate IO, Game theory, Public Enterprise Economics and Economics of Technical Change courses in the three aforementioned universities.

In each session, "rival" players were sitting in the same room, but they were separated and surveyed by the experimentalist, so that they could not talk, or see each other[15]. Within each group (forming a collective player) communication and any other type of spontaneous organisation of collective decision-making was en-

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[15] The subjects knew that the session would end automatically with zero profits for both if they tried to communicate in any way.

couraged. Apart from the written set of instructions[16], the organiser of each session gave detailed explanation of how demands and profits should be calculated given any strategic profile chosen by fictitious subjects. As far as possible learning effects are concerned, we should mention that our experimental design requires far less complex calculations by subjects than those required in continuous strategy experiments reported elsewhere[17], in which subjects end up using try-and-error algorithms only. Contrary to those experiments, our players are not only fully informed on the market conditions, but also, they are exposed to a minimum level of complexity allowing them calculate the consequences of their decisions. In fact, no calculus is needed, and any optimisation exercise (when necessary) can be performed using simple arithmetic operations.

After locations and prices were known for a period, each 'draw' was solved by tossing a coin. The experiments were not computerised. Thanks to the simplicity of the calculations needed, the experimentalist immediately presented the decisions, results of the coin-tossing procedure (when necessary), demands and profits on a blackboard.

At the end of each session, subjects received monetary rewards which were proportional to their profit over the 25 experimental periods. Individual players were paid according to an exchange rate of 10 Spanish Pesetas for each experimental currency unit. In the collective treatment, the exchange rate was multiplied per 7 or 8 (depending on the group size) so that each subject's expected share from group payoffs (equally divided by each group's members) would be as much as that of individual players. The equal-sharing rule adopted for group members is compatible with our objective of motivating all group members to actively contribute to the collective decision, adopting spontaneous and informal ways of communication and

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[16] See Appendix.

[17] For example, García-Gallego (1998) and García-Gallego and Georgantzís (2001) report the results from experiments in which subjects had no information on the true demand model. The estimation of a firm-specific demand by O.L.S. (available to firms) was shown to be of little use to subjects who seemed to lack incentives to learn or capacity to calculate their optimal strategies.

internal conflict resolution. A somehow related argument is put forward by Kroon *et al.* (1993) who, though, find no difference in the performance of groups with individual and collective accountability of results in a collective decision-making task. In both treatments a maximum profit of 6750 Pesetas (approximately, 40.5 Euros) could be earned by each subject corresponding to the case of firms colluding during the 25 periods, setting the risk averse optimal price (9). The theoretical low risk-aversion subjects' strategies during the 25 periods of a session would earn 6125 Pesetas (approximately 36.8 Euros), whereas 875 Pesetas (5.2 Euros) would be earned by a strongly risk averse subject conforming with the *maximin* strategy over the whole experimental session.

Therefore, our experiments were designed to be worth participating in. Furthermore, subjects were given strong incentives to abandon the conservative (*maximin*) attitude (central locations and unit prices) guaranteeing the maximum certain payoff.

3 Results

3.1 Aggregate Results

Our aggregate results indicate (Figures 2 and 3) that collective players have differentiated significantly[18] less than individual players did. Also, their prices have been significantly lower[19]. Average earnings from subjects in the basic treatment have been of 2.631 pts., ranging from 360 pts. to 5510 pts. In the collective treatment,

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[18] A Kolmogorov-Smirnov test has indicated ($KS = 3.67$ against the theoretical value of 1.36) that the difference in the distribution of degrees of differentiation observed in aggregate data from the two treatments is statistically significant at the 0.05 level. It is also significant at the 0.01 level but we will use the 0.05 level throughout the paper for consistency. A Mann-Whitney test can also be used to show that, on average, locations from the collective treatment are more central and less differentiated than those from the basic treatment ($MW = -4.492$ and $MW = -6.303$ against 1.96 respectively).

[19] $KS = 1.4613$ against 1.36 and $MW = -2.581$ against 1.96.

average earnings were 2.394 pts., ranging from 820 pts. to 4.610 pts.

