The Max-Min Principle of Product Differentiation: An Experimental Analysis

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February 2001

Abstract

Theoretical models of multidimensional product differentiation predict that in duopoly firms differentiate maximally along one dimension and minimally along the other dimensions. We experimentally reproduce a market in which firms can differentiate their products along two horizontal dimensions. The main result is that subjects do not differentiate their products and locate near the center consumers' distribution.

Introduction

A major issue in Industrial Organization literature is to determine firms' strategies when technology allows for product differentiation. It is well known that two products can be horizontally differentiated (Hotelling, 1929) when there is no ranking among consumers based on their willingness to pay for the product, and vertically differentiated (Mussa, Rosen, 1978) when all consumers agree over the most preferred mix of characteristics and, more generally, over the preference ordering. A typical example of vertical characteristic is quality; with vertically differentiated products, at equal prices there is a natural ordering over the characteristics' space. In these settings, the main question is the equilibrium degree of product differentiation. With products defined by one characteristic only (vertical or horizontal), research has determined that the

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principle of minimum differentiation (Hotelling, 1929) does not hold when models are "well-behaved" (D'Aspremont et al, 1979, Shaked, Sutton, 1983). The rationale for this result is that vertical or horizontal differentiation are needed to relax price competition, which should be fierce if firms choose similar locations (Shaked, Sutton, 1982).

Recently, authors have explored the case of multidimensional product differentiation, for which products can be defined by two or more characteristics. Several models have been developed. In Vandenbosch, Weinberg (1995) and Garella, Lambertini (1999) products are defined by multiple vertical characteristics, while Tabuchi (1994), Economides (1986), Braid (1999), Irmen, Thisse (1998), Economides (1993), and Ansari et al. (1997) analyze theoretical markets in which products are defined by n-horizontal characteristics. Besides, Neven, Thisse (1990), Bester (1998), and Canoy, Peitz (1997) assume products which possess both vertical and horizontal attributes. See, finally, Degryse (1996) for an example of application of theoretical framework in a context of a real market.

The majority of these works suggest a general result in terms of firms' strategies: in equilibrium, products are expected to be maximally differentiated along one dimension, and minimally differentiated along the other characteristics. This result has been explained as follows: differentiation along only one dimension is enough to relax price competition, and firms can exploit the (demand) advantages of a central location along the other dimensions. Central location means that firms tend to agglomerate towards the center of consumers' distribution along the $n-1$ characteristics.

Notwithstanding, found equilibria are not unique; there are some analytical difficulties in computing every subgame perfect equilibria at the location stage of the game proposed. In addition, theoretical predictions on firms "strategies" in a context of multidimensional product differentiation are difficult to test empirically, because of the lack of data and agree among researchers about how to measure vertical and horizontal differentiation. Recently, in order to fill this gap, some papers have dealt with experimental analysis on product differentiation, but so far, to our knowledge, no one has tried to test a model of multidimensional product differentiation by means of an experiment[1].

Brown-Kruse et al. (1993) present theoretical and experimental results on spatial competition between two firms. In their model, firms choose locations simultaneously along a linear market, in the spirit of Hotelling (1929). Along the line representing the market, identical simulated consumers are distributed uniformly. The aim of the authors was, among others, to investigate the effects of communication among subjects in deciding locations.

Subjects-sellers were randomly paired within each session and were told that they would remain in those pairings throughout the experiment (this could have caused rep-

[1] The majority of existing experimental literature on spatial competition is based on voting models and considers the behavior of candidates and voters in a spatial context. It should be noted that in voting models there is no price competition.

utation and path dependence effects) and no one was able to detect the identity of the other seller in his market. The price they could charge was fixed, with a linear transportation cost to the consumer. In addition, subjects were given fixed and variable costs of production they would incur each period. There was one treatment in which no communication was allowed between subjects, and another treatment where subjects were allowed to engage in anonymous non-binding communication with the other seller. Communication was allowed to be continuous and voluntary throughout the course of the session.

The results reported are from 24 duopoly markets which involved 48 subject-firms. The duration of a market was probabilistic and ranged from 4 to 15 trading periods. The authors had previously found the set of strongly symmetric equilibria: Hotelling's concept of minimal differentiation is one of the many experimental outcomes that can be supported by Brown-Kruse at al. (1993). Introducing non-binding communication, it is also found that the set of equilibria contains both collusive and competitive outcomes if the discount factor is sufficiently large. Without communication, subjects cluster near the center of the market, and this occurs despite the fact that there are much more lucrative equilibria. The authors conjecture that this result is due to the failure of sellers to coordinate when they are unable to communicate, a conjecture supported by the second set of experiments where communication was allowed: coordination at the joint profit maximization quartile equilibrium was the overwhelming result.

Collins, Sherstyuk (2000) report the results of an experimental study of the three agent location problem. In the case of three firms, no pure strategy location equilibrium exists, as first was noted by Lerner, Singer (1937) and formally shown by Eaton, Lipsey (1975). Shaked (1982) determines the symmetric mixed strategy Nash equilibrium for the case of three firms and uniform (one-dimensional) distribution of consumers: the only symmetric equilibrium is for each firm to locate randomly with equal probability at each point in the middle two quartiles of the market[2]. Four experimental sessions were conducted, each containing between 9 and 18 subjects, each lasting for 35 periods. Subjects knew that the number of the periods was fixed but were not informed of the actual last period. As in the previous experiment, the subjects were asked to choose their location from the set $0, 1, 2, \ldots, 100$, and the price of units sold was fixed; therefore competition was only in locations.

The findings are consistent with the theory: the subjects did not cluster at the very center of consumers' distribution and chose, most frequently, to locate in the central quartiles of the market. However, the location choices were more dispersed than predicted by the theory: the agents often located in the out-of-equilibrium range. The authors suggest three alternative hypotheses to explain the above phenomena: subjects'

[2]Osborne, Pitchik (1986) find other asymmetric mixed strategy equilibria for this case and further characterize symmetric location equilibria for arbitrary distributions of consumers along the market spectrum and arbitrary number of firms.

inexperience with the game, approximate equilibrium behavior, and risk aversion, but only the latter explanation seems reasonable.

