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Przemysław Kusztelak

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Przemysław Kusztelak
University of Warsaw
Faculty of Economic Sciences
e-mail: pkusztelak@wne.uw.edu.pl

Abstract

This study presents the results of an experiment on spatial differentiation of products in Hotelling-type models with different grades of complexity for companies' choices of space. Three models were compared, including models with a single decision variable (single-dimensional space with automatically calculated prices), two decision variables (single-dimensional space with prices assigned by the participants) and three decision variables (bi-dimensional space with prices assigned by the participants). The research revealed that in more complex conditions, the product differentiation was smaller and that the prices were lower than in a simple environment when the Nash equilibrium was confirmed. Companies that function in complex conditions do not take advantage of the opportunity to make high profits based on product differentiation. This has a greater impact on price rigidity with respect to product variety than could be theoretically predicted. Strategies based on product differentiation are, therefore, less profitable than expected based on theoretical predictions.

Keywords:
spatial competition; product differentiation; laboratory experiments

JEL:
C72, C92, D43

1. Introduction

Commonly known spatial models based on the work of Hotelling (1929) or Salop (1979) explore the effects of horizontal product differentiation on companies working within specific structures. The applicability of these models is limited based on several unrealistic assumptions, including e.g. (for example) the one-dimensional choice space of a company (two decision variables – the single-dimensional goods' location and price), the linear (or quadratic) transportation costs, non-uniform consumer distributions, perfectly inelastic demand, a homogeneous product provided by two companies, and the assumption of full-market saturation (market demand is fully served by the market players).

As a response to the discrepancies between existing theories and market realities, many studies have sought to explore the role of factors such as the form of the transportation costs function (e.g. d'Aspermont, Gabszewicz and Thisse - 1979, Economides – 1986), the demand distribution function (e.g. Shilony - 1981, Caplin and Nalebuff - 1991, Tabuchi and Thisse - 1995, Anderson, Goeree and Ramer - 1997, Scrimitore - 2003), its elasticity (e.g. Smithies - 1941, Anderson, de Palma and Thisse - 1992, Rath and Zhao - 2001) and endogeneity (e.g. Fujita and Thisse - 1986, Bloch and Manceau - 1999, Garcia-Gallego, Georgantzis and Orts-Rios - 2001), the size of companies in the market (e.g. Böckem - 1994, Hinloopen and Marrewijk - 1999, or Kopczewski, Kusztelak and Pogorzelski -2009) and the number of firms (e.g. Salop - 1979, Economides -1993a, Brenner - 2001)). However, many models have emerged, which explore the influence of the choices that companies make regarding the spatial placement of their products choice companies' space form on the equilibria they obtain and describe the following placements of products: on a circle (Salop - 1979), on an unlimited quantity of straight parallel lines or a perpendicularly crossed – Manhattan metric (Braid - 1999), on a rectangle (Vendrop and Majeed – 1995, in the case of symmetrical placement, and Tabuchi - 1994 for any not necessarily symmetrical placement), in a tri-dimensional space (Ansari, Economides and Steckel - 1998) and in a multi-dimensional space (Irmen and Thisse - 1998).

In the Nash equilibrium, predictions theoretically indicate two or more dimensions of models in which companies differentiate their products using one profile (the more significant profile is used), providing a homogenous product in all remaining dimensions. Companies are not able to increase their profits by differentiating their product in more than one profile. Market practice seems to prove that on the one hand, companies contribute products in many dimensions to the market, but on the other hand, these products' profiles differ insignificantly. Moreover, this type of multidimensional, apparent differentiation allows for a decrease in the price competition between companies, leading customers to believe that each specific product type represents a unique form with no close substitutes. In this study, we verified the hypothesis that increasing the number of choice space dimensions provides a company with a decrease in product differentiation while limiting price competition at the same time, which contradicts the predictions of theoretical models.

To verify the theoretical predictions and the hypothesis, the experiment with three different grades of complexity for companies' choices of space was performed. The published literature suffers from lack of experiments analysing the effects of spatial differentiation of products and its influence on price competition. This research can be divided into experiments that analyse the influence of the elasticity of demand and the demand distribution function (e.g. Brown-Kruse, Cronshaw and Schenk - 1993, or Kruse and Schenk - 2000), the number of companies in the market (e.g. Collins and Sherstyuk - 2000, Huck, Müller and Vriend - 2002, Orzen and Sefton – 2008, Morgan, Orzen, and Sefton – 2006, or Garca-Gallego and Georgantzis – 2001), the sizes of companies (e.g. Barreda - 2000, Kopczewski, Kusztelak and Pogorzelski - 2009) and the demand endogeneity (Camacho-Cuena, Garcia-Gallego, Georgantzis and Sabater-Grande - 2005). Our findings demonstrate that theoretical predictions are not often confirmed in research, and a key value of spacial experiments is that they show possible causes for discrepancies. Discrepancies between theory and reality may result from communication problems (Brown-Kruse, Cronshaw and Schenk – 1993, or Kruse and Schenk – 2000), incomplete rationality of firms that use near-epsilon equilibrium strategies (Collins and Sherstyuk – 2000), entities' risk aversion (Collins and Sherstyuk – 2000), or model complexity (Kruse and Schenk 2000).[1]