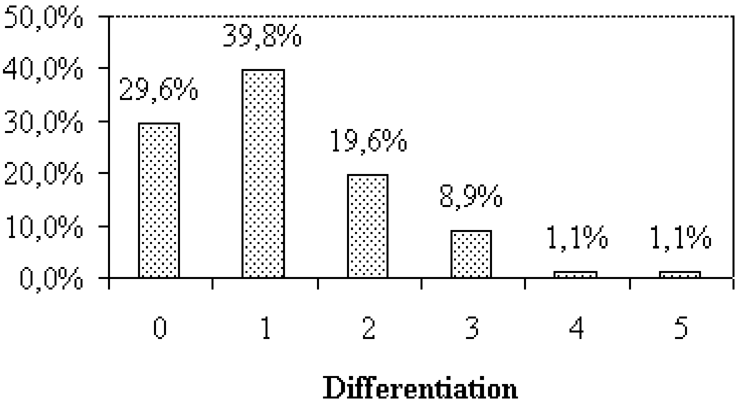

Figure 2: Percentages of differentiation in the basic treatment (BT). (*Differentiation* refers to the distance between the two firm's locations measured in sixths of the segment).

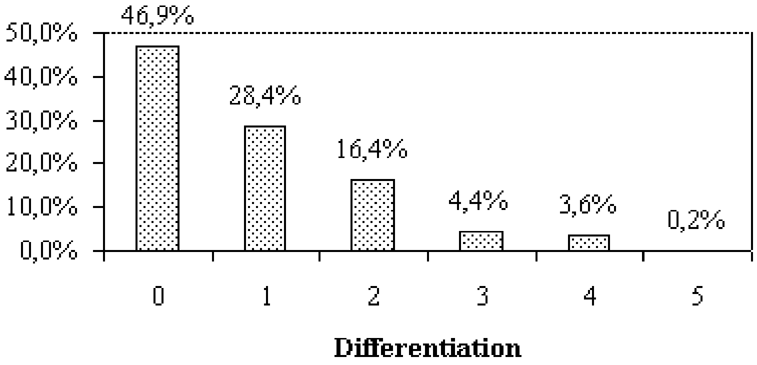

Figure 3: Percentages of differentiation in the collective treatment (CT).

For the degrees of differentiation between pairs of firm locations for which a sufficiently large number of observations were obtained, we can affirm the following[20]:

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[20] We have performed the analysis taking into account the achieved degree of differentiation, and not the absolute location pairs because, there are so many location combinations that, for most of them, we end up having very few observations on which to base our analysis.

In the absence of product differentiation[21] (zero distance between competing firm locations) the distribution of prices in sessions with collective and individual subjects present no significant[22] differences (Figure 4). Average price is only slightly higher in the BT (2.81) than in the CT (2.77). In fact, the most frequent result is the pure strategy Nash equilibrium prediction for the corresponding price subgames ($P = 1$).

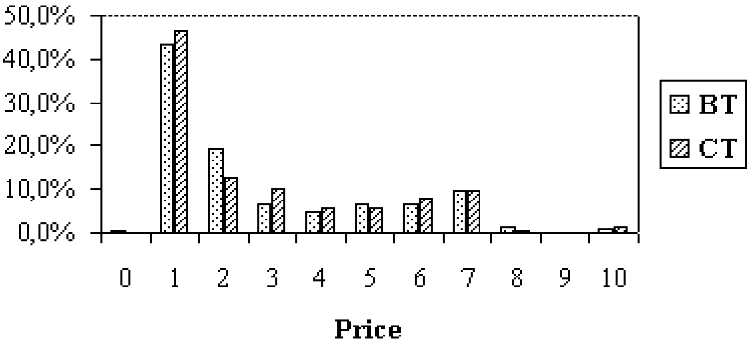

Figure 4: Price distribution when differentiation is 0.

With a unit difference between firm locations[23], we find that the distributions of prices obtained from the two treatments are significantly[24] different (Figure 5). More specifically, in both treatments subjects have used prices whose distribution has a peak on 2, but average prices are higher (3.54) for the basic treatment than for the collective treatment (2.61). Individual players have managed to set significantly higher prices with a low degree of differentiation. On average, the equilibrium prediction of prices equal to 1 or 2 (depending on the locations on which unit-differentiation takes place) is exceeded by observed behaviour.

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[21] 266 observations in the basic treatment and 422 in the collective treatment.

[22] $KS = 0.5$ against 1.36 and $MW = -0.336$ against 1.96.

[23] 358 observations for the BT and 256 for the CT.

[24] $KS = 2.47$ against 1.36 and $MW = -5.24$ against 1.96.

