# *Experimental Economics and Political Decision Making*

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*Price Competition and Product Differentiation: Experimental Evidence*

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# Price Competition and Product Differentiation: Experimental Evidence

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**Abstract**

We use experimental methods to study product differentiation and price competition in a discretised version of the Hotelling (1929) game. The subjects attitude towards risk is found to play an important role in the framework considered here. Beyond the standard arguments in favour of the principle of minimum product differentiation, we identify further factors inducing variety clustering associated with strong risk aversion. Collective players strategies are found to exhibit a stronger tendency towards agglomeration in the middle.

**J.E.L:** L13, C91.

**Key Words:** *product differentiation, price competition, economic experiments, (mixed-strategy) Nash equilibrium, risk aversion.*

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# I Introduction

Product differentiation has been broadly studied by economists. However, while numerous theoretical models have been used to explain a large number of phenomena related with product differentiation[1], empirical work aimed 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[2]. Furthermore, in empirical work in which product differentiation is accounted for, the latter is treated as an explanatory variable of other economic phenomena. Therefore, in a strict sense, product differentiation theory remains an empirically unexplored eld 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) and Collins and Sherstyuk (2000) study experimental spatial markets with 2 and 3 rms, respectively. Both articles report experiments with subjects whose only decision variable is location. 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

[1] 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.*

[2] 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).

Brown-Kruse and Schenk (2000), as well as  intermediate [3] 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 obtained directly applicable to the voting literature[4].

However, a standard intuition which has motivated most of the theoretical work on the economics of product differentiation is that a  rm may want to differentiate its product from products sold by rival  rms in order to relax price competition. Our aim in this paper is to experimentally test the predictions of location-and-price competition models of horizontal product differentiation. As we will see in section IV, 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 (design) decisions in an efficient way.

Apart from considering price competition, in our study we introduce several changes in the original Hotelling (1929) model of product differentiation. Most of these changes, which are described in detail in the following section, are motivated by real world situations and a few of them are inspired in the  ndings of previous experimental results.

The resulting theoretical model highlights the importance of using discrete variables as the strategic space of players. Another feature which emerges as a determinant factor of observed behaviour is a subject s attitude towards risk. Interestingly but not surprisingly, this is also pointed out by Collins and Sherstyuk (2000) for

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

[4] 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).

the non-price competition version of the framework. Finally, unlike the framework adopted in the three aforementioned articles, our framework allows for incomplete market coverage, which is, though, observed in a much smaller number of occasions than we would have initially thought[5].

Despite important differences between our framework and the Hotelling (1929) model, our subject s aggregate behaviour con rms to some extent the principle of minimum product differentiation and almost competitive price levels. Finally, a treatment with collective players indicates that groups are more conservative and, thus, less successful than individual players in adopting product differentiation strategies. However, given a high degree of product differentiation, groups are more successful in establishing higher prices than individuals are.

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

# II Framework

The aim of this paper is to study human behaviour in economic situations which deviate in one or more ways from the ideal environments implied by the assumptions of theoretical economic models. A simple example of such an assumption, which is too often considered to be innocuous by theorists, is coordination by rms locating on a linear segment. Experimental results show that the lack of implicit coordination possibilities may yield frustration among subjects which fail to differ-

[5] In fact, we have only observed incomplete market coverage in 1 out of 450 cases in the basic treatment, 1 out of 450 cases in the collective treatment, and in 24 out of 450 cases in the even treatment, a bit higher but still negligible.

entiate from each other in a successful way (for example, rm A on the left and rm B on the right of the segment)[6]. One could argue that this is a minor issue in terms of intuition for decision making and economic policy in real world markets, but there is no doubt that ignoring coordination problems altogether might yield misleading conclusions concerning the bene ts from explicit communication among rms. In the framework proposed here, a number of standard assumptions in product differentiation models are modi ed in order to analyse the difficulties faced by experimental subjects when acting in a more realistic environment than that assumed in existing product differentiation theory. The main modi cation introduced is motivated by the fact that, in the real world, product prices are chosen from a discrete space of values (dictated by each country s monetary units and other factors related with the buyer s capacity of calculation and comparison of available alternatives). Furthermore, product differentiation itself may be subject to technological restrictions which limit the possible varieties of a differentiated product which can be supplied by the manufacturers to the consumers. The latter ideal varieties may also be dictated by the technologically feasible options available to manufacturers.

Following these observations, we propose a theoretical model which is a discretised version of the Hotelling (1929) model of product differentiation. That is, in our setup, locations and prices are chosen by rms from nite strategic spaces (with a nite number of elements each). In the location strategic space, feasible rm locations are chosen to coincide with a number of (discrete) locations on which (a nite number of non-zero mass) consumers are assumed to be.

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 veri ed 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 re-

[6] We have observed this implicit coordination in less than 20% of the cases in any treatment.

peated 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 here. In the case of 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)[7], a mixed strategy equilibrium may also fail to exist. However, it can be shown that, in the special case considered here under the assumption of risk-neutrality, 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.

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)[8] subjects. Therefore, consumers are not treated as zero-mass particles of a population whose individual ideal varieties 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 (potentially) for the product supplied by the manufacturers. It is important to note the difference between our basic and even treatments. In the basic treatment we have considered an odd number of equally spaced locations, and in the even one an even number of consumers and feasible firm locations exist. Our interest in the odd number case is

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

[8] 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 from each of the two firms involved.

that, together with some difficulties which are explained below, a further difficulty seems to arise when an attractor (which does not necessarily coincide with a theoretical equilibrium of the game) of subjects' strategies implies an *ex post* asymmetric outcome following an *ex ante* symmetric initial situation.

The experimental design is such that the two stage (location-then-price competition) game is modified in order to gain in realism by introducing sets of periods during which firms can only modify their prices, taking product design as given. The repetition of this sequence (product design, price, price, price...) over a finite number of times implies few (if any) complications of the theoretical equilibrium predictions and constitutes a useful way of implementing the usual multistage representation of (more) long-run and (more) short-run economic variables in experimental environments.

As far as learning is concerned, our experimental design requires far less complex calculations by subjects than the continuous (in locations, prices and consumer tastes) framework. Therefore, players are not only fully informed on the market conditions, but also, they are exposed to a minimum level of complexity in their decisions, which can be made using straightforward calculations. García-Gallego (1998) and García-Gallego and Georgantzís (2000) report the results from experiments in which subjects had no information on the true demand model. The estimation of a firm-specific demand model by OLS (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. Implicit learning with trial-and-error algorithms were not found to guarantee convergence to the theoretical predictions. Contrary to these findings, we would not expect that divergence between predicted behaviour and that obtained from our experiments could be due to the aforementioned limitations in our subjects' learning possibilities. Rather, we will argue that such divergence is due to the differences between our subjects' attitude towards risk and that assumed in the predicted theoretical equilibrium. This observation closely relates to a special feature of the *discrete* model presented here. That is, when individual (rather than zero-mass) consumers are considered, the probability of a "draw" on a given consumer location has nonnegligible probability of occurring. We assume that draws are solved by a random mechanism (tossing a coin). Then, the attitude of rms towards risk emerges as an important determinant factor of observed behaviour and this may be used to explain the divergence between our initial theoretical predictions, under risk-neutrality, and our subjects observed behaviour. As stated before, a solution of the theoretical model is presented, assuming a very weak version of risk aversion (we refer to it as *risk-neutrality*) which makes a subject prefer a certain payoff to an expected gain of the same size, but prefer any expected gain to a certain one of a lower size. That is, subjects risk aversion is assumed to motivate their preference for the least risky among a number of equal payoffs, whereas subjects are never sufficiently risk averse to prefer a lower payoff to a higher one, no matter how high the risk implied in the latter may be. As we will see, our results indicate that, in reality, our subjects may have been much more conservative than the theoretical model has assumed them to be. In fact, our results are more compatible with a demand maximising behaviour (or *maximin* playing), which may emerge from subjects strong aversion towards low-demand outcomes. This result is compatible with a similar observation in Collins and Sherstyuk (2000) whose theoretical foundation is Osborne s (1993) result that the characterisation of mixed strategy equilibria may vary according to assumptions concerning a player s attitude towards uncertainty.[9]

# III A Model

Let two rms, $A$ and $B$, play a two-stage game. In the rst stage, rm $i \in \{A, B\}$ chooses a location $L_i \in \{1, 2, ...n\}$ (in the experiments, $n = 7$ in the Basic and Collective Treatments and $n = 8$ in the Even Treatment) among $n$ equally spaced points along a unit-length linear segment, as shown in Figure 1 for the case in which $n = 7$. In the second stage, after the location choices are known, each rm chooses a price $P_i \in \{0, 1, 2, ...P^{\max}\}$ (given the assumptions stated below, $P^{\max} = 10$).