This study presents the results of an experiment that evaluated the effects of spatial differentiation of products using Hotelling-type models with different grades of companies' choices of space complexity. To the best of our knowledge, there have been no other studies that systematically analysed the influence of spatial complexity on a company's location and the degree of price competition. Mangani and Patelli (2002) performed the spatial experiments with a greater than single-dimensional choice space for a company. They analysed a model with two companies that made price and location decisions in various sequences. The experiment consisted of three stages. In the first stage (FT), decisions were made in two substages: (1) the participators chose a location in two-dimensional space at the same time and independently; (2) having knowledge of their own and their opponent's location, the participants fixed the prices. In the second stage of the experiment (ST), the decisions were also made in two substages. The only difference was the location choice frequency, which was one choice for every four price decisions. In the third stage (TT), the decisions concerning prices and locations were made in the same substage. In this case, there are no Nash equilibria, which has been proved by Economides (1987). The results obtained by Mangani and Patelli show that theoretical predictions could not be confirmed. Participants chose locations near the centre with slight product differentiation, which, according to Mangani and Patelli, was caused by the participants' risk aversion. Participants provided the most demanded product types to minimise their market exclusion. The results did not reflect the existence of reliance between the product differentiation and the price. The price level was generally higher than predicted by the model, and even with zero product differentiation, it

[1] Kruse and Schenk (2000) performed a series of single-stage spacial experiments (with choice of location for products sold for fixed prices only) with two companies and flexible demand expressed by a line function. Model 2x2 results have been compared in which the participants chose between two options only (central vs. edge-based), with the, so called, complete model 100x100, in which each of the participants chose one of one hundred points signifying possible locations in the experiment with or without a communication option. The results showed that the tested persons recognized the optimal Pareto point, but they were not able to achieve it. It was much easier in the simplified version of the experiment (2x2 model), and it was even easier when the communication option was included.

did not reach the marginal cost level. A definite disadvantage of the research was the improper structure of the experiment. Successive research stages conducted together resulted in an inability to distinguish two overlapping effects that influenced participants' decisions: (i) increasing experience and (ii) changes in the tested environment. The experiment did not test the relationship between the space complexity and participants' decisions, which was the main goal of this study.

2. The model

We assume the K-dimensional company choice space, where each dimension length is identical and approaches l. The customers' preferences are distributed uniformly in the space. There are two companies in the market: 1 and 2, which offer products located at points defined as $x_1 = (x_{1,1}; x_{2,1}; \dots; x_{K,1})$ and $x_2 = (x_{1,2}; x_{2,2}; \dots; x_{K,2})$, respectively, where a particular companies point location is defined as the distance between $(0; 0; \dots; 0)$ and the point, whereas $x_{k,1} \in [0; l]$, $x_{k,2} \in [0; l]$, for $k = 1, \dots, K$. Without loss of generality, assume that $x_{k,1} \leq x_{k,2}$ for $k = 1, \dots, K$, i.e., we set the characteristics of the product offered by company 1 closer, or even identical, to the starting point of the product characteristics for the second company. The unit cost of buying a product different from the consumer's ideal choice comes to w_k and is proportional to the square of the distance between the perfect product and the one offered by a given company. The distance is defined as a second norm (Euclidean distance). Furthermore, it was assumed that a single product is produced at zero cost by each firm, each consumer buys only one unit, all consumers feel the same satisfaction from purchasing their perfect product ($k_j = k$ for each j), and the consumers show no preferences for particular companies.

The usefulness of the consumer located at point $z = (z_1; z_2; \dots; z_K)$ coming from purchasing company i product placed in point $x_i = (x_{1,i}; x_{2,i}; \dots; x_{K,i})$ can be defined as:

$$u_z^i = k_z - p_i - \sum_{k=1}^{K} w_k^2 (z_k - x_{k,i})^2 \tag{2.1}$$

where $k_z = k$ per each z - reservation price is equal for all consumers; p_i is the company i product price, where $i = 1,2$ - two companies in the market; K is the number of space dimensions; z is the analysed consumer's perfect product; x_i is location of the product offered by a company i; w_k is unit transportation (mismatch) cost; and $\sum_{k=1}^{K} w_k^2 (z_k - x_{k,i})^2$ is the total product transportation cost.

Indifferent consumers gaining equal utility from purchasing both product types results in the following equation:

$$p_1 + \sum_{k=1}^{K} w_k^2 (z_k - x_{k,1})^2 = p_2 + \sum_{k=1}^{K} w_k^2 (z_k - x_{k,2})^2 \tag{2.2}$$

Deriving z_K from the equation above, we obtain:

$$\hat{z}_K(z_1, z_2, \dots, z_{K-1}) = \frac{p_2 - p_1 + \sum_{k=1}^{K} w_k^2 ({x_{k,2}}^2 - {x_{k,1}}^2)}{2w_K^2 (x_{K,2} - x_{K,1})} - \frac{\sum_{k=1}^{K-1} w_k^2 (x_{k,2} - x_{k,1}) z_k}{w_K^2 (x_{K,2} - x_{K,1})} \tag{2.3}$$

Equation (2.3) describes indifferent consumer's location with an assumption that there are K-1 fixed characteristics and that only the K-th characteristic is variable. We then obtain a single point set. Generally, the space defining all indifferent customers is a point for a single-dimensional space, a straight line for a two-dimensional space, a plain for a three-dimensional space and a K-1 space for a K-dimensional space.

Knowing the indifferent consumer's location, we can determine the demand for particular goods:

$$D_1 = \int_{\{z: U_z^1 \geq U_z^2\}} g(z) dz = \int_0^l \int_0^l \dots \int_0^{\hat{z}_K} 1 dz_K dz_{K-1} \dots dz_1 = \int_0^l \dots \int_0^l \hat{z}_K(z_1; z_2; \dots; z_{K-1}) dz_{K-1} \dots dz_1$$

The outcome of this model is a subgame perfect Nash equilibrium (SPNE) for two stages: (1) in the first stage, companies simultaneously and independently of one another define their product's location; (2) in the second stage, while knowing the location of all the products sold in the market, companies assign their prices simultaneously and independently.