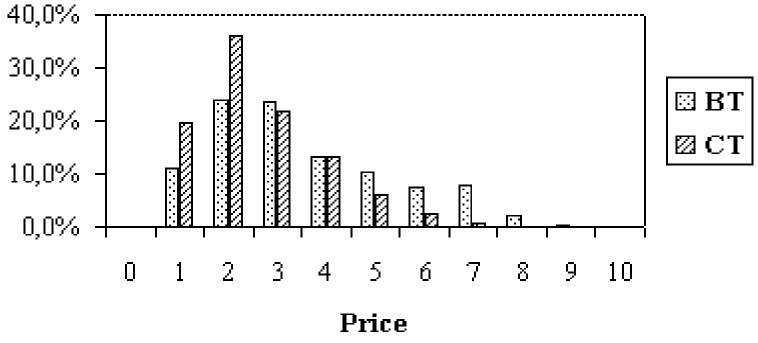

Figure 5: Price distribution when differentiation is 1.

When firm locations differ by two[25], the distributions of prices from the two treatments do not present significant[26] differences (Figure 6). A peak is observed for a price of 3 in both cases, and collective prices only have a slightly higher average (4.24) than individual ones (3.85). A higher price dispersion may reflect the fact that a pure strategy equilibrium in the pricing stage does not exist. Mixed strategy equilibria prices range from 1 to 6, which seems roughly compatible with our subjects' behaviour.

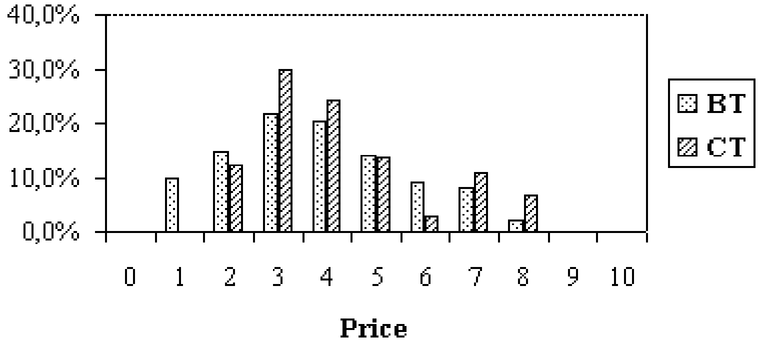

Figure 6: Price distribution when differentiation is 2.

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[25] 176 observations in the BT and 148 in the CT.

[26] $KS = 1.14$ and $MW = -1.31$.

Locations differing by 3 sixths of the segment[27] present price distributions which significantly[28] vary across treatments (Figure 7). Individuals have set lower prices on average than collective players (respectively, peaks on 3 and 5 are observed and respective average prices are 3.30 and 4.55). The mixed strategy equilibrium prediction of prices ranging from 2 to 7 is compatible with the behaviour of both types of players, although individuals have set some prices below the minimum of the aforementioned interval. Finally, location differences of more than 3 (4 or 5) were observed in very few occasions and any conclusions based on this evidence would lack statistical significance.

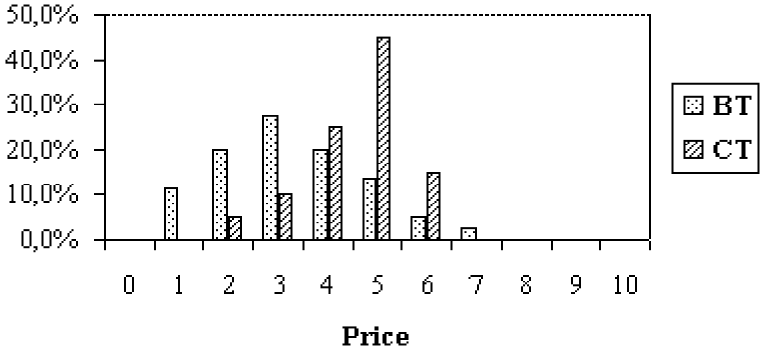

Figure 7: Price distribution when differentiation is 3.

On aggregate, a positive relationship between product differentiation and prices is observed (Figure 8) and this relationship is stronger for collective subjects. Apart from the aforementioned differences across treatments, our results indicate that our subjects have differentiated much less and they have set much lower prices than those of the low risk-aversion perfect equilibrium ($(L_i, L_k, P_i, P_k) = (2, 6, 7, 7)$). In fact, the predicted outcome occurred only in two periods of one of the sessions in the collective treatment. The global, the symmetric and the risk-averse joint profit maximum occurred only once each. We have only had incomplete market coverage

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[27] 80 observations for the BT and 40 for the CT.