Barreda et al. (2000) use experimental methods to study product differentiation and price competition in a discrete version of the Hotelling (1929) game. The experiment designed is characterized by the fact that is a two stage location and price game with two sellers, there is a small number of location and price choices which leads to high risk in subject's decision making, and it has been allowed to compare individual and group decision making, and also the results with an odd or even number of possible varieties. Beyond the standard argument in favor of the principle of minimum product differentiation confirmed by experimental results, further factors are identified, which induce variety clustering associated with strong risk aversion. Collective players' strategies are found to exhibit a stronger tendency towards agglomeration in the middle. In the treatment with even locations it is observed higher prices and lower differentiation than in one with odd locations.

Finally, Garcia Gallego, Georgantzis (2001) test the predictive power the Bertrand-Nash equilibria in a symmetric differentiated oligopoly with multiproduct firms. Subjects are not informed on the specification of the underlying model. In the presence of intense multiproduct activity, and provided that a parallel pricing rule is imposed to multiproduct firms, strategies tend towards a non-cooperative multiproduct solution.

In this paper we take in consideration the model of multidimensional product differentiation proposed by Irmen, Thisse (1998), in which products can be differentiated along two horizontal dimensions (in the general version of the model, products can be differentiated along several horizontal dimensions, but the general results do not change), and we test the max-min product differentiation outcome. In the second session we introduce the theoretical model used in the computerized experiment, while in section 3 the experimental framework is described. In section 4 we show and discuss the main findings, and in the last section some concluding remarks are provided.

1 The Model

Irmen, Thisse (1998) investigate how firms differentiate when there are many characteristics of products, and how many characteristics are involved in the differentiation process, inspired by the preliminary results obtained by Neven, Thisse (1990) and Tabuchi (1994). The main question is: in the case of n horizontal characteristics, do we observe maximum or minimum differentiation along all but one characteristics? Here we will use the two-characteristics case, in order to make tractable the experimental procedure.

There are two firms in the market, A and B. The products' variants are given by the firms' locations in $\mathbb{R}^2$. Firm's A location is described by a vector $\boldsymbol{a} = (a_1, a_2)$ whereas firm B's location is given by $\boldsymbol{b} = (a_1, a_2)$, with $a_1, a_2 \in [0, 1]$. There is a continuum of consumers distributed over the characteristics' unit square $C = [0,1]^2$ according to a nonnegative continuous density function $g(z)$, where $\boldsymbol{z} = (z_1, z_2)$ is a consumer's address, so that

$$\int_{\mathbb{R}^2} g(z)dz = N \tag{1}$$

is the total population. It is assumed that $g(z)$ is uniform and, without loss of generality, the total population is normalized to 1. Consumers have a conditional indirect utility function $V_i(z)$, $i = A, B$: a consumer buying at A enjoys an utility equal to

$$V_A = S - p_A - \sum_{j=1}^{2} t_j(z_j - a_j)^2 \tag{2}$$

where S denotes the gross surplus a consumer at z enjoys from consuming either variant, and p_A is the price of variant A. The last term of this expression is the square of the weighted Euclidean distance between the consumer's ideal point and the location of variant A; t_j stands for the salience coefficient of characteristic j. However, for simplicity, we assume the same weights across consumers and characteristics ($t_k = t = 0.5$).

Simulated consumers have unit demands. It is assumed that S is large enough for all consumers to buy at the price equilibrium corresponding to any location pair. The demand for variant A is then defined by the mass of consumers for whom variant A is weakly preferred to B:

$$D_A = \int_{\{z; V_A(z) \geq V_B(z)\}} g(z)dz. \tag{3}$$

Any variant can be produced at the same constant marginal cost, which is normalized to zero without loss of generality. Consumers indifferent between purchasing product A or B are located on a line defined (in terms of z_j) by

$$p_A + \sum_{j=1}^{2} t_j(z_j - a_j)^2 = p_B + \sum_{j=1}^{2} t_j(z_j - b_j)^2. \tag{4}$$

Assuming that b/a, the slope of the indifferent line is negative along each dimension.

Using this basic framework, we have determined the demand functions for A and B considering all the possible cases, and we have introduced demand functions in the experimental software. For details concerning the determination of the demand system, see Irmen, Thisse (1998); the process is tedious, so we do not report it here[3].

In the general case of n dimensions, the following results are showed by Irmen, Thisse (1998). First, when all weights (t_j) are equal, there are n local equilibria in which firms choose maximum differentiation along one characteristic and minimum differentiation

[3] Deatils are available upon request.

along the remaining ones. In this way, duopolists offer similar products but are still able to relax price competition. Second, when there is a dominant characteristic, the Nash equilibrium involves maximum differentiation along the dominant characteristic only; in other words, differentiation in a single dimension is sufficient to relax price competition and to permit firms to enjoy the advantages of a central location in all other characteristics.

In particular, Irmen, Thisse (1998) show that, assuming $t_k = t$ for all t, for each $k = 1, \ldots, n$, there exists $\epsilon > 0$ such that

$$\boldsymbol{a}^* = (1/2, \ldots, 0, 1/2, \ldots, 1/2), \;\; \boldsymbol{b}* = (1/2, \ldots, 1, 1/2, \ldots, 1/2)$$

is the only equilibrium of the first stage of the game, if deviations by firm A (resp. B) are restricted in a particular domain defined by

$$\begin{cases} \frac{1}{2} - \epsilon < a_i < \frac{1}{2} + \epsilon & (\text{resp. } \frac{1}{2} - \epsilon \leq b_i < \frac{1}{2} + \epsilon) \quad \forall i \neq k \\ 0 \leq a_i < \epsilon & (\text{resp. } 1 - \epsilon < b_i \leq 1) \quad \text{if } i = k. \end{cases}$$

Also, the authors show that some candidate configurations can be disregarded as possible equilibria. Among these, a maximal product differentiation where $\boldsymbol{a} = (0, \ldots, 0)$, $\boldsymbol{b} = (1, \ldots, 1)$, can never be a location equilibrium[4].

In the experiment, we have used the case of two characteristics and equal weights, in order to better analyze the results. Of course, future research will take in consideration other possible cases discussed in theoretical literature.