[9] 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.

In each stage, decisions are simultaneously made by the two rms, whose aim is to maximise individual pro ts. Firms sell their product to $n$ consumers, each one located on each one of the equally spaced points on the linear segment.

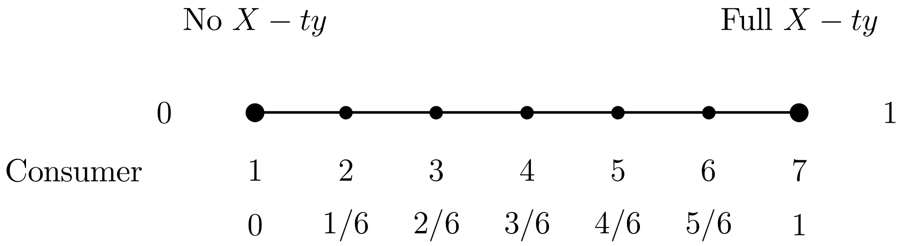


Figure 1: Linear city with discrete locations.

A consumer $j \in \{1, 2, 3...n\}$ (here $n = 7$ or 8, depending on the treatment, as stated above) buys a maximum of *one* unit of the product from rm $i \in \{A, B\}$ in order to maximise her 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 rm $i$, and $t$ (here $t = 6$ for the Basic and Collective Treatments, and $t = 7$ for the Even Treatment) is a unit-transportation cost parameter (disutility suffered for each unit of distance between a consumer s ideal and consumed varieties). 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 choose one of the two rms (with a probability of 1/2 for each rm).

## III.1 Optimal and equilibrium strategies

As stated before, a pure strategy equilibrium does not exist for all combinations of rm locations. Before calculating a mixed strategy equilibrium, we propose and discuss some combinations of location and pricing strategies that can be thought of as globally optimal solutions. Although these are not predicted as equilibria of the game considered, 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 speci c assumptions concerning players attitude towards uncertainty.

### III.1.1 Basic and Collective Treatments

**Tacit collusion** A *global maximum* in the two rms joint pro t is obtained with rms 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 pro t is given by $8 \cdot 4 + 9 \cdot 3 = 32 + 27 = 59$. A main problem associated with this optimum as a target of subjects acting individually and in the lack of any communication and tacit coordination possibilities is asymmetry. It is very unlikely that one of two *ex ante* symmetric players will accept the role of the low-pro t (the one whose price is 9 earns 27 monetary units against 32 earned by his rival ) rm, especially when side payments are impossible. A more complex coordination mechanism could be used by rms in order to change roles over subsequent periods as a pro t-sharing device, but this, given our experimental results seems a rather unrealistic scenario.

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

A *risk-averse* joint pro t-maximising solution could be the symmetric strategy pro le $P = 9$. Then, given rm locations 2 and 6, the consumer in the middle (location 4) will prefer not to buy the good at all. Firms earn certain pro ts of $9 \cdot 3 = 27$ monetary units each (joint pro ts are 54). This strategy would be chosen by tacitly colluding rms 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 nal remark concerns the optimality of multi-location (-plant) operation. It can be easily checked that locating in the middle of the segment (one or two plants) can at most yield (for the optimal price $P = 7$) 49 monetary units of pro t, which is far below the multi-location optima above.

**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 pro table. In order to discuss the Subgame Perfect Equilibrium of the game, we will, rst, have to calculate equilibrium prices for all rm 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 rm locations for which the distance between rms $x_{ik}$ satis es $x_{ik} \notin [2/6, 3/6]$. For location combinations implying differences in the interval $[2/6, 3/6]$, we have computed mixed strategy equilibria of the price-setting stage[10]. We provide here the (expected) payoff matrix corresponding to price-equilibrium for all possible location combinations.

| | 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 1: Mixed (*) and pure strategy price equilibrium (expected($^{e}$)) payoffs for the Basic and Collective Treatments.

[10] In the Appendix we provide the tables which summarise the mixed and pure strategy price equilibria for each location combination.

Following this payoff matrix, it is easy to see that *risk-neutral* players equilibrium location and pricing equilibrium is that given in Table 2:

| Locations | Prices | Expected Demands | Expected Pro ts |
|---|---|---|---|
| (2, 6) | (7, 7) | (3 5, 3 5) | (24 5, 24 5) |

Table 2: Location and price equilibrium of the supergame for the Basic and Collective Treatments.

As stated above, in the calculation of the subgame perfect equilibrium of the game we have assumed risk-neutrality, according to which only in the case of equality between a certain and an expected payoff subjects prefer certainty. However, it is worth noting that this assumption may be stronger than what one would think. An alternative solution in which strong risk aversion is assumed can be sketched in the following lines.

From textbook game theory, we know that playing *maximin strategies* 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 the other player s rationality may lead a subject to treat strategic interaction and uncertainty in the same way. In any 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) behaviour for strongly risk averse (or pessimistic) players.

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

**Theoretical predictions:**

**1)** *In the basic and collective treatments, the joint pro t-maximising and the risk-neutral 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, the symmetry requirement and the degree of players  risk 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 playing *by strongly risk averse players choosing the central location* $L_i = 4$ *and the minimum positive price* $P_i = 1$.

### III.1.2 Even Treatment

**Tacit collusion** Now a *global maximum,* which besides is *risk-averse*, in the two rms joint pro t is obtained with rms locating on 2 and 6 and prices $(P_{i,}P_k) = (9, 8)$, for $(i, k) = (A, B)$. Then, all consumers are served and the joint pro t is given by $9 \cdot 3 + 8 \cdot 5 = 27 + 40 = 67$. Or with rms locating on 3 and 7 and setting prices $(P_{i,}P_k) = (8, 9)$, for $(i, k) = (A, B)$. Pro ts are $8 \cdot 5 + 9 \cdot 3 = 40 + 27 = 67$. A problem associated with these optima is, as in the other two treatments, the lack of symmetry.

A *symmetric*, and *risk-averse*, joint pro t-maximising solution is obtained if rms locate on $(L_{i,}L_k) = (3, 6)$ or $(L_{i,}L_k) = (2, 7)$, for $(i, k) = (A, B)$, and set a price $P = 8$. Joint pro ts are, now, given by $8 \cdot 8 = 64$. And rms will share them equally. This could be a good attractor for collusion.

Finally, locating only one plant near the middle of the segment, in 4 or 5, can at most yield (for the optimal price $P = 7$) 49 monetary units of pro t, which is less than the multi-location optima.