[28] $KS = 2.26$ and $MW = -4.76$.

in one case out of 450 in each treatment. Implicit coordination (having each firm in a different half of the market) has occurred in less than 10 % of the cases in the BT, and in less than 20% of the cases in the CT.

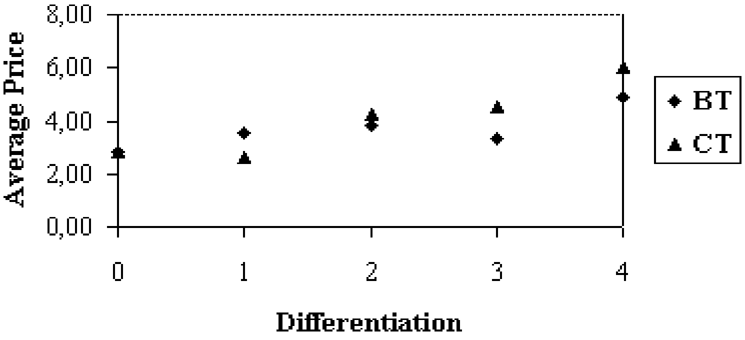

Figure 8: Relationship between differentiation and average prices.

Far more support is offered for predicted behaviour under strong risk aversion for location decisions. For example, the central location was chosen in more than half of the 'product design' periods, as can be seen from the aggregate data on locations (Figure 9), which were found to exhibit significant differences across treatments[29].

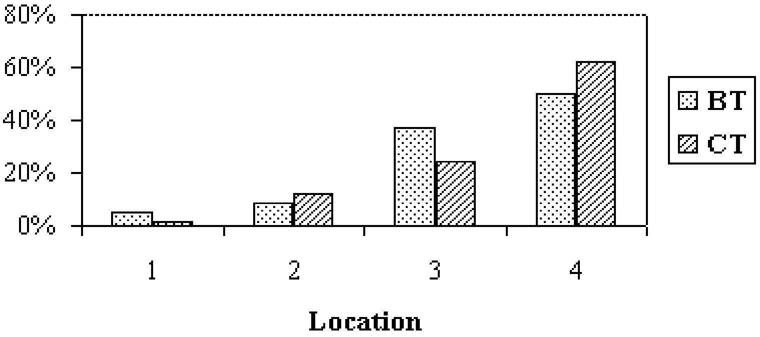

Figure 9: Aggregate location distribution.[30]

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[29] $KS = 2.61$.

[30] We have considered that location 1=7, 2=6, and 3=5.

Along the same line, aggregate price data, which, as we have already noted, significantly vary across treatments, give more support to the strong risk-averse players' prediction of unit prices (it is the most frequent price), than to a price of 7, predicted under the assumption of very low risk aversion (Figure 10). Anyway, we observe too a high price dispersion to be able to support any unique result in aggregate terms. Prices have been, more or less, close to the equilibrium prediction for their corresponding price subgames.

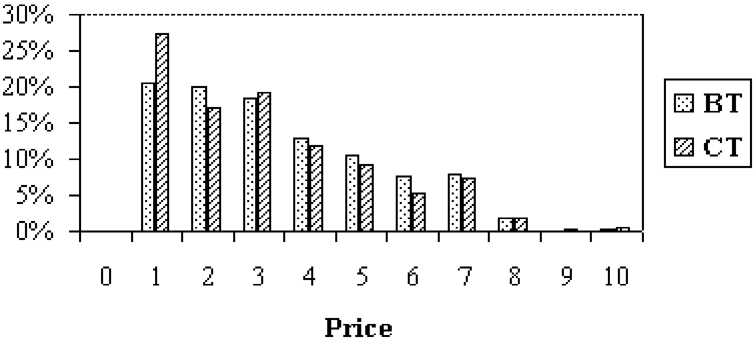

Figure 10: Aggregate price distribution.

We can summarise our partial conclusions up to this point in the following results:

Result 1: *On aggregate, our subjects' behaviour has yielded less product differentiation than would be the non-cooperative equilibrium prediction under very low risk aversion. In both treatments, more than half of the observed locations are compatible with* maximin *playing. Comparison across treatments shows that individual players differentiate significantly more than collective players do.*

Result 2: *Subjects seem to have realised the benefits from locating apart from each other, given that observed prices are higher, the higher is the distance between firm locations. In fact, collective subjects have exploited product differentiation more (even if they have used it less) than individual players did, given that the formers' prices have exceeded prices charged by the latter, as well as than the theoretical levels* *predicted for the corresponding degrees of differentiation, when differentiation was high.*

Result 3: *In the case of locations leading to pure strategy equilibria, prices have been close to them, even if there is high dispersion. In the case of locations leading to mixed strategy equilibria, price dispersion is observed over intervals that are compatible with theoretical predictions.*

3.2 Dynamic Results

The repetition of the same structure ('product design-price-price...') over several periods gives rise to a number of dynamic phenomena which could have not been captured by previous experiments with exogenous prices. We briefly refer here to the most interesting of these phenomena.