D'Aspremont C. J., Gabszewicz J., and Thisse J. F. (1979) demonstrated that in a single-dimensional model (section located) with square transportation costs, companies obtain profits when they provide spatially differentiated products in the market. The equilibrium principle of maximum product differentiation is satisfied, i.e., company 1 will provide product $\tilde{x}_1 = 0$, company 2: $\tilde{x}_2 = l$, and market prices will be equal: $\tilde{p}_1 = \tilde{p}_2 = w^2 l^2$. Companies share the market 50/50 and gain profits: $\tilde{\pi}_1 = \tilde{\pi}_2 = 0.5 w^2 l^3$.

Tabuchi (1994) performed an equilibria analysis in two-dimensional space, and Irmen and Thisse (1998) performed this analysis in multi-dimensional space. In the equilibrium model, in a space with more than one dimension, companies will only maximally differentiate their products in one dimension, providing homogenous goods in all other aspects. Irmen and Thisse (1998) proved that if all of the characteristics have similar significance, the model of K-dimensional space has K location equilibria in the form of: $\tilde{x}_1 = \left(\frac{1}{2}; \dots; 0; \dots; \frac{1}{2}\right)$ and $\tilde{x}_2 = \left(\frac{1}{2}; \dots; 1; \dots; \frac{1}{2}\right)$, in which companies differentiate their products in dimension $k = 1, \dots, K$ and provide homogeneous products in the remaining K-1 dimensions. However, if those characteristics are identical, $\text{i.e.}, w_1 = w_2 = \dots = w_K$, all SPNE market prices are equal: $\tilde{p}_1 = \tilde{p}_2 = w^2 l^2$, and companies equally share the market and profits: $\tilde{\pi}_1 = \tilde{\pi}_2 = 0.5 w^2 l^3$, which are equal as in single- and two-dimensional space models.

3. Experiment design

The experiment was performed in sessions, which differed based on company choice space (single or bi-dimensional) and the price decision mechanisms (price level was assigned automatically or by the participants). The remaining parameters of the model were the same in all of the sessions. We assumed that the unit product transportation cost in each dimension comes to $w = \sqrt{20}$ and is proportional to the square of distance between the perfect product and a product offered by a given company, the length of each dimension is equal to $l = 1$, the customers' preferences are distributed uniformly in the space, consumers present perfectly inelastic unit demand (reservation price $k = 40$), and there are only two companies in the market, each one producing only one type of product with 0 production costs. Decisions were made in two stages. In the first stage the participants, simultaneously and independently defined their products' characteristics. Participants could exchange messages concerning product location in the market. The message content was strictly defined, and there was no possibility for any other communication. This communication limit was used to eliminate coordination problems. In the second stage, having learned all of the products' characteristics, the participants simultaneously and independently one from another assigned prices to the products.

Three experimental sessions were conducted, each one with different model complexity. In session 1, the only decision variable was the location in a single dimension. In session 2, the participants defined the levels of two variables – location and price. In session 3, there were three decision variables – two location dimensions and product price. In the first experimental session, the company choice space was single-dimensional and consisted of 101 location fields (between 0 and 100). The experiment participants made location choices, and prices were assigned automatically by the computer program according to the best response procedure used in the Nash equilibrium price subgame.[2] In the second experimental session, the company choice space remained single-dimensional and consisted of 101 location fields (between 0 and 100). In this session, the participants made both location and (later) price level decisions. In the third session, the choice space was two-dimensional and consisted of 101*101 location fields (between 0 and 100 in each dimension). The participants made both location and price level decisions, just as in session 2.

The participants' registration of their choices was performed online with ORSEE software. Over 90% of the participants were students of Warsaw University, 33% (total) were students of the Department Faculty of Economy Sciences, 17% were students of the Faculty of Journalism and Political Science, 13% were students of the Faculty of Law and Administration, and 9% were students of the Faculty of Philosophy and Sociology. Women constituted 56% of the participants, and the remaining 44% were men. Participants were between 19 and 26 years old, and the average age was 22. The total number of research participants was 90 persons, including 36 in the first session (divided into 4 groups), 28 in the second session (in 3 groups), and 26 in the third session (in 3 groups). The entire study lasted approximately 50 minutes. The decisions were made anonymously. All of the sessions proceeded according to the following schedule: the participants had 15 minutes to familiarise themselves with printed instructions, and simultaneously, to improve their comprehension of

[2] The precise instructions were the following: *Decisions about the price level for both you and another participant's product is made by the "Assistant" program. This program assigns the best prices to products based on profit maximization, i.e., your product price, compared to the price of the other product. The other participant's product price maximizes his profits compared to your product price. In summary, the "Assistant" chooses the price that is the best response (in both products locations given) to the price expected from the second player. The "Assistant" determines the potential prices of this equilibrium model (Nash equilibrium).*

the profit calculation mechanism, they could train their decisions on a simulator on which they were informed about profits and shares in the market after having been given the location and price of the products of each company. The experiment was performed using specially designed software based on the LabSEE platform.[3]

All of the sessions consisted of 30 stages with three trial stages at the beginning. The number of stages was not revealed to the participants to eliminate the final stage effect. During each stage, a random selection of participants took place, and the participants were joined in pairs. The pairs were switched to prevent reputation development and to ensure that the participants' decisions were independent from the other player's previous decisions. The first experimental session was extended with an additional 10 stages based on the second session rules, and these additional stages were performed immediately after the 30 regular stages in the first environment. At the end of the experiment, the participants were given short surveys with brief questions about their age, sex, course of study, faculty and number of economics semesters passed.