**Non-cooperative equilibria** The Subgame Perfect Equilibrium of the supergame is calculated in the same way as for the other two treatments. Now, pure strategy Nash equilibria exist in the price-setting subgame for all rm locations for which the distance between rms $x_{ik}$ satis es $x_{ik} \notin [2/7, 3/7]$. For location combinations implying differences in the interval $[2/7, 3/7]$, we have computed mixed strategy equilibria of the price-setting stage[11]. The (expected) payoff matrix corresponding to price-equilibrium for all possible location combinations is:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | (4, 4) | (1, 7) | (4, 12)* | (9, 22)* | (18, 35) | (24 5, 36)$^{e}$ | (28, 32) | (28, 28) |
| 2 | (7, 1) | (4, 4) | (2, 6) | (9, 16)* | (18, 28)* | (28, 32) | (32, 32) | (32, 28) |
| 3 | (12, 4)* | (6, 2) | (4, 4) | (6, 10) | (17, 18)* | (28, 28) | (32, 28) | (36, 24 5)$^{e}$ |
| 4 | (22, 9)* | (16, 9)* | (10, 6) | (4, 4) | (12, 12) | (18, 17)* | (28, 18)* | (35, 18) |
| 5 | (35, 18) | (28, 18)* | (18, 17)* | (12, 12) | (4, 4) | (10, 6) | (16, 9)* | (22, 9)* |
| 6 | (36, 24 5)$^{e}$ | (32, 28) | (28, 28) | (17, 18)* | (6, 10) | (4, 4) | (6, 2) | (12, 4)* |
| 7 | (32, 28) | (32, 32) | (28, 32) | (18, 28)* | (9, 16)* | (2, 6) | (4, 4) | (7, 1) |
| 8 | (28, 28) | (28, 32) | (24 5, 36)$^{e}$ | (18, 35) | (9, 22)* | (4, 12)* | (1, 7) | (4, 4) |

Table 3: Mixed (*) and pure strategy price equilibrium (expected($^{e}$)) payoffs for the Even Treatment.[12]

According to this payoff matrix, one can check that *risk-neutral* players pareto superior equilibrium in location and prices is that given in Table 4:

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (2, 7) | (8, 8) | (4, 4) | (32, 32) |

Table 4: Location and price equilibrium of the supergame for the Even Treatment.

Observe that the Nash equilibrium coincides with one of the symmetric and risk-averse joint pro t maximising strategies.

In the even treatment we have two possible *maximin strategies:* $(L_i, P_i) = (4, 1)$ and $(L_i, P_i) = (5, 1)$, both offering a minimum expected payoff of 4 experimental units.

[11] In the Appendix we provide the tables which summarise the mixed and pure strategy price equilibria for each location combination.

[12] Note that we have omitted the decimals from the mixed strategy price equilibrium payoffs in the table for space reasons, but they can be found in the appendix.

We can make the following predictions according to the theoretical solutions for the even treatment:

**Theoretical predictions:**

**3)** *In the even treatment, the joint pro t-maximising and the risk-neutral players non-cooperative equilibrium locations range from* 2 *to* 3 *for one rm and from* 6 *to* 7 *for the other. The prediction for the corresponding prices ranges from* 8 *to* 9, *depending on the symmetry requirement and the degree of players risk aversion.*

**4)** *However, more central locations leading to lower prices are expected in the case of stronger risk aversion, up to the extreme case of* maximin playing *by strongly risk averse players choosing the nearest to the center location,* $L_i = 4$ *or* 5, *and the minimum positive price* $P_i = 1$.

# IV Experimental design and results

## IV.1 Experimental design

Three treatments were organised in 18 experimental sessions each. In the basic treatment (BT) and in the even treatment (ET), players are individual subjects, whereas in the collective treatment (CT) each player consists of a group of 10 to 15 subjects. Within each group (forming a collective player) communication and any other type of spontaneous organisation of collective decision was permitted. No communication between rival rms was allowed. Apart from the written set of instructions, the organiser of each session gave detailed explanation of how demands and pro ts should be calculated given any strategic pro le chosen by ctitious subjects. The simplicity of the discrete version of the model was found to be a very appropriate environment for full understanding of the consequences of all possible strategies. In fact, no calculus is needed and any optimisation exercise (when necessary) can be performed using simple arithmetic operations.

Subjects were Economics students from three Universities (Universitat Jaume I in Castellón, University of Valencia and University of Zaragoza). In fact, 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. Most of them had some knowledge of oligopoly theory and some of them had already been taught the Hotelling (1929) model of product differentiation.

Players were paid at the end of each session according to an exchange rate of 10 Spanish Pesetas for each experimental monetary unit. In the basic and collective treaments a maximum pro t of 6750 Pesetas (approximately, 40.5 Euros) could be earned by each subject in rms which would collude during the 25 periods, setting the risk averse optimal price (9). The risk-neutral subjects playing equilibrium 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.

In the even treament a maximum pro t of 8000 Pesetas (approximately, 48 Euros) could be earned by each subject in rms which would collude during the 25 periods, setting the risk averse optimal price (8). The risk-neutral subjects playing equilibrium strategies during the 25 periods of a session could earn the same amount, whereas 1000 Pesetas (6 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 minimum payoff.

Each session consists of the repetition of the same basic structure for a total of 25 periods. The duration of each session is known by subjects at the beginning of the game. The basic structure contains product design and pricing decisions. On periods 1, 5, 10, 15, 20 and 25, rms simultaneously choose locations on the line. In each product design period, after rm location decisions are publicly announced, prices are chosen. Following a product design period, rms can only modify prices, taking their last location decision as given until the next product design period. The location-price...price sequence is repeated over and over until the 25th period is reached. In the last (25th) period of the session, a location-price sequence is played. We have opted for this strategy as a way to isolate possible end-game behaviour in both location and price strategies.

## IV.2 Aggregate results from basic *vs.* collective treatment

Our aggregate results indicate (Figures 2 and 3) that collective players have differentiated signi cantly[13] less than individual players did. Also, their prices have been signi cantly lower[14].

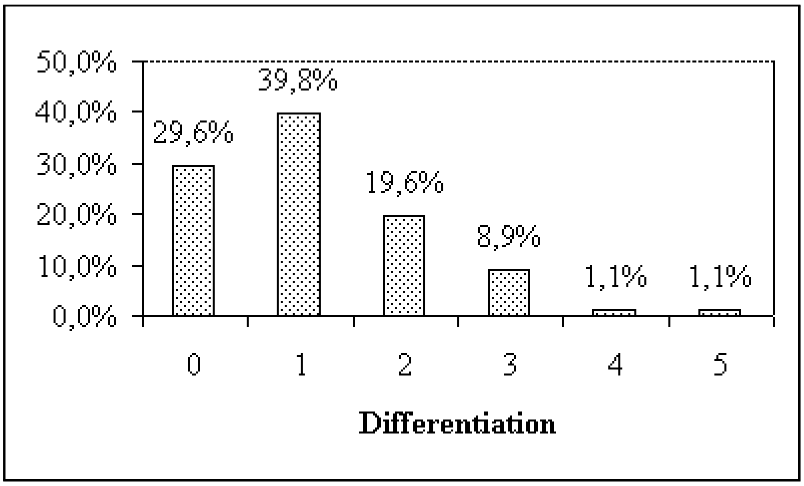


Figure 2: Percentages of differentiation in the basic treatment (BT). (*Differentiation* refers to the distance between the two rm s locations measured in sixths of the segment).

[13]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 signi cant at the 0.05 level. It is also signi cant 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).

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

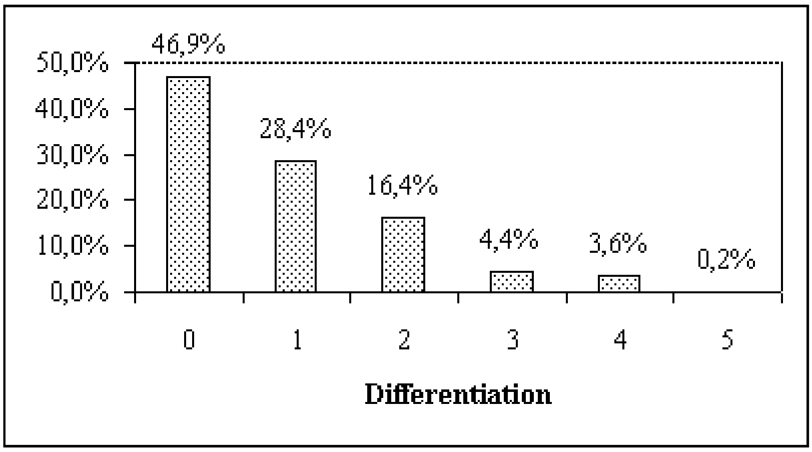


Figure 3: Percentages of differentiation in the collective treatment (CT).