A first observation is that within each 'product design-price-price...' sequence of periods, in a vast majority of the cases, prices have exhibited two different trends: A declining and a constant one. In order to formalise this observation, we have run one linear model of the type:

$$P_t = \beta \cdot P_{t-1},$$

for price sequences for each degree of differentiation ranging from 0 to 4[31]. The declining trend would be reflected on $\beta < 1$ and constant prices are implied by $\beta = 1$. A total of 5 such regressions were estimated for each treatment. On aggregate, a moderately declining trend was observed[32]. However, the most interesting phenomenon associated with declining prices relates to product differentiation.

As can be seen in Figure 11, in both treatments, we find a positive relationship between product differentiation and the corresponding β's, which tend to (and may even slightly exceed) unity (constant prices) when product differentiation is high.

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[31] As we do not have many observations with differentiation levels of 4 or higher (less than 30 prices), any conclusions based on those regressions might be misleading.

[32] The average β estimate for the 14 regressions estimated (in the three treatments) is 0.937.

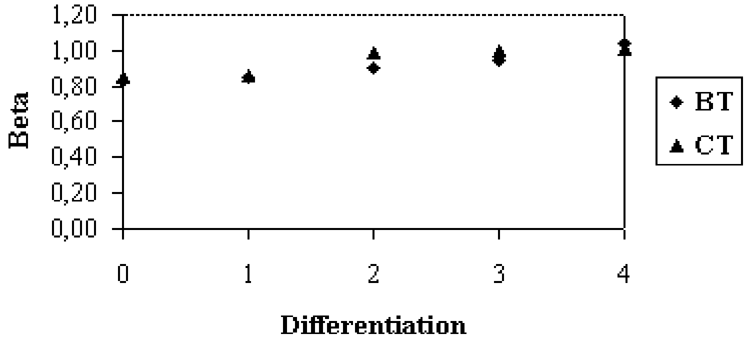

Figure 11: β estimates as a function of differentiation.

The positive relationship between differentiation degree and estimated β is virtually identical for both treatments. So, we obtain the following conclusion.

Result 4: *Lower (higher) degrees of product differentiation, together with lower (higher) prices also imply declining (constant) prices.*

This result can be the logical consequence of the fact that equilibrium prices in the pricing subgames in which differentiation is low are lower than in those with high differentiation.[33] So, when subjects try to support high prices, the pressure to decrease them over the price setting sequences is much stronger in the low differentiation cases.

Another interesting result relates with end-game behaviour. From textbook game theory we know that, while the equilibrium of a static game that is repeated a finite number of periods coincides with the equilibrium of the stage game, subjects may have incentives to signal friendly behaviour in order to encourage cooperation during the session, switching to a competitive strategy at the end of the game.

In the framework adopted here, both non-cooperative equilibrium and collusive behaviour could have lead subjects with low degrees of risk aversion to differentiate from each other as implied by Theoretical Prediction 1. However, we have also

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[33] See Appendix.

argued that such a high degree of (or any) product differentiation may never occur if subjects are sufficiently risk averse.

Therefore, a friendly attitude by one player is not only a signal of cooperative behaviour but, also, a guarantee that the other player should not fear the worst of all outcomes. Therefore, during each session we would expect such a friendly attitude to be more likely to observe in intermediate periods. That is locating and pricing in a less aggressive way makes less sense in the last period of the game in which no future profits exist to compensate possible short run losses.

In our experiment 8 out of 36 individual subjects decide to locate in the middle of the segment (location 4) at the end of the game, not being located there the period before the last. The same event occurred in 8 out of the 36 possible occasions in the collective subjects treatment. However, the same kind of behaviour can be found with similar frequencies in periods: 5, 10, 15, or 20. So, we cannot find clear evidence of an end game behaviour.