Payment of participants was proportional to their results in the experiment. An "Experimental dollar" unit had a value equal to 10 Polish Groszy (1ED=0.1PLN). Average remuneration was 24 PLN (minimal remuneration was 16 PLN, and the maximal was 38). The payments were made directly after the experiment termination.

4. Research hypotheses and theoretical predictions

According to predictions resulting from the theoretical models, the companies should differentiate their products in one dimension only, providing a homogeneous product in the second characteristic if it exists. In the first and second session, according to the SPNE, one of the companies should locate its product at the 0 point, while the second should locate its product at the 100 point; the product prices should come to $\tilde{p}_1 = \tilde{p}_2 = 20$; market shares should be 50% for each participant; and profits should be $\tilde{\pi}_1 = \tilde{\pi}_2 = 10$. In the third session, the products should be located in the middle of the opposite sides, and prices, market shares and company profits will be the same as in the previous sessions. According to theoretical predictions, **the companies are unable to increase their profits by differentiating the product they offer in more than one characteristic**. In market practice however, companies provide multidimensionally differentiated products, but the differences between the accessible products in each characteristic are insignificant. Furthermore, such multidimensional, illusionary differentiation can help to decrease price competition between companies, creating an impression among customers that the products are unique and have no substitutes.

The main hypothesis of this study was consistent with market observations: ***Increasing the dimension number of company choice space results in reduction of product differentiation and price competition limiting. Companies strive to create many dimensions of differentiation to increase their profits.***

[3] LabSEE – is a platform for performing economic experiments that is used by the Experimental Economy Laboratory FES WU. For decision mapping purposes, the special graphic design has been prepared – see appendix 1.

The verification of this hypothesis is described in section 5 based on four sub-hypotheses:

H1: In the complex structure model, the participants do not use the equilibrium strategies. Companies provide products differentiated similarly in all of the dimensions into the market instead of single-dimensional differentiation, as occurs according to theory.

H2: Increasing model complexity results in lower product differentiation and irrevocable social loss (product transportation cost increase).

H3: Increasing model complexity results in market price growth and decline of consumer surplus.

H4: Increasing model complexity results in company profit growth.

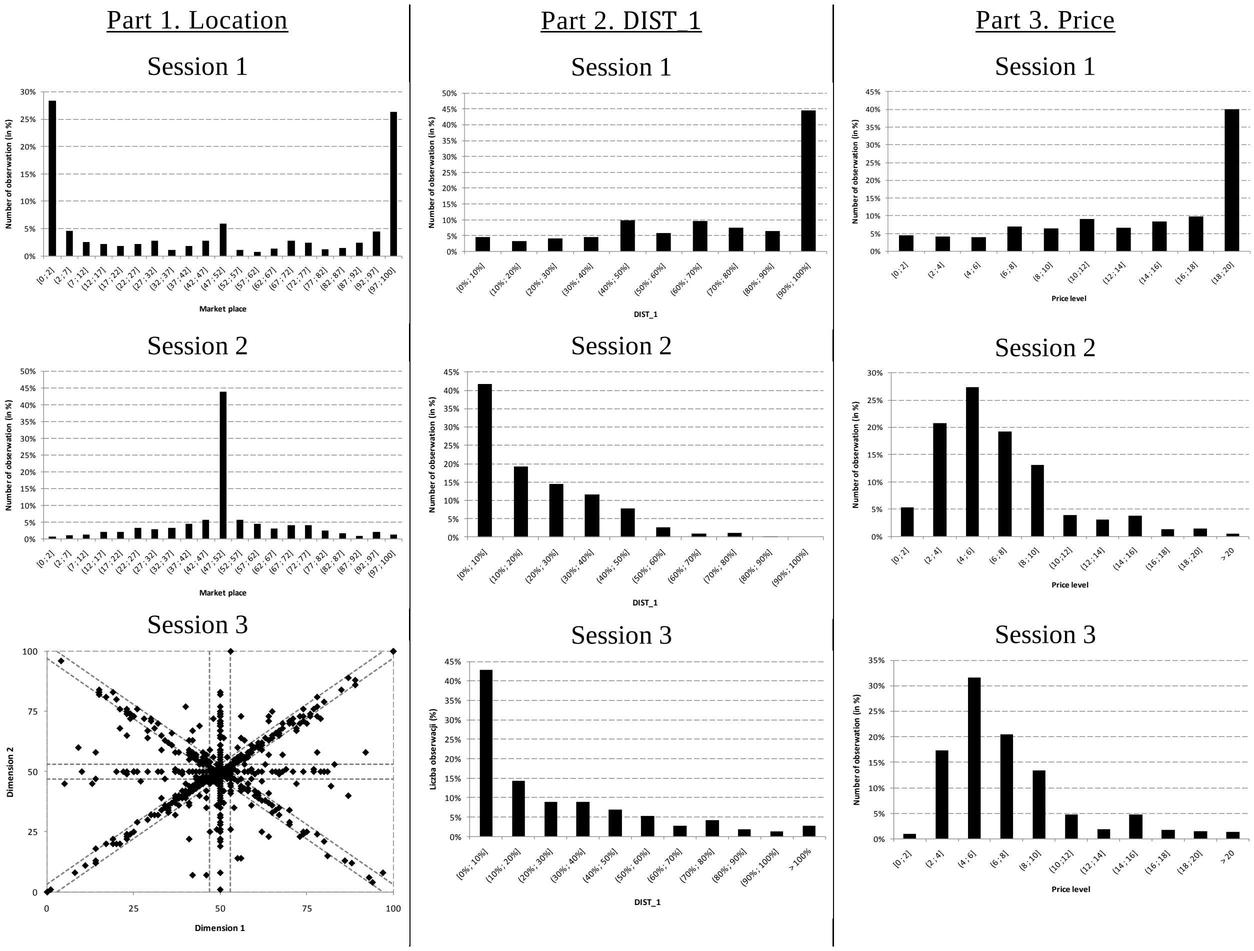
Verification of the presented hypothesis is significant; economists engaged in the subject of spatial product differentiation concentrate on differentiation determinants, pointing out that assumptions made in the basic model flatten the structure of competing companies excessively. The models that are emerging are, however, very mathematically complex, and it seems impossible to find any equilibria in a general model that could describe reality in a proper way. From the predictions of theoretical models, the multidimensional choice space reveals that companies will maximally differentiate their products in one characteristic only, producing homogeneous products in all remaining dimensions. Empirical verification of the hypothesis would mean that the theoretical predictions cannot be confirmed in the real world, mainly because of the assumptions guiding the decision mechanisms used by the participants and not because of assumptions about the individuals functioning in the market.