2 Experimental design and expected results

The experiment was computerized, and the software has been developed by the authors. All computers (12) were connected through a local area network, and on a supplementary computer of the network the master program was installed, controlling all the experiment. Each player independently made his/her choice, and transmitted it to the master program. The master program sent back to each player's screen the complete information, and with this information players started the next period and decided on their next strategy.

Sixty students in economics were recruited at the University of Trento, divided in 5 groups of 12 people each. During the experiments, each subjects was paired with another subject, but each period he/she was paired with a different anonymous subject; after five periods (defined as follows according to the running treatment) the subjects

[4] Ansari et al. (1998) conduct a very similar analysis and they obtained identical results from the model hypothesized: with two or three dimensions of products' attributes, firms maximize product differentiation in one dimension only.

re-played with the same subjects, and so on. The randomization of pairs was made in order to avoid reputation and path-dependence phenomenon. Individuals were sitting in the same room, but they could not talk with each other, were separated and controlled by the experimentalist. Each session lasted about 1 hour including instruction time. Instructions (see Appendix B) were written on paper and distributed in the beginning of each session. For each group of subjects three different treatments were organized.

The first treatment (FT) best reproduces the theoretical model. Subjects had to choose the location of their product in the characteristics' space defined by $S = [100 \times 100]$; in other words, students had to choose two varieties of the product: $v_1 \in [0, 100]$ and $v_2 \in [0, 100]$. After this choice, subjects were made aware about the location of their opponent, and they also could see the location of both firms displayed on the screen. At the second stage of the game, subjects were asked to price their product, with $p \in [1, 100]$. After the price stage, the results in term of market share, profits, and opponent choices were disclosed. This treatment lasted for 10 periods.

In the second treatment (ST) subjects were told to take the same decisions (v_1, v_2 and, at the second stage, price), but this time, after the first period, there were 3 periods in which they could change only the level of price, maintaining the same location. After these price periods, they could relocate their product. This treatment lasted for 10 periods (that is, 10 choices of location and 40 choices of price).

In the third treatment (TT), subjects chose simultaneously product location (v_1 and v_2) and price for ten periods; after the simultaneous choice of these 3 variables, they knew about their profits and market share, and information regarding their opponent was disclosed. Also this treatment lasted for 10 periods. Therefore, in aggregate, a player chose for 30 times his/her location, and for 60 times the price of his/her product. At the end of the experiment each subject was paid in cash according to his/her cumulative profit. The maximum a student could earn was 50,000 ITL. In the following figure it is shown an illustration of computer screen.

Theoretical predictions about the games described above are described as follows.

- Firstly, there is a qualitative predictions concerning firms' location strategies: subjects are expected to locate in order to maximize differentiation along one dimension and differentiate along the other dimension. The result of max-min product differentiation implies an Euclidean distance between subjects equal to 100; that is, for example, $\boldsymbol{a} = (0, 50)$ and $\boldsymbol{b} = (100, 50)$: as described in the previous section, if salience coefficients are equal, there exist n local equilibria in which both products are differentiated (maximally) along any single characteristic and bunched along all the others at the center of the unit interval. This prediction is expected, in particular, in the FT, because in this treatment the theoretical model is best reproduced. Naturally, a backward induction process is assumed, even if it has been shown that individuals rarely adopt it. In the ST, predictions remain unchanged: the game theoretical solution for a finite repetition of the game would, by the

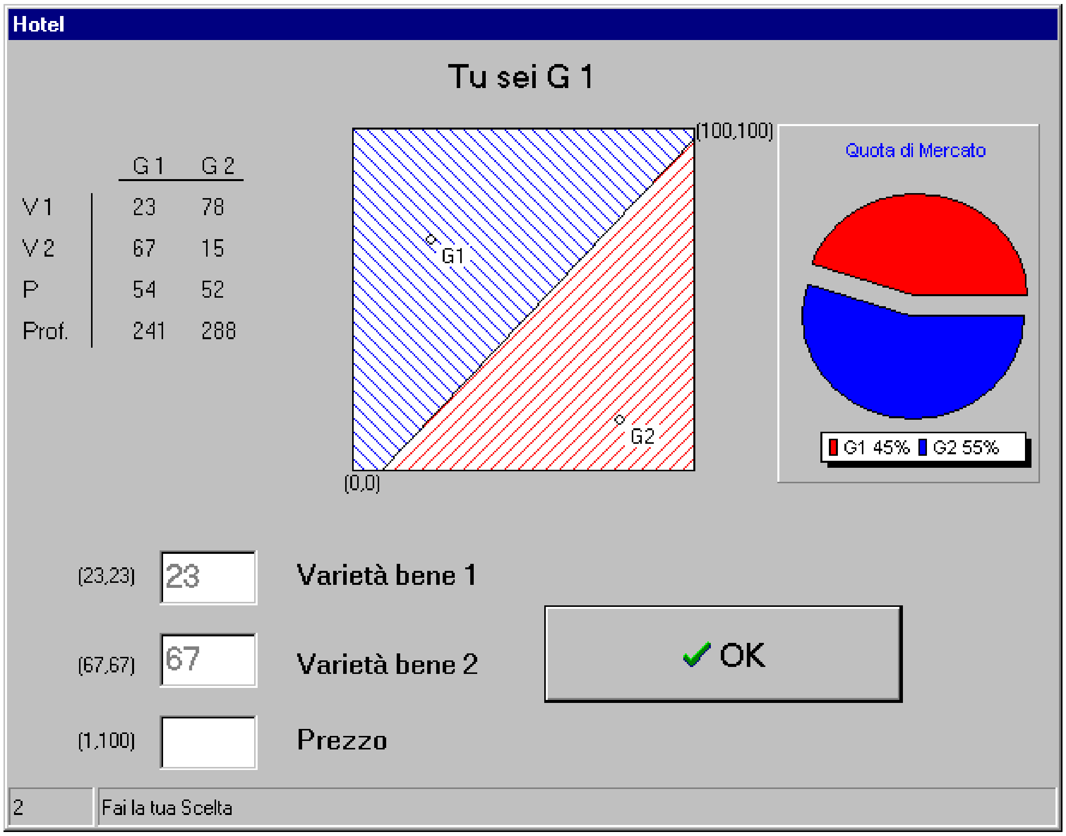

Figure 1: Experiment user interface.

backward induction argument, prescribe in each repetition the same behavior as the subgame perfect equilibrium solution of the source game[5].