Result 5: *No significant end-game behaviour is exhibited by subjects in the basic and collective treatments.*

Finally, the degree of product differentiation does not seem to significantly[34] vary during each experimental session, although subjects have significantly[35] changed their 'central' first period strategies with less central ones in periods 5, 10, 15 and 20. We are not able to identify any other trend in the locations over time.

The central location in initial periods could be justified as an equilibrium selection problem, given that if one player assigns a probability of $\frac{1}{2}$ to the other playing any of the two possible location equilibrium strategies, his best response will be to play center. But after one player has seen that the other has chosen a given strategy this belief will no longer be valid, and best response dynamics could take him to the

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[34] Mann-Whitney tests showed that differentiation in each 'product design' period is not significantly different from that obtained in the same period for the other treatments and from that in previous and subsequent periods.

[35] $MW = -2.25$ for the basic treatment and $MW = -2.246$ for the collective treatment.

equilibrium in few steps.

The rather paradoxical observation that firms choose, over time, less central locations without achieving a significantly higher degree of product differentiation relates to coordination problems faced by firms which are simultaneously trying to differentiate from each other. Locating far from the center cannot guarantee success in a firm's effort to differentiate with respect to its rival, if the latter decides, at the same time to do the same on the same direction. This may indicate that, although subjects are faced with a problem of low complexity, in which simple arithmetic operations are required, coordination requires more and better learning than can be achieved by our subjects in the six 'product design' periods of a session. One could argue that, with more such periods in a session, coordination and/or trust by one firm in its rival's capacity to differentiate in the 'right' way would be more likely to observe. However, we would like to point out that, in many real world cases, firms' possibilities of re-designing a product are not as many as theory would like them to be either.

Result 6: *Subjects moved away from the middle in periods 5-20, but this did not lead to a higher differentiation.*

4 Conclusions

The behaviour by individual and collective players is studied and compared in a series of experiments based on a discrete version of the Hotelling (1929) model of product differentiation. Unlike previous experimental work on spatial competition, we study endogenous prices and allow for incomplete market coverage.

In our model, theoretical predictions depend on specific assumptions concerning firms' attitude towards risk. As a result, two extreme cases are used as benchmarks. On one hand, intermediate differentiation and high prices are predicted as the non-cooperative equilibrium with low risk-aversion firms. On the other hand, minimum differentiation and minimum prices are predicted as the result of *maximin* strategies play by strongly risk averse firms. Thus, the principle of minimum differentiation is far from being the unique subgame perfect equilibrium solution for the case considered here.

Despite the aforementioned modification of the original framework proposed by Hotelling (1929) and the resulting cognitive difficulties for subjects competing in a two-variable repeated strategic situation, the principle of minimum differentiation is shown to be the most frequently observed among all possible outcomes. Overall, price levels are higher than the prediction corresponding to the degree of differentiation observed. However, the prediction of a positive relationship between product differentiation and price levels is confirmed.

Collective players' behaviour is more conservative in locations (they differentiate less) and less conservative in prices (given a high differentiation prices are higher) than behaviour observed in the basic treatment. This observation may indicate that collective players make a more systematic effort to calculate the consequences of their strategies than individual players do, but groups are more reluctant to precommit to a risky option than individuals are. In the case of location combinations for which a pure strategy equilibrium exists, price distributions present peaks near the equilibrium prediction. When mixed strategy equilibria correspond to a certain location combination, price dispersion along the predicted interval is observed.

Our dynamic results indicate that low degrees of product differentiation do not only relate to lower prices but also to declining ones. Some learning dynamics are observed. However, despite the fact that, from the beginning of each session, subjects can calculate the consequences of any strategic profile using simple arithmetic operations, learning how to differentiate is not found to be an easy task. This can be explained as a result of the fact that learning not to play 'central' locations fails to be translated in learning to *coordinate* and successfully differentiate between firms. No significant end-game behaviour is obtained for any treatment.

Despite the evidence in favour of the principle of minimum differentiation which is rather easy to accommodate in existing textbook economic theory, we feel that some of the phenomena reported above deserve further study both in experimental economics laboratories and in theoretical work in the future.

A rather systematic evidence seems to exist for more ‘competitive’ results than would be predicted by the theory. This finding seems to relate with the results obtained from experiments conducted within non-expected utility frameworks in which strong risk aversion is associated with less cooperative outcomes [Sabater-Grande and Georgantzís, (2002)]. In the results reported here, an immediate consequence of this result seems to give rise to differences between collective and individual players’ behaviour.