5. The experiment results

A preliminary illustration of the data is given in Fig. 1 (Part 1). The products' location frequency in a particular space in the experimental sessions is presented. In session 1, the edge locations prevailed (54.63% edge locations, with only 5.93% locations in centre), whereas in the remaining sessions, the majority of the products were located near to centre (in session 2, 1.90% of locations were at the edge, with 43.93% of locations in the centre, and in session 3, 0.26% of locations were to the side of the centre, with 39.1% of locations in the centre). Furthermore, in session 3, except for the centralised locations, the diagonal product locations prevailed (33.46%), with the same products on the straight lines joining the centres of the opposite sides (22.82%).[4] These observations indicate, that in sessions 2 and 3, the theoretical predictions were not confirmed.

[4] All of the results define the percentage of observations that were no more than 2% of maximum distance from the point indicated. The 3rd part of the drawing 5.1 shows the areas around the diagonal and straight lines joining the centers of the opposite sides.

Fig. 1 Products location, differentiation and price in experimental sessions.



Products differentiation

According to hypothesis H2, increasing model complexity results in lower product differentiation. To verify this result, indexes have been calculated that measure the distance between the location of the products and the Nash equilibrium locations:

$$DIST\_1 = \frac{\Delta x\_1}{\widetilde{\Delta x\_1}} \tag{5.1}$$

where: $\widetilde{\Delta x\_1} = \left(\sum_{k=1}^{K}\left(\tilde{x}_{k,2} - \tilde{x}_{k,1}\right)^2\right)^{0,5}$ is the distance between company i product and the central point in the Nash equilibrium model and $\Delta x\_1 = \left(\sum_{k=1}^{K}\left(x_{k,2} - x_{k,1}\right)^2\right)^{0,5}$ is the actual distance from that point, whereas K is the location's dimension number (K=1 in session 1 and 2, K=2 in session 3). Index $DIST\_1$ is explained as the percentage of product differentiation in relation to equilibrium differentiation. It takes values between 0 and 1 (in sessions 1 and 2) or $\sqrt{2}$ (in session 3).

Average product differentiation was definitely higher in session 1 than in the remaining sessions, which is confirmed by the $DIST\_1$ - average (session 1: 73%, session 2: 19%, session 3: 22%), and median (respectively: 84%, 15%, 18%). The product differentiation layout spread was the largest in the first session, which is shown by the absolute differentiation measure (the distances between third and first quartile came to 50%, 26%, and

26%, respectively). Because of significant difference in average values between experiment 1 and the remaining experiments, relative differentiation measures indicate the opposite relationship (proportion of distances between the quartiles and the median comes to 56%, 173%, and 144%, respectively). The statistical density $DIST\_1$ in each session is shown by Fig. 1 (Part 2).

Both the Kolmogorov-Smirnov and U Mann-Whitney test demonstrated the significant differences between the $DIST\_1$ statistical distribution in session 1 and in the remaining session.[5] Hypothesis H2, stating that growing model complexity results in a decrease in product differentiation, has been partially confirmed. Surprisingly, increases in double decision variables resulted in inversion of the complete product differentiation layout. However, adding the next decision variable caused relatively small changes.

Market prices

According to the theoretical predictions, there is a positive relationship between the product differentiation level and the market price level. Therefore, in session 1, the highest prices are to be expected. However, the price competition level in sessions 2 and 3 could be lower than the theoretical predictions, which is indicated in hypothesis H3. Such a situation might explain the lesser product differentiation in these cases. The experimental results, however, show that in session 1, in which the prices were determined automatically by the computer program, they were almost two times higher than in sessions 2 and 3 (the average price in the following sessions came to 14.55, 7.02, and 7.53), which is shown in Fig. 1 (Part 3). In session 1, the prices were usually placed at a level between 18-20 (approximately 40% of observations), whereas in experiments 2 and 3, prices between 2 and 10 prevailed (approximately 80% of observations). The tests performed prove the statistical significance of the differences of the price level between the experimental session 1 and the remaining prices.[6] Therefore, hypothesis H3, stating that growing model complexity results in market price increases, has been rejected.

The obtained result is rather surprising. It shows that during the sessions, when the participants defined their products prices themselves, the price competition was stronger than could be deducted from the Nash equilibrium. The results of economic experiments usually indicate the opposite situation – the participants cooperate with each other, pacifying the price competition and gaining higher profits than in the competition equilibrium. In this case, the competition was greater than in competition equilibrium, in which the result was a lower profit level.