- In the TT, nothing can be said about theoretical predictions, because locations are chosen at the last (and unique) stage of the game. In fact, as explained in Economides (1987), *any game structure where locations are chosen in the last*

[5]Caplin, Nabeluff (1991) have identified conditions under which both existence and uniqueness of the price equilibrium hold. The existence of a price equilibrium depends on the functional form and the distribution of consumer preferences. The utility function (2.2) is a special case of the utility considered by Caplin, Nalebuff (1991). Since the uniform distribution complies with concavity assumed by those authors, there exists a pure strategy price equilibrium for any location pair. The demand functions are twice differentiable and the uniform distribution is log-concave, thus implying the uniqueness of the price equilibrium for each location pair. This determines that, from the point of view of theoretical predictions concerning location equilibrium, nothing should change passing from FT to ST.

stage does not have a (subgame-perfect) equilibrium. The last treatment has been organized for two reasons: firstly, it was interesting to analyze whether a different subjects' behavior would emerge from such a different setting, which represents the way in which sometimes markets operate; secondly, in cases like this, experimental analysis shows to be a real alternative to theoretical analysis, when the last fails to predict market characteristics. In fact, the result of no equilibrium with location choice in the last stage of a game is a robust analytical result, but it does not help to explain market characteristics when that circumstance occurs. However, also considering other experiments' results, in the TT we expect subjects–firms to choose more central locations.

- Since product differentiation along at least one characteristic should relax price competition, we expect the higher is the product differentiation, the higher should be the level of prices. Again, we measure product differentiation as the Euclidean distance between firms.
- In the theoretical equilibrium, when $t_k = t$ for all t, in each n local equilibrium prices are expected to be equal to (or near to) $t = 0.5$ and firms are expected to earn the same profits. This prediction derives directly from the theoretical model (Irmen, Thisse, 1998).

3 Results and discussion

A total of 1800 observations of locations and 3600 observations of prices were recorded during the experiment. Descriptive statistics for the data pooled by treatment and by session are given in tables 3 and 3, where AvD is average product differentiation (the Euclidean distance between the two firms' locations), Sd is standard deviation, AvP is average price, and Avp is average profits.

From table 3 it is clear that, in aggregate, the theoretical Nash equilibrium of *max-min* product differentiation does not have great explanatory power for the data. In the course of the experiment subjects chose locations which tend towards the center of consumers' distribution. This is described, in particular, by figure 2, where the data are aggregated by session and by treatment, and where for each period the average total differentiation is computed.

A Wilcoxon sign-rank test ($\alpha = 0.05$) confirms that product differentiation is different treatment to treatment; this result is confirmed also when the test is conducted by session. From table 3 is also clear that price and profits are declining during the experiment. However, prices and profits reach a sort of equilibrium ($p \simeq 20, \pi \simeq 50$) after the beginning of the ST, with the price keeping away from the theoretical equilibrium level

	AvD	Sd	Mode	Median	AvP	Avπ
Nash Eq.	100	0	100	–	1	–
FT	31.74	21.53	0	27.69	39.74	161.63
ST	24.41	19.74	0	20.61	16.57	64.93
TT	18.50	18.36	0	13.47	16.92	64.07

Table 1: Summary statistics, data pooled by treatment

	AvD	Sd	Mode	AvP	Avπ
s1	25.82	20.33	0	19.29	80.54
s2	29.74	23.14	0	17.14	66.98
s3	23.60	21.11	0	14.68	52.22
s4	25.26	19.64	0	33.60	135.25
s5	20.00	17.35	0	17.83	69.51

Table 2: Summary statistics, data pooled by session

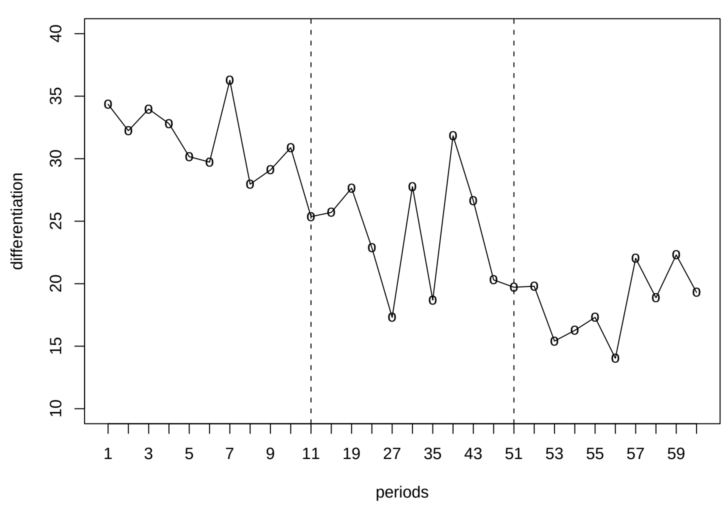

Figure 2: Average of total differentiation. Data are aggregated by sessionon and by treatment. The vertical lines are delimitating the treatments.

$t = 0.5$ (fig. 3 and 4)[6].

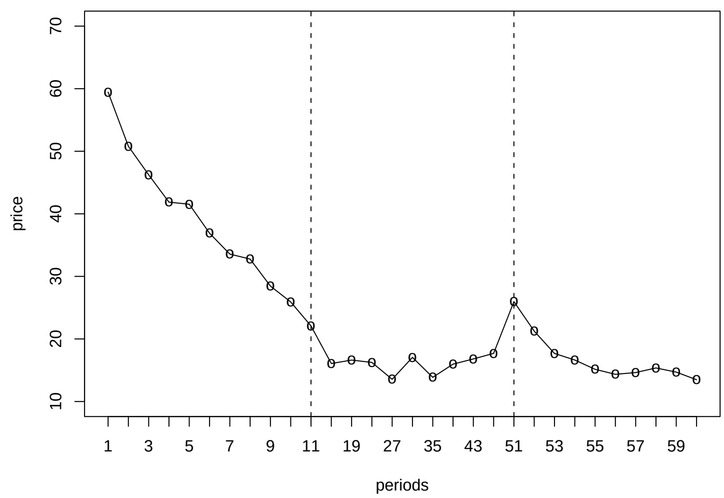

Figure 3: Price average per period. Data are aggregated by sessionon and by treatment. The vertical lines are delimitating the treatments.