Product differentiation theory should be extended with generalisations, which do not necessarily go on the direction of more complex functional forms leading to a choice between the extreme results of maximal and minimal differentiation. Instead, behavioural aspects like collective decision making in the presence of risk should inspire a framework in which the lack of clear-cut theoretical predictions is not necessarily a shortcoming. For the moment, we have shown that standard simplifying assumptions (e.g. coordination, risk neutrality) are less innocuous than is usually thought.

Appendix

4.1 Pricing Stage Equilibria

In order to discuss the Subgame Perfect Equilibrium of the game, we will, first, have to calculate equilibrium prices for all firm location combinations. A pure strategy equilibrium in prices exists for some of the location combinations. In fact, it is straightforward to check that pure strategy Nash equilibria exist in the price-setting subgame for all firm locations for which the distance between firms x_{ik} satisfies $x_{ik} \notin [2/6, 3/6]$. For location combinations implying differences in the interval $[2/6, 3/6]$, we have computed mixed strategy equilibria of the price-setting stage, considering all the plausible price supports,[36] and we have chosen the Pareto superior one in

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[36] That is, all prices which could have a positive probability of being played in an equilibrium strategy.

case of multiplicity. Below we present a summary of the pricing equilibria which have then been used to build Table 9.

Locations	Prices	Demands	Profits
(1, 1)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)
(2, 2)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)
(3, 3)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)
(4, 4)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)
(5, 5)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)
(6, 6)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)
(7, 7)	(1, 1)	(3'5, 3'5)	(3'5, 3'5)

Table 2: Both firms are located on the same point.

Locations	Prices	Demands	Profits
(1, 2)	(1, 1)	(1, 6)	(1, 6)
(6, 7)	(1, 1)	(6, 1)	(6, 1)
(2, 3)	(1, 1)	(2, 5)	(2, 5)
(5, 6)	(1, 1)	(5, 2)	(5, 2)
(3, 4)	(2, 2)	(3, 4)	(6, 8)
(4, 5)	(2, 2)	(4, 3)	(8, 6)

Table 3: Firms differentiate their products $1/6$ of the segment.

Locations	Prices	Probabilities	Demands	Profits
(1, 3)	([1, 3], [3, 4])	([0'31, 0'68],[1, 0])	(2'45, 4'54)	(4'5, 13'6)
(5, 7)	([3, 4], [1, 3])	([1, 0],[0'31, 0'68])	(4'54, 2'45)	(13'6, 4'5)
(2, 4)	([2, 4, 5], [4, 5, 6])	([0'23, 0'12, 0'64],[1, 0, 0])	(2'76, 4'24)	(10, 16'9)
(4, 6)	([4, 5, 6], [2, 4, 5])	([1, 0, 0],[0'23, 0'12, 0'64])	(4'24, 2'76)	(16'9, 10)
(3, 5)	([4, 5, 6], [4, 5, 6])	([0'1, 0'47, 0'41],[0'1, 0'47, 0'41])	(3'5, 3'5)	(18'2, 18'2)

Table 4: Firm's products are differentiated in $2/6$ of the segment.

Locations	Prices	Probabilities	Demands	Profits
(1, 4)	([2, 4, 5], [5, 6, 7])	([0’16, 0’07, 0’76],[1, 0, 0])	(2’53, 4’47)	(10, 22’3)
(4, 7)	([5, 6, 7], [2, 4, 5])	([1, 0, 0],[0’16, 0’07, 0’76])	(4’47, 2’53)	(22’3, 10)
(2, 5)	([4, 6], [6, 7])	([0’06, 0’93],[0’33, 0’66])	(3’43, 3’56)	(20, 23’6)
(3, 6)	([6, 7], [4, 6])	([0’33, 0’66],[0’06, 0’93])	(3’56, 3’43)	(23’6, 20)

Table 5: Firms differentiate their products 3/6.

Locations	Prices	Demands	Profits
(1, 5)	(6, 7)	(3, 4)	(18, 28)
(3, 7)	(7, 6)	(4, 3)	(28, 18)
(2, 6)	(7, 7)	(3’5, 3’5)	(24’5, 24’5)

Table 6: Firms differentiate their products 4/6.

Locations	Prices	Demands	Profits
(1, 6)	(7, 7)	(3, 4)	(21, 28)
(2, 7)	(7, 7)	(4, 3)	(28, 21)

Table 7: Differentiation is 5/6.

Locations	Prices	Demands	Profits
(1, 7)	(7, 7)	(3’5, 3’5)	(24’5, 24’5)

Table 8: The products are maximally differentiated (6/6).