Company profits

In the analysed model, the companies' profits were determined by the price and location decisions. As the price level was the highest in session 1 and the lowest in session 2, similar relationships were found in the companies' profits – the average prices in sessions 1, 2 and 3

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[5] The test statistics comparing sessions: 1 to 2 and 1 to 3 were D=0.719 and D=0.677, respectively, in the K-S test, and to Z=31.452 and Z=29.559, respectively, in the M-W test.
[6] Test statistics comparing the sessions: 1 to 2 and 1 to 3 were D=0.624 and D=0.603, respectively, in the K-S test and to Z=25.232 and Z=23.45, respectively, in the M-W test.

were 7.31, 2.82, and 3.21, respectively. The tests performed confirm the statistical significance of profit level differences between experimental session 1 and the other sessions.[7] Hypothesis H4, stating that increasing model complexity results in profit gains by companies, has been rejected. Admittedly, the profits in session 3 were higher than in session 2; yet, the difference was relatively small, and the highest profits were gained by the participants of session 1, in which the model complexity was the smallest.

To summarise the analysis, the hypothesis states that increasing the number of dimensions in the companies choice space causes lower product differentiation with simultaneous limiting of price competition. It is possible that the increase of the model complexity will be gradual as new decision variables are introduced. However, it appeared that introducing a second decision variable only (level of prices) caused a complete change in the participants' decision process, which was reflected by completely inverted market prices and the spatial differentiation of products in the comparable models. Adding the decision space dimensions of another company resulted in relatively insignificant changes.

6. Assessment of the discrepancy between the empirical results and the theoretical predictions

In this section, we attempt to provide an explanation for the discrepancies between the results of the experiment and the hypothesis and the theoretical predictions that were made. The aim of this analysis is also to explain the decision processes used by the participants in the experimental sessions.

Decisions coordination problems

The basic reason for the failure of the theoretical predictions in reality could be problems with the coordination of decisions made by the participants.[8] To provide a diversified product, the participants had to choose its type – closer to the left or to the right edge of the area. Lack of decision coordination results in peripheral types of simultaneous choices that have no large differences between each other. This trend was the motivation for introducing limited communication into the test. However, even in this case, the participants can use a strategy based on maximisation of demand, which is reflected in the choice to locate one product next to another based on the central type. We can then propose the following hypothesis:

H5: Coordination problems affected the location decisions.

When analysing product differentiation, we must note that the participants cannot define the product differentiation level directly, as they have no influence on the other participants' decision. The participants only decided their product location, which can be described as the distance from the centre in proportion with the distance in Nash equilibrium, which means:

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[7] Test statistics comparing the sessions: 1 to 2 and 1 to 3 were D=0.612 and D=0.573, respectively, in the K-S test and Z=26.799 and Z=24.494, respectively, in the M-W test.

[8] Coordination problems in product differentiation models were subjects of research of Brown-Kruse, Cronshaw and Schenk (1993).

$$DIST\_2 = \frac{\Delta x\_2}{\Delta \widetilde{x\_2}} \tag{6.1}$$

where: $\Delta \widetilde{x\_2} = \left(\sum_{k=1}^{K}\left(\tilde{x}_{k,i} - 50\right)^2\right)^{0,5}$ is the distance of i company product in the Nash equilibrium from the central point, $\Delta x\_2 = \left(\sum_{k=1}^{K}\left(x_{k,i} - 50\right)^2\right)^{0,5}$ is the actual distance from this point, and K is the location's dimension quantity (K=1 in session 1 and 2, K=2 in session 3). $DIST\_2$ is explained as a per cent of the product distance from the centre area regarding the location in the Nash equilibrium. It takes values between 0 and 1 (in session 1 and 2) or $\sqrt{2}$ (in session 3). A value below 1 means that the product's distance from the centre is lower than it would be based on theoretical predictions.

In practice, the $DIST\_2$ statistics layout may differ from the $DIST\_1$ statistics layout (the distribution of product distances in relation to the central type may differ from the product differentiation layout). To compare them, a coordination measure formula has been created:

$$COOR = \frac{DIST\_1}{DIST\_2} \tag{6.2}$$

The $COOR$ statistic measures the distance between companies as a proportion of distance from the centre – expressed as a percentage of the equilibrium. It takes values between 0 and 1 $[0;1]$, where 0 indicates the complete lack of coordination, and 1 indicates complete coordination. For $COOR = 1$, all locations are symmetric towards the centre of the area, and for $COOR = 1$, the products are located toward one side of the market.

The coordination of location decisions in all of the sessions was high and had no inner significant differences (the average values were 94% in the first session and 88% in the other sessions). This result means that the coordination problems did not cause failure of the theoretical predictions concerning the spatial product differentiation. Moreover, they cannot be the basis for explaining the differences in the decisions made by the participants in the successive experimental sessions. The basic statistic describing the distance between products and the centre ($DIST\_1$) are close to the product differentiation statistic ($DIST\_2$) – the average values in the successive sessions were 77%, 23% and 26%, respectively, and the median values were 98%, 10%, and 15%, respectively. Both the Kolmogorov-Smirnov and U Mann-Whitney test demonstrated the significant differences between the $DIST\_2$ statistical distribution in session 1 and in the remaining session.[9] We confirmed that the coordination problems were not responsible for the results, which means that hypothesis H5 has been rejected.

Lack of experience

Another problem that often occurs during the experimental research is the participants' lack of experience. We can give the following hypothesis:

H6: The participants are characterised by lack of experience.