Table 3 show that also between sessions there are significant differences (Kruskal–Wallis test, $\alpha = 0.05$). This is true for product differentiation but also with respect to the level of price. However, it is evident from table 3 that session 4 is responsible for the statistical result. Conducting a Kruskal-Wallis test without session 4 leads to accept the null hypothesis ($\alpha = 0.05$).

Fig. 5, 6 and 7 illustrate all the locations treatment to treatment; it is possible to see that subjects have chosen locations near to the center of consumers' distribution, keeping away from the angles of characteristics' square.

Therefore, subjects rarely adopt the strategy described by theoretical predictions. There are few locations given, for example, by $(1, \frac{1}{2})$ or $(0, \frac{1}{2})$. Subjects chose to aggregate around the center of consumers' distribution, and this trend becomes stronger in the course of the experiment.

From the point of view of "single variety choice", the majority of subjects chose central locations for each variety (fig. 8).

In general, students seem to choose a location v_1 and v_2 higher than 50 (this is true for each treatment); this may be explained with the fact that individuals "think" about

[6]Note that, however, the minimum price allowed was 1.

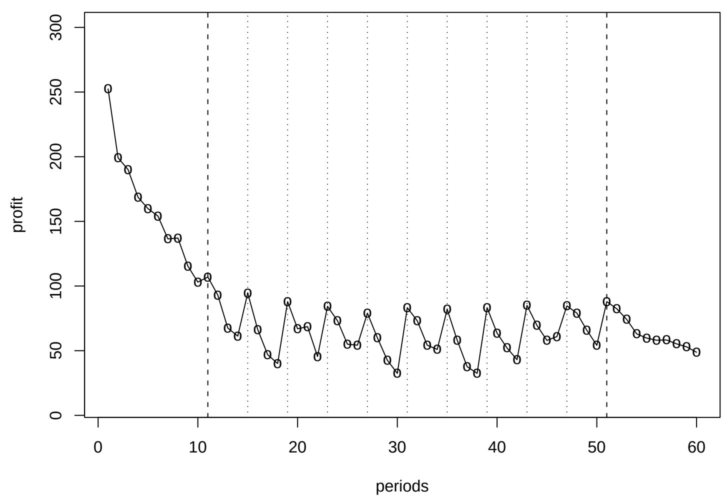

Figure 4: Average profits per period. Data are aggregated by sessionon and by treatment. The vertical lines are delimitating the treatments.

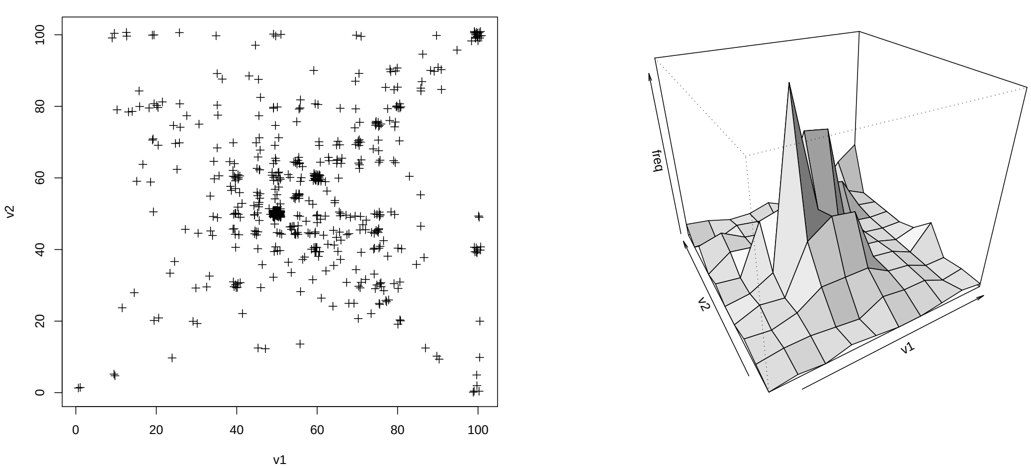

Figure 5: Locations - FT. In the left plot a small random number is added in order to allow the visualization of overlapping points. In the right plot data are binned in 10 by 10 classes.

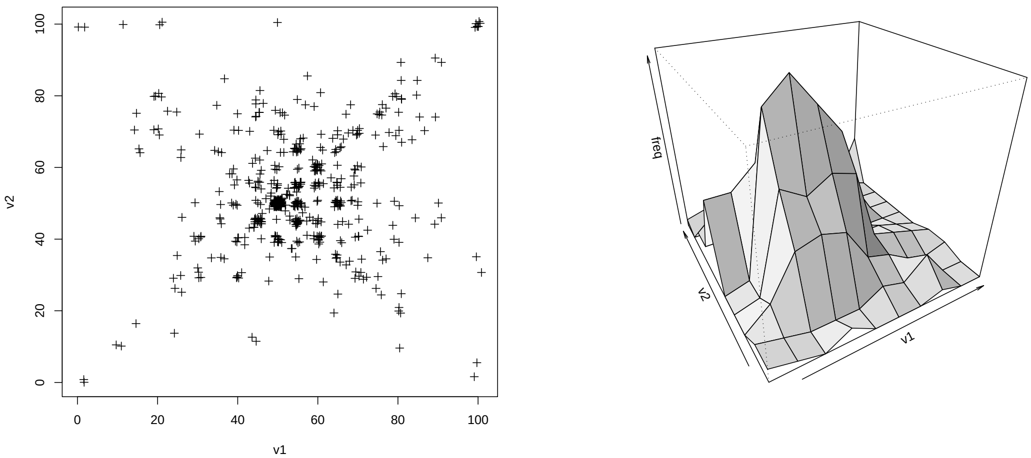

Figure 6: Locations - ST.