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

In the absence of product differentiation (zero distance between competing rm locations) the distribution of prices in sessions with collective and individual subjects present no signi cant[15] differences (Figure 4). In fact, we obtain strong support for the pure strategy Nash equilibrium prediction for the corresponding price subgames ($P = 1$).

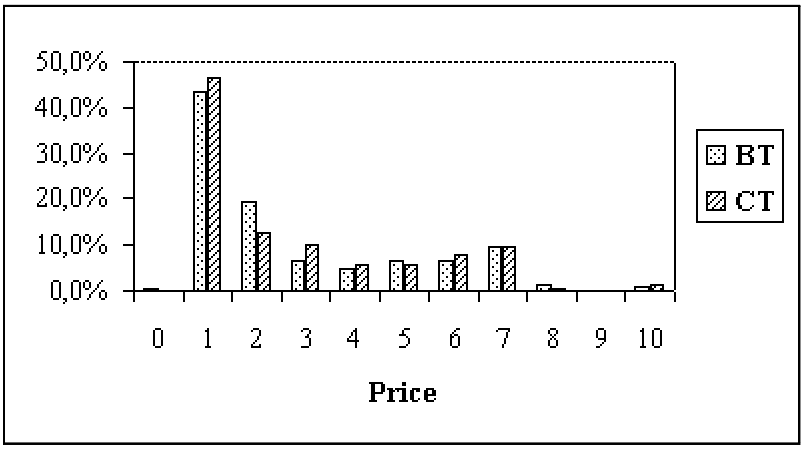


Figure 4: Price distribution when differentiation is 0.

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

With a unit difference between firm locations, we find that the distributions of prices obtained from the two treatments are significantly[16] 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). On average, the equilibrium prediction of prices equal to 1 or 2 (depending on the locations on which unit-differentiation takes place) is slightly exceeded by observed behaviour.

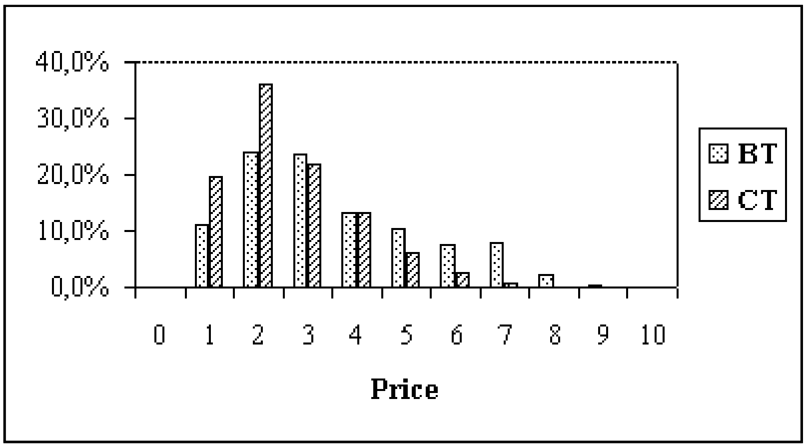


Figure 5: Price distribution when differentiation is 1.

When firm locations differ by two, the distributions of prices from the two treatments do not present significant[17] 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.

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

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

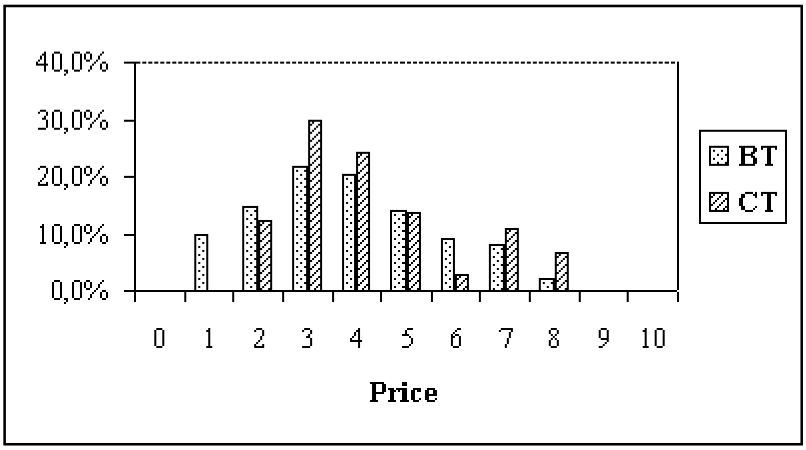


Figure 6: Price distribution when differentiation is 2.

Locations differing by 3 present price distributions which signi cantly[18] 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 signi - cance.

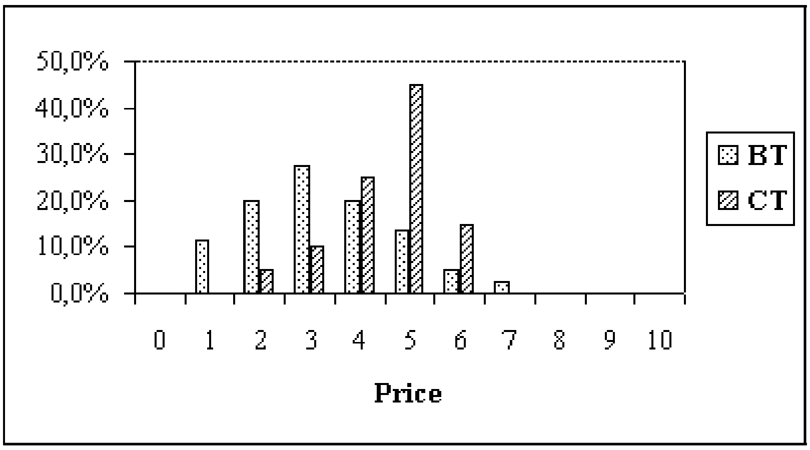


Figure 7: Price distribution when differentiation is 3.

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

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 been far more conservative (risk averse) than we have assumed them to be when calculating the risk-neutral 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 pro t maximum occurred only once each, besides, in the same experimental session.

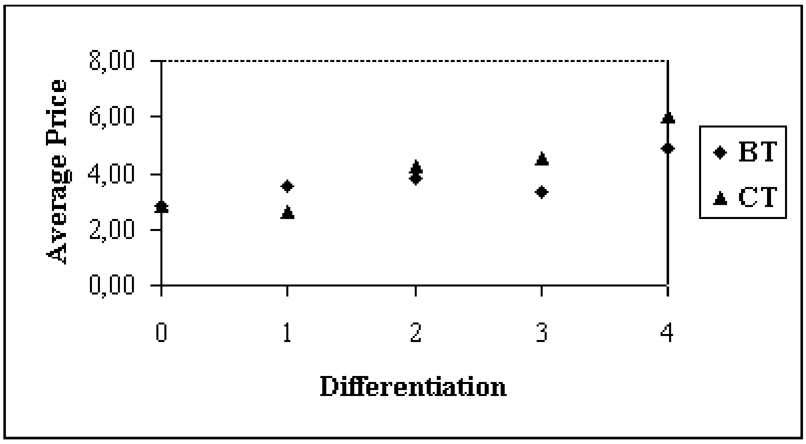


Figure 8: Relationship between differentiation and average prices.

Far more support is offered for predicted behaviour under strong risk aversion. 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 signi cant differences across treatments[19].

[19] $KS = 2.61$.