[9] Test statistics comparing sessions 1 with 2 and 1 with 3 were D=0.613 and D=0.619, respectively, in the K-S test and Z=28.817 and Z=26.667, respectively, in the M-W test.

The verification of this hypothesis can be performed in two ways. On the one hand, we can determine if the decisions made in successive stages had higher stability and came closer to the theoretical equilibrium, according to the following hypothesis:

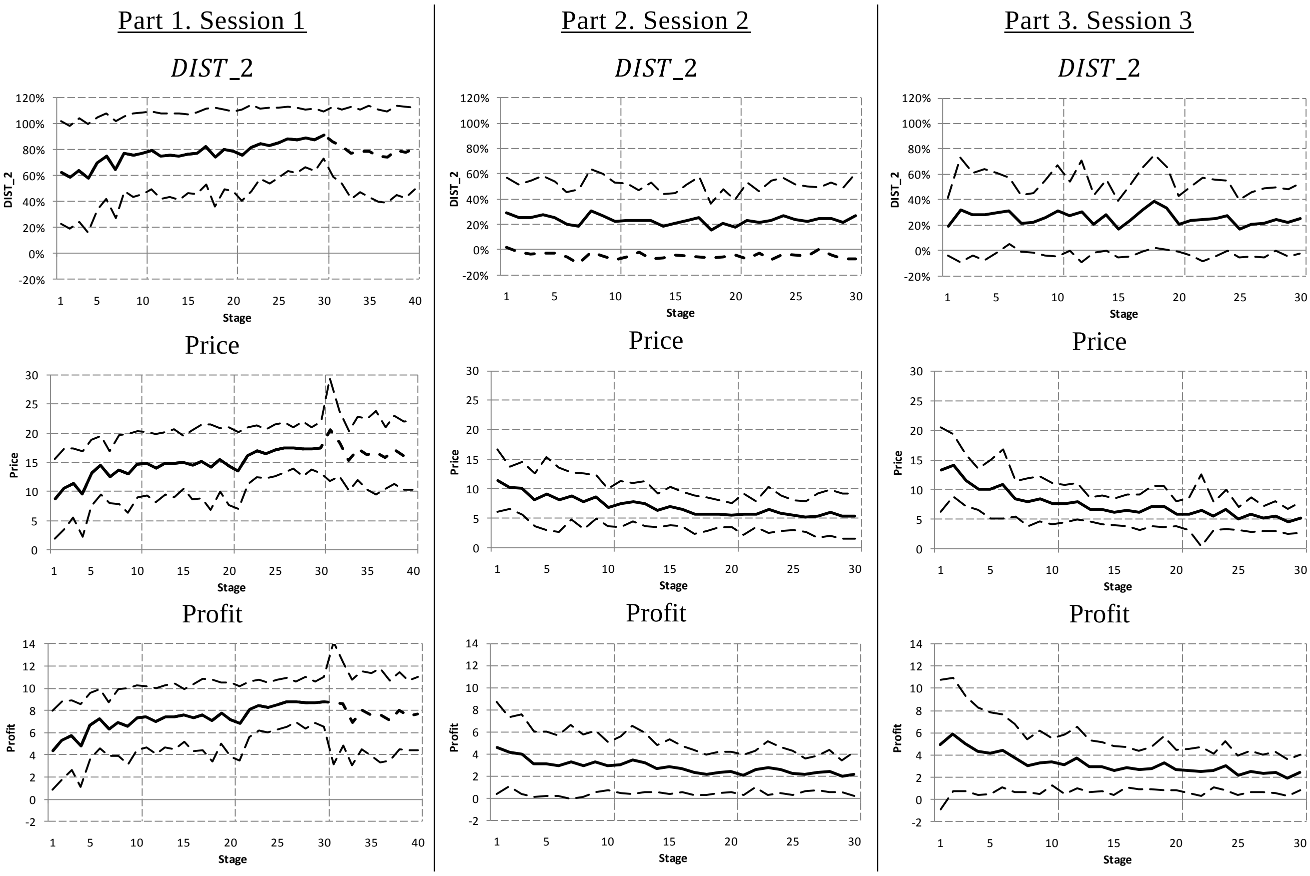
H6_1: There is convergence of stabilisation points in the successive stages.

On the other hand, we can determine whether the participants who were economics students and had finished courses in this field (the students who should have wider knowledge of the theoretical equilibrium) behave in a different way than the individuals with no such skills. The following hypothesis is proposed to describe this situation:

H6_2: The economics students, who have finished basic courses in microeconomics, use strategies closer to equilibrium, which helps them to gain higher profits than the students of other sciences, who lack knowledge in economics.

The first experimental session was performed in 40 stages. In stages 1-30 the participants decided only on the location of the product in single-dimensional space, whereas in stages 31-40, they decided on the price level as well. Fig. 2 presents the distances from the area centre ($DIST\_2$ statistics), the prices and the profits for successive stages in individual experimental sessions. The average values have been connected by thick lines, and the variability range is indicated with dashed lines (average plus/minus standard deviation).

Fig. 2 Average variable values and variability ranges in successive stages.