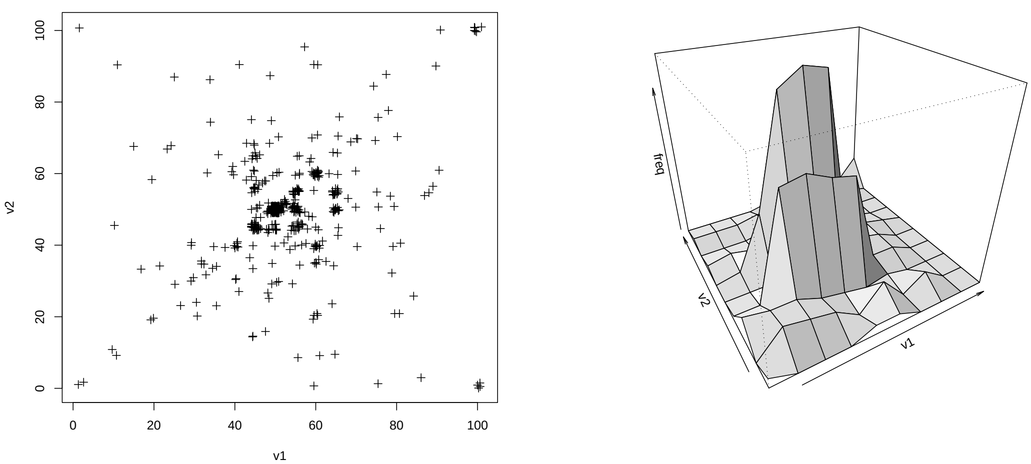

Figure 7: Locations - TT.

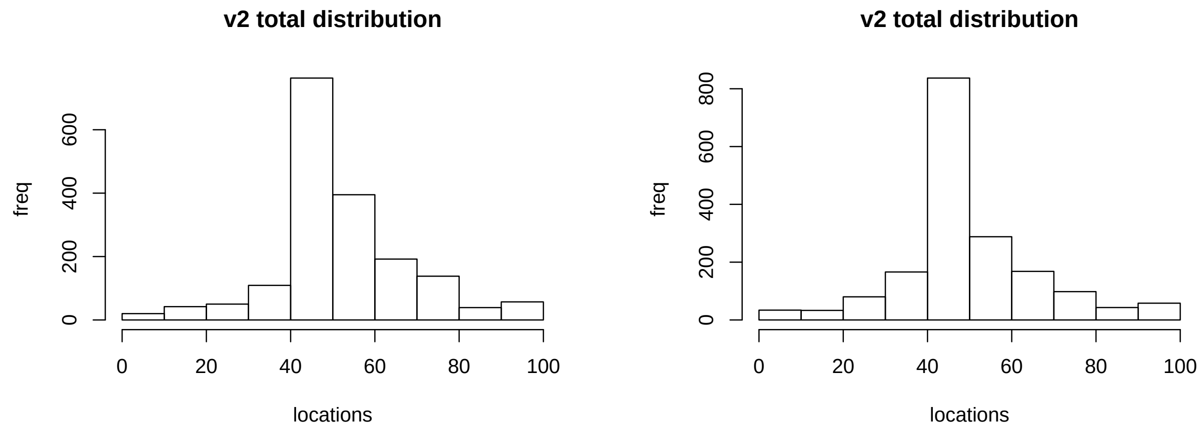

Figure 8: Variety distributions: the left histogram shows the v_1 variaty distribution, the right one the v_2.

the varieties in terms of quality; note, however, that at the beginning of each session students were informed that it was not so. Evidently, this was not sufficient to avoid the outcome described.
Product differentiation decreases during the experiment: in the TT a distance between duopolists in the range [0, 10] account for more than 40% (fig. 9).

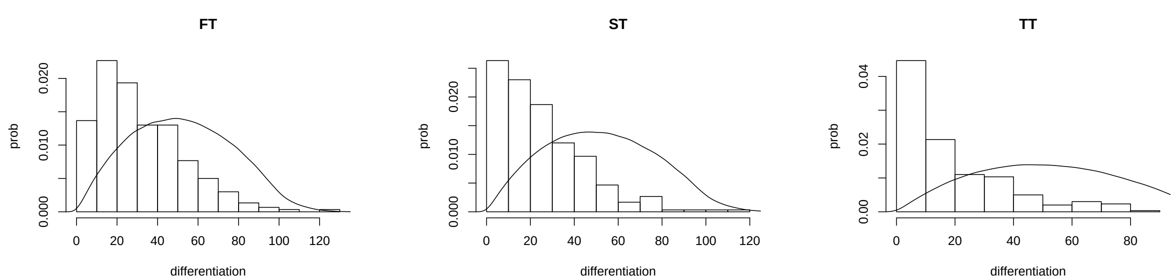

Figure 9: Distribution of variety differentiation in the three traitments. The line represent the theoretical variety distribution when agents choose randomly.

Naturally, it should be noted that in the third treatment no result of max-min product differentiation was expected. However, also in the second treatment few subjects decided to locate apart from their opponents. Only in the first treatment some attempts to differentiate have been observed, but they were too few to resemble the theoretical equilibrium.

Apparently, there is no relationship between prices and product differentiation, in the treatments conducted (fig. 10, 11, 12: each point represents the distance between each pair of duopolists and the average price). This result is confirmed also if we analyze data session by session. In ST and TT product differentiation seems completely independent with respect to price, which, as observed above, reaches an equilibrium level of about 20.

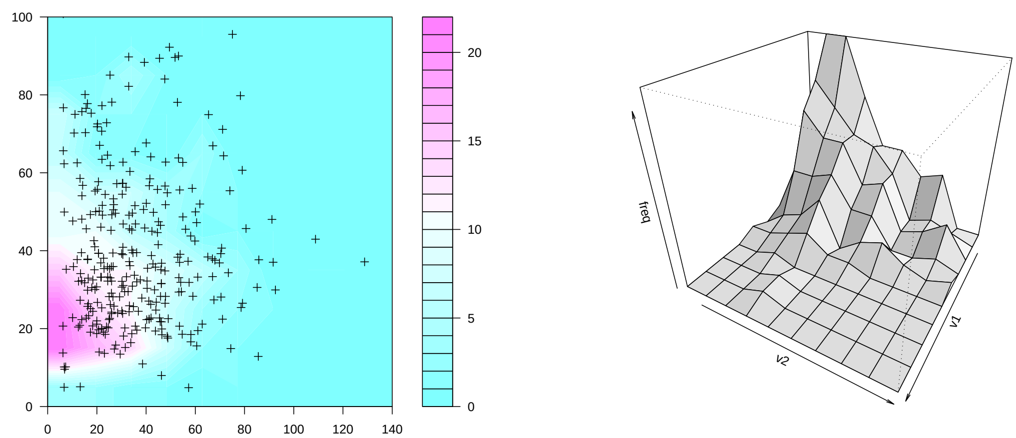

Figure 10: Price and differentiation in FT. In the left plot a small random number is added in order to allow the visualization of overlapping points. The background colour represent the frequency. In the right plot data are binned in 10 by 10 classes.