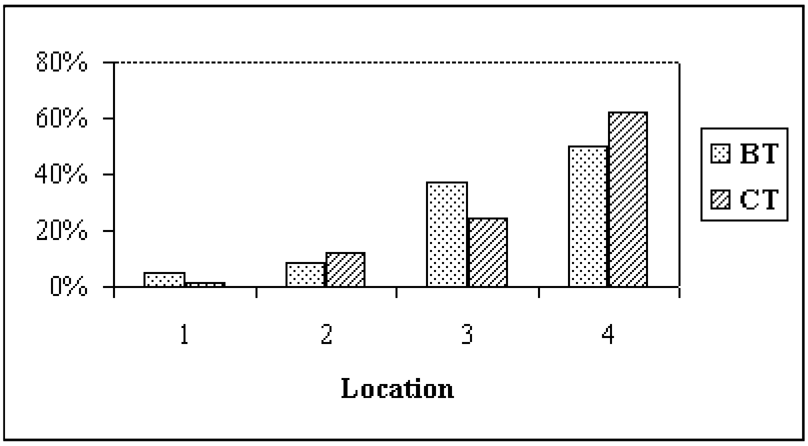


Figure 9: Aggregate location distribution.

(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, signi cantly vary across treatments, give far more support to the strong risk-averse players prediction of unit prices, than to a price of 7 predicted under the assumption of risk-neutrality (Figure 10).

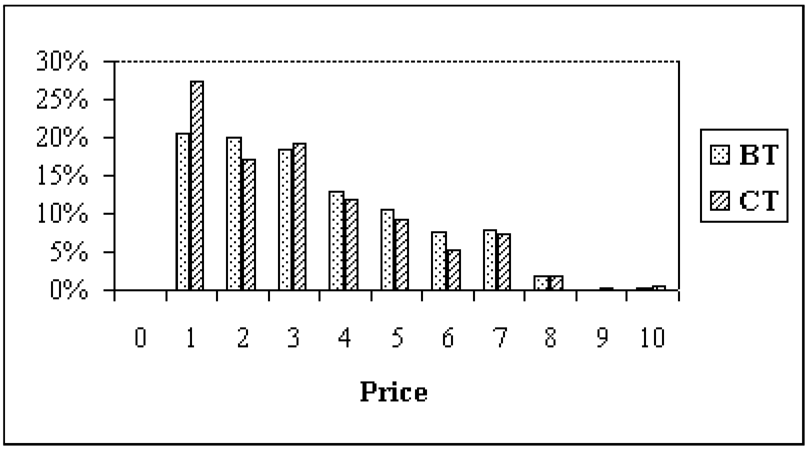


Figure 10: Aggregate price distribution.

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 risk-neutrality. In both treatments, more than half of the observed locations are compatible with* maximin *playing. Comparison across treatments shows that individual players differentiate signi cantly more than collective players do.*

**Result 2:** *Subjects seem to have realised the bene ts from locating apart from each other, given that observed prices are higher, the higher is the distance between rm locations. In fact, collective subjects have exploited product differentiation more than individual players did, given that the formers prices have exceeded prices charged by the latter, and also the theoretical levels predicted for the corresponding degrees of differentiation, when differentiation was high.*

**Result 3:** *In the case of locations leading to mixed strategy equilibria, price dispersion is observed over intervals that are compatible with theoretical predictions.*

## IV.3 Dynamic results from basic *vs.* collective treatmnent

The repetition of the same structure ( product design-price-price... ) over a number of periods gives rise to a number of dynamic phenomena which could not have been predicted by our theoretical solutions of the two-stage game analysed in section III.3. We brie y refer here to the most interesting of these phenomena.

A rst 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 each one of the aforementioned sequences. The declining trend is represented by $\beta < 1$ and constant prices are implied by $\beta = 1$. A total of 180 such regressions were estimated for each treatment. On aggregate, a moderately declining trend was observed[20], which was not found to exhibit signi cant differences across treatments. However, the most interesting phenomenon associated with declining prices relates to product differentiation. The estimates of $\beta$ obtained for each one of the aforementioned period sequences were, then, averaged by groups according to degrees of product differentiation.

[20] The average $\beta$ estimate for the 540 regressions estimated (in the three treatments) from rm behaviour over the 180 product design-price-price... sequences is 0.891.

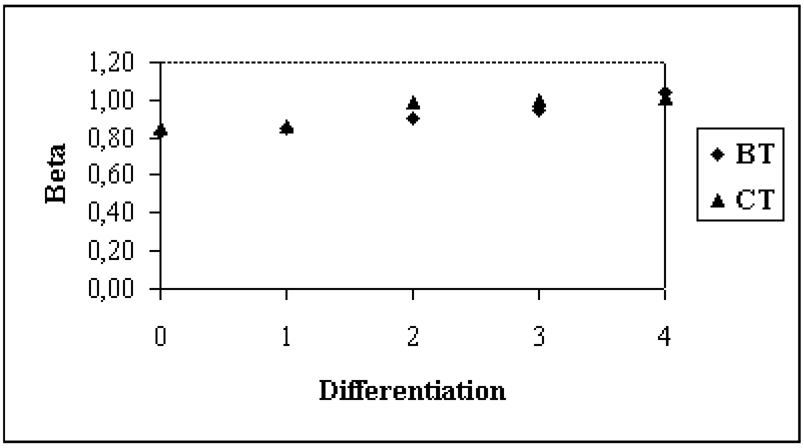


Figure 11: Average $\beta$ estimates as a function of differentiation.

As seen in Figure 11, in both treatments, we nd a positive relationship between product differentiation and the corresponding $\beta$ s, which tend to (and may even slightly exceed) unity (constant prices) when product differentiation is high. However, this relationship is more gradual (ranging from 0.82 to 1) in the case of individual players, whereas a more clear-cut jump from 0.860 to 0.998 is observed for collective players as differentiation is increased from 1 to 2. Then, we reach the following conclusion:

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

Another interesting result relates with end-game behaviour. While the equilibrium of a static game that is repeated a nite number of periods coincides with the equilibrium of the stage game, it is reasonable to think that subjects may have incentives to signal friendly behaviour in order to encourage cooperation. In the framework adopted here, both non-cooperative equilibrium and collusive behaviour could have lead risk-neutral subjects to differentiate from each other as implied by Theoretical Prediction 1. However, we have also 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 observed in intermediate periods. That is locating and pricing in a less aggressive way (as specified in the collusive solution in section III.3.1.1) 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 exhibit end-game behaviour. As such, we consider the decision of a firm to locate in the middle of the segment (location 4) at the end of the game, provided that the firm was not located there the period before the last. The same event occurred in 8 out of the 36 possible occasions in the collective subjects treatment.

**Result 5:** *A clear end-game behaviour is observed in 22% of the basic treatment sessions and in 22% of the collective treatment ones.*

Finally, the degree of product differentiation does not seem to significantly[21] vary during each experimental session, although subjects have significantly[22] changed their "central" first period strategies with less central ones in periods 5, 10, 15 and 20. 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 (with respect to the center). 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

[21] 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.

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

as many as theory would like them to be either. Therefore, in (strategically) uncertain environments, the little attention paid to coordination problems may ignore a signi cant factor favouring minimum differentiation: risk aversion.

**Result 6:** *Despite the simple framework used, in which no calculus is required for subjects to foresee the consequences of their strategies, learning to differentiate is not synonymous of learning the bene ts of less central locations , because the former requires also learning to coordinate .*

## IV.4 Aggregate results from basic *vs.* even treatment

Our aggregate results indicate (Figures 12 and 13) that players in the even treatment have differentiated signi cantly[23] less than players in the basic treatment did. But, their prices have paradoxically been signi cantly higher[24].

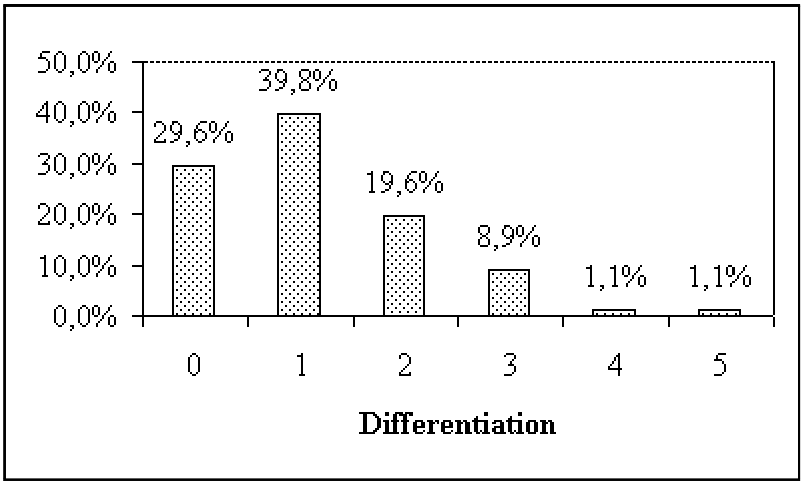


Figure 12: Percentages of differentiation in the basic treatment (BT). (*Differentiation* refers to the distance between the two rm s locations measured in sixths of the segment).