	1	2	3	4	5	6	7
1	(3’5, 3’5)^{e}	(1, 6)	(4’5, 13’6)*	(10, 22’3)*	(18, 28)	(21, 28)	(24’5, 24’5)^{e}
2	(6, 1)	(3’5, 3’5)^{e}	(2, 5)	(10, 16’9)*	(20, 23’6)*	(24’5, 24’5)^{e}	(28, 21)
3	(13’6, 4’5)*	(5, 2)	(3’5, 3’5)^{e}	(6, 8)	(18’2, 18’2)*	(23’6, 20)*	(28, 18)
4	(22’3, 10)*	(16’9, 10)*	(8, 6)	(3’5, 3’5)^{e}	(8, 6)	(16’9, 10)*	(22’3, 10)*
5	(28, 18)	(23’6, 20)*	(18’2, 18’2)*	(6, 8)	(3’5, 3’5)^{e}	(5, 2)	(13’6, 4’5)*
6	(28, 21)	(24’5, 24’5)^{e}	(20, 23’6)*	(10, 16’9)*	(2, 5)	(3’5, 3’5)^{e}	(6, 1)
7	(24’5, 24’5)^{e}	(21, 28)	(18, 28)	(10, 22’3)*	(4’5, 13’6)*	(1, 6)	(3’5, 3’5)^{e}

Table 9: Mixed (*) and pure strategy price equilibrium (expected(^{e})) payoffs.

Following this payoff matrix and Table 6, it is easy to see that low *risk-aversion* players' equilibrium locations (2, 6) and prices (7, 7) for the supergame are those given in Table 1.

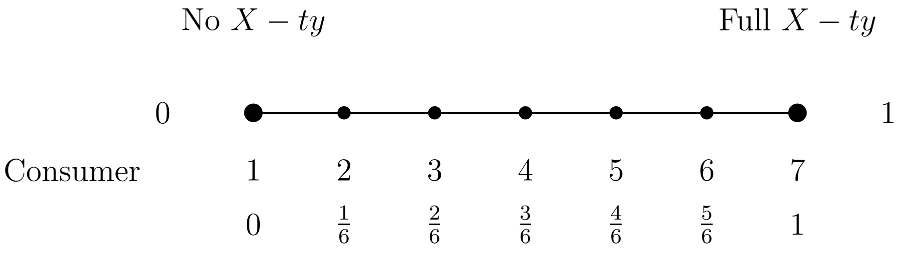
4.2 Instructions

Consider a market for a product which can be differentiated according to a characteristic that we will call '*X-ty*'. There are 7 potential consumers, each of them with different preferences regarding their ideal product's '*X-ty*' degree. Each consumer wants to buy a unit of the product, if his utility in doing so is not negative. He will buy his unit from the firm which makes the most interesting offer to him, in terms of price plus the monetary quantification of the 'non-consumption' of his ideal variety, according to the following utility function:

$$U = 10 - p - 6x,$$

where x is the distance between the consumer's ideal variety and the one actually consumed.

You are one of the two firms which sell the product in this market. The different consumer preferences are represented in the following graph:



where the points coincide with the '*X-ty*' degree most preferred by each one of the seven consumers, and besides, they are the only location points available for you and your rival.

You are in the following situation:

- The market exists for a total of 25 periods (years).

- Every **five** periods (starting in period 1) you can ‘redesign’ your product with regard to the offered degree of ‘X-ty’.
- Every period you will set the price of your product, taking into account that your variable costs are: $C = 0$.
- Your goal is getting as much profit as you can after the 25 periods (you will get 10 pts. for each experimental monetary unit you win).
- Every consumer is always rational and decides to buy or not to buy according to his utility function. So, he will buy (if he decides to buy) from the firm which is less expensive for him after considering price and transportation costs (because he obtains a higher utility in this way).
- If you are in a draw with your rival (a consumer is indifferent between buying from you or from your rival) regarding a consumer or a group of them, the final decision will be reached by tossing a coin for each consumer for whom there is a draw.
- Some time after the beginning of each period, your product design and price decisions will be communicated to the experimentalist, simultaneously to those of your rival. **The period in which you must make both decisions, you will communicate first your location on the segment and, then, after the experimentalist has written your decision and that of your rival on the board, you will make and communicate your price decision.**
- The information on the location and pricing decisions, and the results, in the past periods, will appear on the board for you and your rival to see. But we suggest that you write them down too.

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