Another exploration conducted analyzing the data individuals by individual has given the same result: there is no relationship between prices and product differentiation. On the contrary, there is a strong relationship between average prices and average profits (fig. 13).

Briefly, the main findings of experimental analysis can be summarized as follows.

Firstly, aggregate results from the experiment are neither qualitatively nor statistically consistent with the Nash equilibrium predictions. This experimental result is particularly strong with respect to location choice. In general, subjects do not seem to choose a strategy of max-min product differentiation, and normally try to exploit the

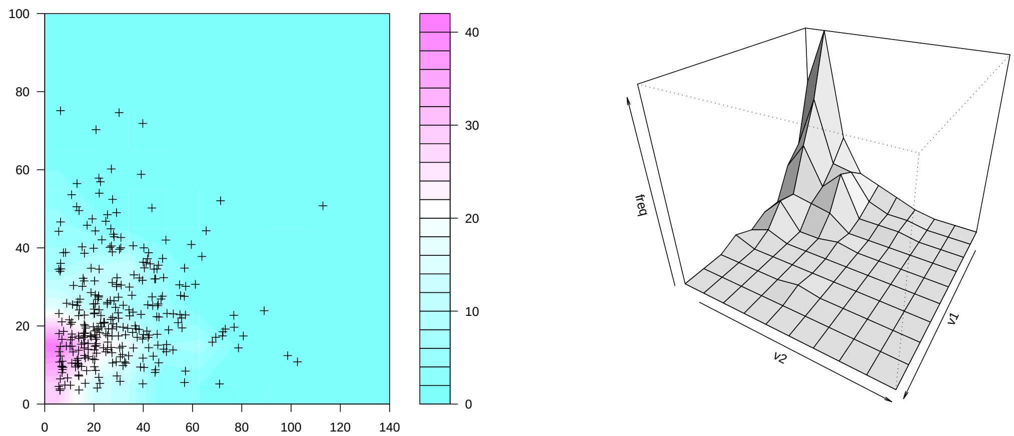

Figure 11: Price and differentiation in ST. In the left plot a small random number is added in order to allow the visualization of overlapping points. The background colour represent the frequency. In the right plot data are binned in 10 by 10 classes.

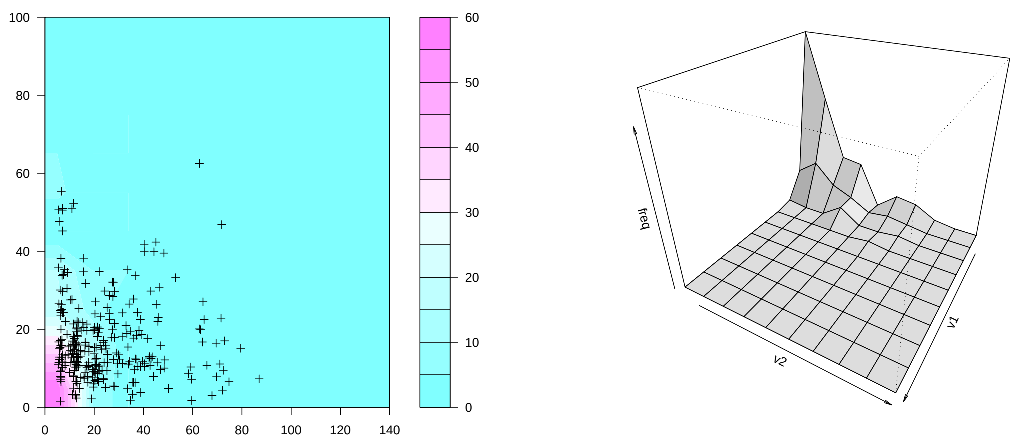

Figure 12: Price and differentiation in ST. The background colour represent the frequency. In the left plot a small random number is added in order to allow the visualization of overlapping points. In the right plot data are binned in 10 by 10 classes.

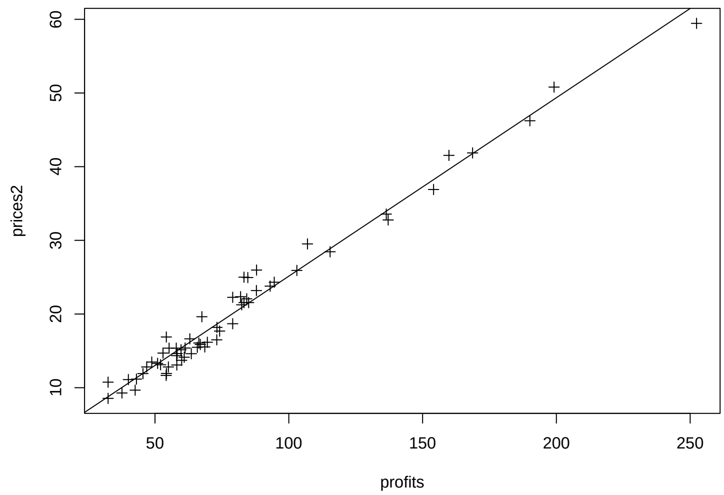

Figure 13: Price and Profits. Linear model: adjusted R-squared = 0.9777.

advantages of a central or quasi-central location inside the area representing consumers' distributions on characteristics.

Following Collins, Sherstyuk (2000) and other works, we could argue that a possible explanation of this phenomenon is due to risk aversion. Even if we have not conducted an analysis in order to explore this possibility, we can confirm, after some discussions with students after the experiments, that risk aversion was a fundamental cause of their aggregation towards the center of consumers' distribution.