[23] $KS = 3.15$. A Mann-Whitney test can also be used to show that, on average, locations from the even treatment are more central and less differentiated than those from the basic treatment ($MW = -12.949$ and $MW = -5.026$ respectively).

[24] $KS = 1.649$ and $MW = -2.809$.

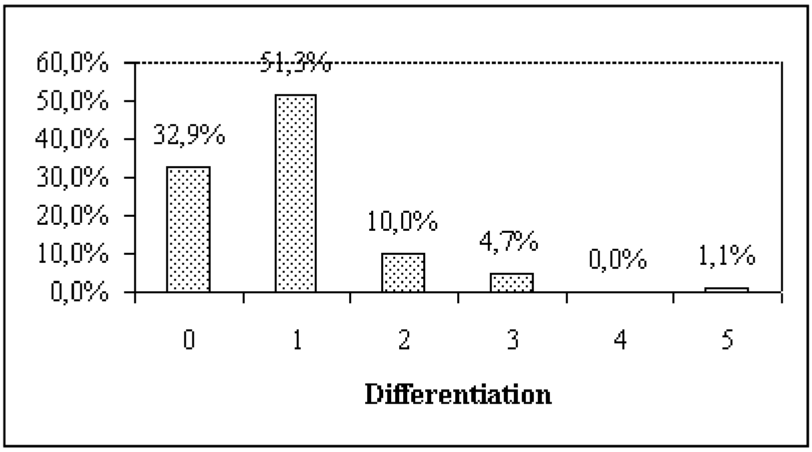


Figure 13: Percentages of differentiation in the even treatment (ET).

(*Differentiation* is measured in sevenths of the segment).

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

In the absence of product differentiation (zero distance between competing  rm locations) prices have been on average signi cantly higher in the even treatment[25] (Figure 14). The pure strategy Nash equilibrium prediction for the corresponding price subgames ($P = 1$) which can be supported for the basic treatment is a bit harder to believe for the even treatment.

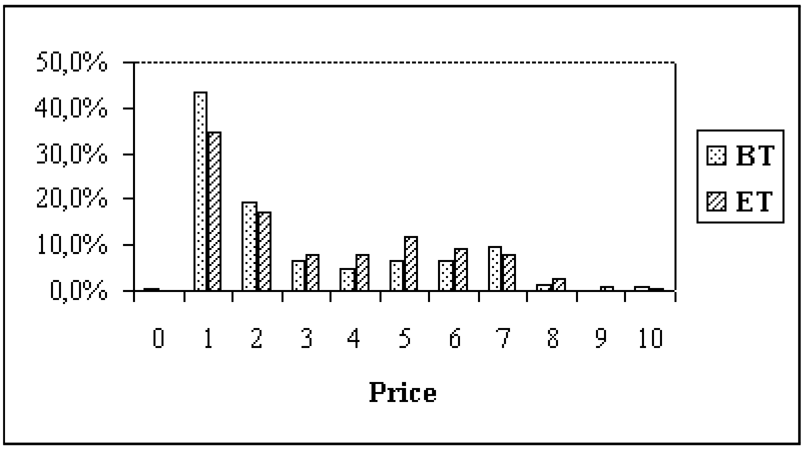


Figure 14: Price distribution when differentiation is 0.

[25] $KS = 1,36$ against 1.36 and $MW = -2.44$ against 1.96.

With a unit difference between firm locations, we also find that the distributions of prices obtained from the two treatments are significantly[26] different (Figure 15). More specifically, in both treatments subjects have used prices whose distribution has a peak on 2, but average prices are higher (4.14) for the even treatment than for the basic treatment (3.54). On average, the equilibrium prediction of prices equal to 1 to 2 for the basic treatment and 1 to 3 for the even treatment (depending on the locations on which unit-differentiation takes place) are exceeded by observed behaviour.

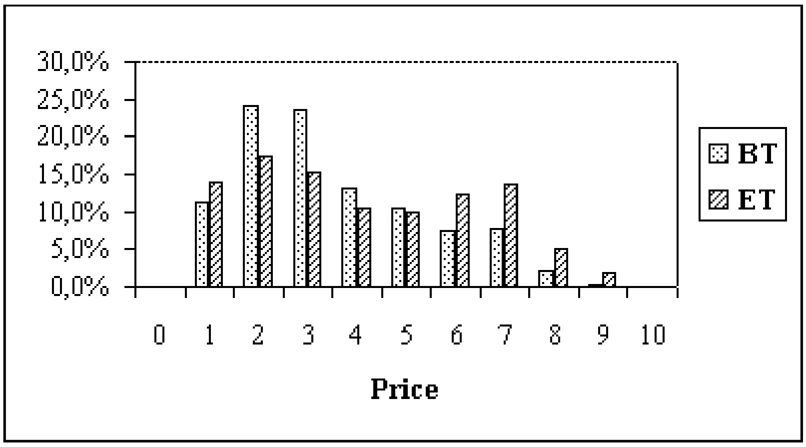


Figure 15: Price distribution when differentiation is 1.

When firm locations differ by two, the distributions of prices from the two treatments do not present significant[27] differences (Figure 16). A peak is observed for a price of 3 in the basic treatment and three peaks on 2, 3 and 4, in the even treatment. Prices in the basic treatment only have a slightly higher average (3.85) than in the even one (3.44). Mixed strategy prices range from 1 to 6 in the basic treatment and from 1 to 5 in the even one, which seems roughly compatible with our subjects behaviour.

[26] $KS = 2.16$ and $MW = -3.41$.

[27] $KS = 0.87$ and $MW = -1.68$.

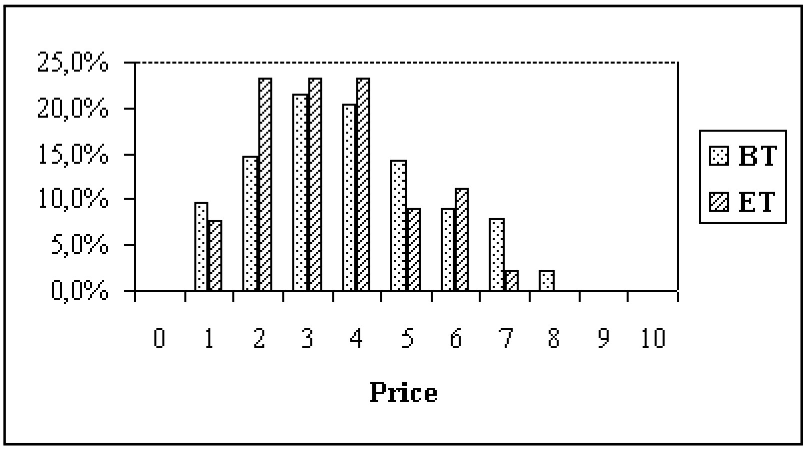


Figure 16: Price distribution when differentiation is 2.

Locations differing by 3 present price distributions which do not signi cantly[28] vary across treatments (Figure 17). Individuals in the even treatment have set lower prices on average than players in the basic one (a peaks on 3 is observed for both treatments and respective average prices are 2.80 and 3.30). The mixed strategy equilibrium prediction of prices ranging from 2 to 7 for both treatments is compatible with the behaviour of both types of players, although some players have set prices below the minimum of the aforementioned interval.

Finally, location differences of more than 3 were observed in very few occasions and any conclusions based on this evidence would lack statistical signi cance.

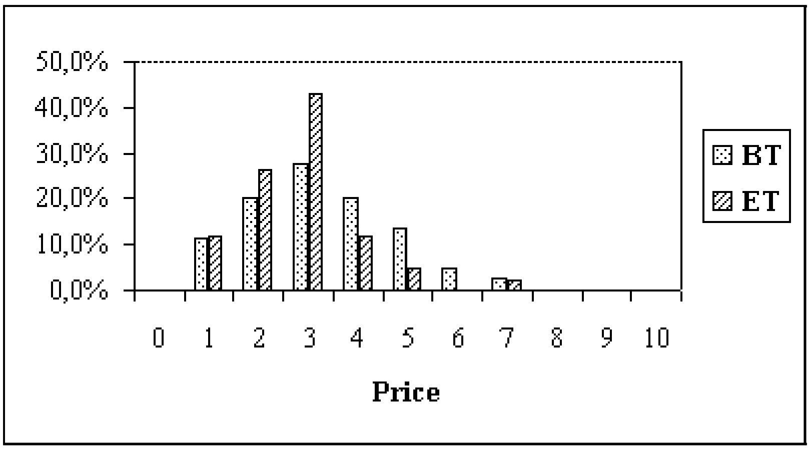


Figure 17: Price distribution when differentiation is 3.

[28] $KS = 1.16$ and $MW = -1.83$.

On aggregate, a positive relationship between product differentiation and prices is observed (Figure 18). But when differentiation is higher than 2 this relationship seems to reverse. However, it is more likely that this phenomenum is due to lack of data with differentiation of two and higher, than to a true reversal of the relationship.

Apart from the aforementioned differences across treatments, our results indicate that our subjects have been again far more conservative (risk averse) than we have assumed them to be when calculating the risk-neutral perfect equilibrium $((L_i, L_k, P_i, P_k) = (2, 7, 8, 8))$. In fact, the predicted outcome never occurred. Neither ocurred the global and the symmetric risk-averse joint pro t maxima.

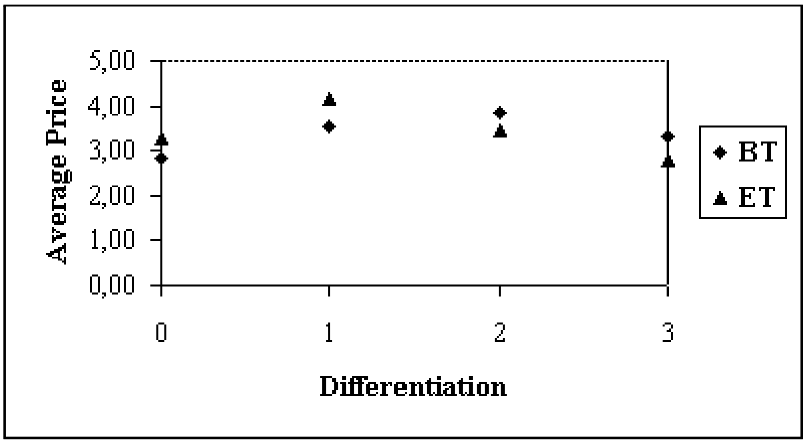


Figure 18: Relationship between differentiation and average prices.

Far more support is offered for predicted behaviour under strong risk aversion. For example, the central locations were chosen in more than half of the product design periods in the basic treatment and in nearly 80% of the cases in the even treatment, as can be seen from the aggregate data on locations (Figure 19), which were found to exhibit signi cant differences across treatments[29].

[29] $KS = 6.41$.

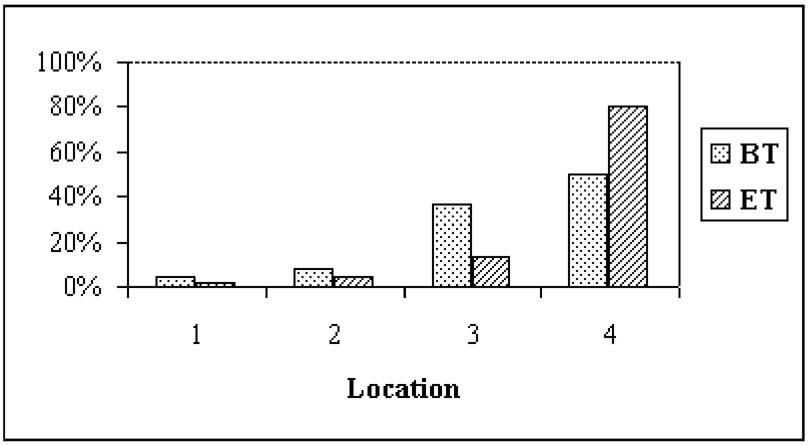


Figure 19: Aggregate location distribution.

(We have considered that location 1=7, 2=6, and 3=5 for the basic treatment, and that location 1=8, 2=7, 3=6 and 4=5 for the even one)

Along the same line, aggregate price data, which, as we have already noted, signi cantly vary across treatments, give far more support to the strong risk-averse players prediction of unit prices, than to a price of 7 predicted under the assumption of risk-neutrality for the basic treatment, and of 8 for the even one (Figure 20).

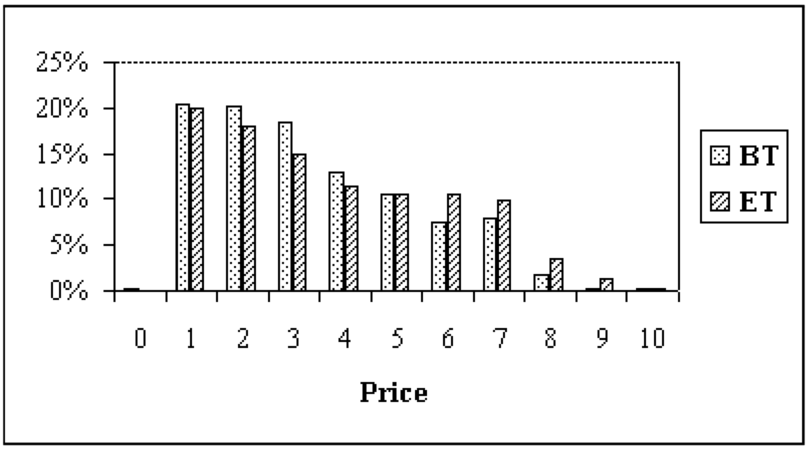


Figure 20: Aggregate price distribution.

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

**Result 7:** *In aggregate, our subjects behaviour has yielded less product differentiation than would be the non-cooperative equilibrium prediction under risk-neutrality. In both treatments, more than half of the observed locations are compatible with* maximin *playing. Comparison across treatments shows that players in the* *even treatment differentiate signi cantly less and take more central locations than players in the basic treatment. This result reinforces Result 1.*

**Result 8:** *Subjects seem to have realised the bene ts from locating apart from each other, given that observed prices are higher, the higher is the distance between rm locations. In fact, subjects in the basic treatment have exploited product differentiation more than those in the even one, given that the formers prices have exceeded prices charged by the latter when differentiation was high, but for low levels of differentiation players in the even treatment have been able to set higher prices. This result reinforces Result 2.*

**Result 9:** *In the case of locations leading to mixed strategy equilibria, price dispersion is observed over intervals that are compatible with theoretical predictions. As in Result 3.*

## IV.5 Dynamic results from basic *vs.* even treatment

Again, prices have exhibited two different trends: A declining and a constant one.