A possible explanation for differences between the data and the equilibrium prediction could be the subjects' inexperience with the game. But we have seen that, as the game progressed, individuals chose location closer and closer the center of consumers' distribution. Then the differences between the behavior observed and the equilibrium prediction can not be explained by subjects' lack of experience with the game.

Of course, given that Nash equilibria found in theoretical analysis are not unique, one could argue that theoretical research should proceed on defining better the possible equlibria resulting from a game structure as that used by Irmen, Thisse (1998) or Ansari et al. (1998). However, it should be noted that the most likely equilibrium according the theoretical analysis, that is, the equilibrium defined by maximum differentiation along one characteristic and aggregation at the center of the other characteristic, is a very rare experimental result if we consider all the experiments conducted on this topic.

Theory succeeds only when it predicts that firms will not maximally differentiate along both dimensions: in our experiment, effectively, this outcome occurs rarely.

Looking at table 3 and 3 above, it is clear that subjects need some periods to decide their "preferred" strategy, although some practice sessions were run before the beginning of each experiment. This could be the reason why we found a different result passing from first treatment to second treatment. However, in both cases a tendency to agglomerate at the center of consumers' distribution is strong.

In the third treatment we do not have theoretical predictions, because the location stage is at the last (and unique) stage of the game. Notwithstanding, experimental results confirm that in this case the tendency to agglomerate at the center is stronger: given that there are no Nash equilibria of the game, risk aversion is probably higher.

Differently from theoretical predictions, in the course of the experiment higher product differentiation does not imply higher prices. In other words, product differentiation is not enough, at least in the experimental framework that we have utilized, to relax price competition.

Finally, since there were no production costs, prices were expected to decrease towards the parameter t, that in our setting was equal to 0.5. This was not confirmed by experimental results. Prices are decreasing in the first treatment, and they continue to decline during the experiment, even if they seem to reach an equilibrium value. In other words, a phenomenon of tacit collusion on prices seem at work. After the experiment, students have confirmed that their attention was constantly paid to the level of price: they could understand the effect of a low price better than the effect of a strategic location. However, price did not decrease until the hypothetic "marginal cost".

4 Conclusions

Experimental analysis is helpful when theoretical models are complex and a straight application of them to real markets is not possible. This is particularly true in the case of multidimensional product differentiation. In real markets products are normally differentiated along several characteristics, even if there are some examples of markets with homogeneous goods (the stock market, some commodities market, and so on). Although theoretical models of strategic product differentiation have developed and are becoming very complex and refined, it is not easy to evaluate their prediction strength by means of empirical analysis.

For these reasons, in this paper we have tested the theoretical model of Irmen, Thisse (1998) and Ansari et al. (1998), in which two firms compete in locations, defined by several horizontal characteristics, and price. The most important prediction of these models is that firms will differentiate maximally along one horizontal dimension and minimally along the others. In our experiment, we have carefully replicated the analytical framework, which has been slightly modified in two treatments, in order to extend the robustness of results.

Our results do not confirm the theoretical predictions formulated by Irmen, Thisse (1998) and Ansari et al (1998), but they resemble previous experiments on location and pricing: firms tend to agglomerate towards the center of consumers' distribution, in order to exploit the advantages of a central location. Naturally, this is an experimental result obtained in a controlled environment, and nothing can be said about how firms behave in real world. However, the majority of other experimental results confirm our outcomes, and these experimental result can be helpful in exploring the fundamental issue of multidimensional product differentiation.

Acknowledgments

We thank Marco Tecilia for his assistance in conducting the experiment. We also thank Luigi Mittone and Luigi Luini for helpful discussions, and Davide Di Laurea for suggestions during the analysis of data. Financial support by ex 40% fund, PAR fund and LESEC are gratefully acknowledged.

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Appendix

A Translation of instructions

A.1 First treatment

Consider a market in which a product can be differentiated along two characteristics, called $v1$ e $v2$. These two characteristics define the "variety" (or "location") of the product. There are many consumers in the market, and each of them possess an "ideal" combination of varieties', that is, an ideal value of $v1$ and $v2$. Therefore, since a product is defined by $v1$ and $v2$, the utility of a consumer z who purchases that product is given by

$$U = R - 0.5(z_{v1} - v1)^2 - 0.5(z_{v2} - v2)^2 - p$$

where R is a positive parameter which is the same among all consumers, z_{v1} e z_{v2} are the ideal values of $v1$ e $v2$ for the consumer z, and p is the price of the product. Each consumer will buy the product which gives him/her the maximum utility U. In other words, each consumer, in his/her purchase choice, will evaluate the "distance" (in terms of characteristics) of market products with respect to his/her preferred location, given the price at which the products are offered. Each consumer buys one unity of the product. You are one of the two firms which are selling products in this market. The market operates period to period; at the beginning of each period you have to choose the "location" of your product in terms of $v1$ and $v2$, and the same for your opponent. Then you both will know the decisions you have made, and you will have to decide the price of your product. After the price choice, you will know which is your market share, which will be graphically represented, your profits (given by the price chosen multiplied by the quantity you have sold, because production costs are zero) and all the information regarding your opponent (price, location, profits). Then, a new market period will start, and you will be able to maintain or change your choices. Your goal is to maximize profits, proportionally to which you will gain an extra earning (up to 35.000 ITL) as well as the fixed remuneration. The values of $v1$ and $v2$ and price (p) can vary between 1 and 100. In the course of the experiment you are not allowed to communicate with anyone; if you have any doubt, pleas contact an experimentalist.

A.2 Second treatment

In this first variant of the experiment, everything is the same, but this time, once you have chosen the location of your firm (the two varieties) in terms of $v1$ and $v2$, and in the second stage, the price, there will be 3 periods in which you can modify only the price of your product. After these 3 periods, you will be allowed to re-locate your product.

A.3 Third treatment

Now you have to choose simultaneously the location and the price of your product; in other words, at the beginning of each period you will be requested to choose $v1$, $v2$ e p. After that you and your opponent have taken the decisions regarding these three variables, you will know your market share, your profits, and all the information regarding your opponent. Remember that your goal is to maximize your profits.