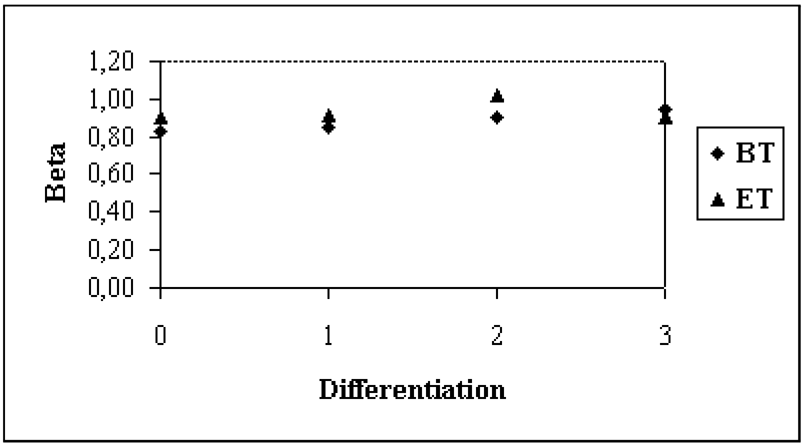


Figure 21: Average $\beta$ estimates as a function of differentiation.

As seen in Figure 21, in both treatments, we nd a positive relationship between product differentiation and the corresponding $\beta$ s, which tend to (and may even slightly exceed) unity (constant prices) when product differentiation is high. Then, we reach the following conclusion:

**Result 10:** *Lower (higher) degrees of product differentiation, together with lower (higher) prices also imply declining (constant) prices. Same as Result 4.*

In the even treatment we have observed end game behaviour only in 2% of the cases. As such, we consider the decision of a  rm to locate in 4 or 5 at the end of the game, provided that the  rm was not located there the period before the last.

**Result 11:** *No end-game behaviour is observed in the even treatment. Contrary to Result 5.*

Finally, the degree of product differentiation and the centrality of the locations does not seem to signi cantly[30] vary during each experimental session.

**Result 12:** *We have not found any evidence of learning in locations in the even treatment. Contrary to Result 6 where at least locations were less central in subsequent periods after the beginning.*

# V Conclusions

The principle of minimum differentiation is revisited using experimental methods. Unlike previous experimental work on spatial competition, we study endogenous prices and allow for incomplete market coverage. The basic framework is a version of the Hotelling (1929) game with discrete location and price variables. The calculation of a subgame perfect equilibrium requires speci c assumptions concerning  rms attitude towards risk. As a result, two extreme cases are used as benchmark theoretical predictions. On one hand, intermediate differentiation and high prices are predicted as the non-cooperative equilibrium with risk-neutral  rms. On the other hand, minimum differentiation and minimum prices are predicted as the result of *maximin* strategies played by strongly risk averse (or pessimistic)  rms. Thus, the principle of minimum differentiation is far from being the unique subgame perfect

[30]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 treatment and from that in previous and subsequent periods. Besides locations do no signi cantly vary their proximity to the center in subsequent location periods.

equilibrium prediction of theory for the case considered here. Instead, a variety of theoretical predictions between the two aforementioned extreme cases (intermediate and minimum differentiation) correspond to different levels of risk aversion. Pure strategy equilibria fail to exist for a broad range of location combinations, which makes the calculation of an equilibrium to be a complex task for our subjects, despite the simplicity of the discrete framework used. The locational non-cooperative equilibrium coincides with that of the joint-pro t maximising pair of locations but lower prices are predicted to emerge from price competition in the basic and collective treatments. In the even treatment the non-cooperative equilibrium and the joint-pro t maximising strategies in location and prices can coincide. This may imply a further complication for the problem with which our subjects are faced on their way to learning the equilibrium of the supergame.

Despite the aforementioned modi cation 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. However, observed price levels are slightly higher than the corresponding equilibrium prediction. The relationship between product differentiation and price levels is con rmed. 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 pre-commit to a risky option than individuals are. On the other hand, players in the even treatment have differentiated signi cantly less than those in the basic treatment, however, they have managed to set higher prices. 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 pro le 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 rms. Some non-negligible end-game behaviour is also obtained for the collective and basic treatments.

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. The basic model should be extended with generalisations, which do not necessarily go on the direction of more complex functional forms, but rather, which are inspired in simple situations in which clear-cut theoretical predictions fail to exist and standard simplifying assumptions are less innocuous than is usually thought.

# VI Appendix

## VI.1 Basic and collective treatments pricing stage equilibria

In order to obtain the pricing-stage Nash equilibria we have calculated a table for each of the possible location combinations with the expected payoffs for every price combination.

When locations were differentiated by less than two or more than three, a pure strategy Nash equilibrium was straightforward to obtain. But when differentiation was two or three we have looked for mixed strategy Nash equilibria, considering all the plausible price supports[31], and we have chosen the Pareto superior one in case

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

of multiplicity.

Below we present a summary of the pricing equilibria which have been used to build Table 1.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (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 A1: Both rms are located on the same point.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (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 A2: Firms differentiate their products 1/6 of the segment.

| Locations | Prices | Probabilities | Demands | Pro ts |
|---|---|---|---|---|
| (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 A3: Firm s products are differentiated in 2/6 of the segment.

| Locations | Prices | Probabilities | Demands | Pro ts |
|---|---|---|---|---|
| (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 A4: Firms differentiate their products 3/6.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (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 A5: Firms differentiate their products 4/6.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 6) | (7, 7) | (3, 4) | (21, 28) |
| (2, 7) | (7, 7) | (4, 3) | (28, 21) |

Table A6: Differentiation is 5/6.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 7) | (7, 7) | (3 5, 3 5) | (24 5, 24 5) |

Table A7: The products are maximally differentiated (6/6).

## VI.2 Even treatment pricing stage equilibria

The even treatment pricing stage equilibria have been summarised in Table 3.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 1) | (1, 1) | (4, 4) | (4, 4) |
| (2, 2) | (1, 1) | (4, 4) | (4, 4) |
| (3, 3) | (1, 1) | (4, 4) | (4, 4) |
| (4, 4) | (1, 1) | (4, 4) | (4, 4) |

Table A8: Both rms are located on the same point.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 2) | (1, 1) | (1, 7) | (1, 7) |
| (2, 3) | (1, 1) | (2, 6) | (2, 6) |
| (3, 4) | (2, 2) | (3, 5) | (6, 10) |
| (4, 5) | (3, 3) | (4, 4) | (12, 12) |

Table A9: Firms differentiate their products 1/7 of the segment.

| Locations | Prices | Probabilities | Demands | Pro ts |
|---|---|---|---|---|
| (1, 3) | ([1, 3], [2, 3]) | ([0 64, 0 36],[0 33, 0 66]) | (3 05, 4 95) | (4, 12 7) |
| (2, 4) | ([2, 4], [3, 4]) | ([0 44, 0 56],[0 33, 0 66]) | (3 37, 4 63) | (9 3, 16 6) |
| (3, 5) | ([3, 5], [4, 5]) | ([0 29, 0 71],[0 14, 0 86]) | (4 10, 3 90) | (17 1, 18 8) |

Table A10: Firm s products are differentiated in 2/7 of the segment.

| Locations | Prices | Probabilities | Demands | Pro ts |
|---|---|---|---|---|
| (1, 4) | ([2, 4], [4, 5]) | ([0 31, 0 69],[0 33, 0 66]) | (3 10, 4 90) | (9 3, 22 7) |
| (2, 5) | ([3, 6], [6, 7]) | ([0 11, 0 89],[1, 0]) | (3 33, 4 66) | (18, 28) |
| (3, 6) | (7, 7) | (1, 1) | (4, 4) | (28, 28) |

Table A11: Firms differentiate their products 3/7.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 5) | (6, 7) | (3, 5) | (18, 35) |
| (2, 6) | (7, 8) | (4, 4) | (28, 32) |

Table A12: Firms differentiate their products 4/7.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 6) | (7, 8) | (3 5, 4 5) | (24 5, 36) |
| (2, 7) | (8, 8) | (4, 4) | (32, 32) |

Table A13: Differentiation is 5/7.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 7) | (7, 8) | (4, 4) | (28, 32) |

Table A14: Differentiation is 6/7.

| Locations | Prices | Demands | Pro ts |
|---|---|---|---|
| (1, 8) | (7, 7) | (4, 4) | (28, 28) |

Table A15: The products are maximally differentiated (7/7).

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