In session 1 (Fig. 2 part 1), the $DIST\_2$ statistic growth is seen from approximately 60% in the first stages to approximately 90% of the distance in the Nash equilibrium at stage 30. This variable had a large standard deviation, which was considerably decreased in successive stages (the variability coefficient dropped from approximately 70% in the first stages to approximately 20% in stage 30). This result indicates that there was initially a large discrepancy between the strategies used by the individual players. However, it dropped successively during the test. In stage 31, the experimental environment had been changed, which did not have any radical impact on the location of the products in relation to the central area. Nevertheless, the growth tendency was stopped. After a gradual decrease in the value of the $DIST\_2$ statistic to the level of approximately 80% in stages 31-33, the results stabilised until the final stage. This change also caused the used strategic differentiation, which is seen in the increase in the variability coefficient from 20% in stage 30 to approximately 40% in the last stages. Similar tendencies were also seen in the products prices and profits. Both variables demonstrated an increasing tendency (average prices: 8.7 – in stage 1, 17.5 – in stage 30 and average profits: 4.4 – in stage 1, 8.7 – in stage 30) and were highly, but decreasingly variable (from approximately 80% – in stage 1 to approximately 25% – in round 30). In round 31, the increasing tendencies of the statistics were stabilised at approximately 16.5 for prices and approximately 8 for profits, with variability coefficients of approximately 40%.

The second experimental session differed significantly from session 1, which can be seen in Fig. 2 (Part 2). The product location, in relation to the central location, changed slightly in the next stages and came to approximately 25% of the Nash equilibrium distance. This variable demonstrated a high standard deviation. The variability range came to approximately 120% and did not change significantly during the experiment, which could be caused by the large differentiation of the location strategies used by the participants. Both prices and profits demonstrated decreasing tendencies. The prices dropped from approximately 11 in stage 1 to approximately 5.5 in stages 17-30, and profits decreased from approximately 4.5 in stage 1 to 2.2 in stages 17-30. The differentiation of both variables decreased during the test. The standard deviation of prices decreased from approximately 5 to 3 in the final stages, and the standard deviation of profits decreased from 4 to approximately 1.7. This result demonstrates that there was a learning process in the first experimental stages. However, the decrease in absolute variability partially resulted from the decrease of the average variable values, as can be seen in the variability coefficient, which oscillated throughout the entire experiment around the value of approximately 60% for prices and approximately 80% for profits.

The 3rd experimental session was similar to session 2, which is shown in Fig. 2 (Part 3). The $DIST\_2$ statistic oscillated between 20% and 30% and was highly variable throughout the testing period (the variability coefficient was approximately 120%). Prices and profits demonstrated a decreasing tendency. In the first stages, the values were approximately 14 for prices and approximately 5 for profits, whereas in the second part of experiment, they stabilised at approximately 5.5 for prices and 2.3 for profits. The variability coefficient throughout most of the stages was approximately 45% for prices and approximately 70% for profits.

The analysis shows that in all sessions, the participants were learning. The points of stabilisation for prices and profits can be seen, and the variable levels approached these points in successive stages. The points differ, however, between session 1 and the remaining sessions. A different trend was observed in the $DIST\_2$ statistic. In the first session, this value grew in the successive stages, reaching over 90%, whereas in the second and third session, it oscillated between 20% and 30%. Still, the difference in the $DIST\_2$ statistic values from the first stages of session 1 and the remaining stages is worth mentioning. This difference results from the fact that before the main experiment had started, the participants had time to learn the instructions and could train their decisions on the simulator. This process clearly helped the session 1 participants to better understand the relationships between the type of products and the profits, which resulted in choosing more peripheral locations from the first paid stage.

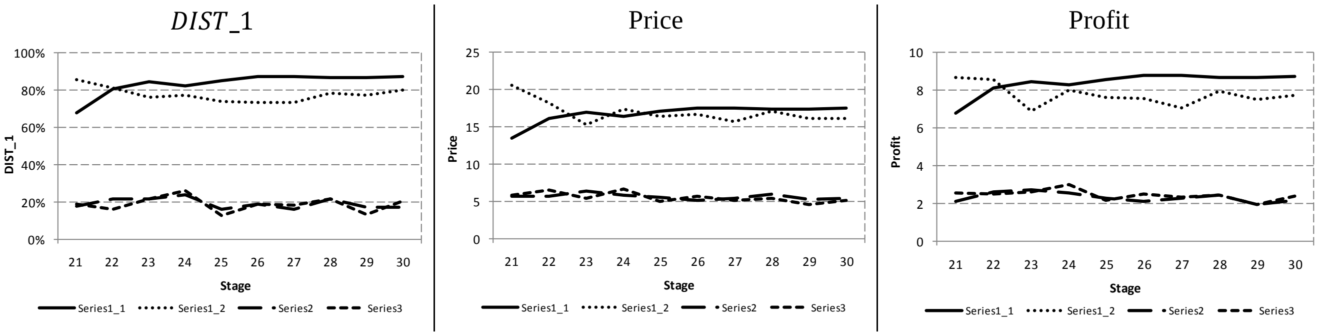
The evaluate hypothesis H6_1, the test period was divided into three parts consisting of equal numbers of stages. The decision variables in the first and last 10 stages were confirmed. Two non-parametric tests for indirect tests were performed – the Wilcoxon Test and the Sign Test, which showed that in the 1st experimental session, location and price decisions changed, whereas in the remaining sessions, only the changes in the price decisions were statistically significant.[10] Therefore, hypothesis H6_1, stating that there is a convergence to the stabilisation points in the successive stages, has been then confirmed.

Positive verification of the H6_1 hypothesis means that when comparing individual experimental sessions, it is not necessary to review all of the stages. Instead, stages after stabilisation should be selected, which includes only last 10 stages. However, it is necessary to repeat the comparative analysis of the results obtained in individual experimental sessions in the last 10 stages to evaluate the main research hypotheses, including: H2-H4.

Verification of hypotheses H2-H4 for results obtained in the last 10 stages

Fig. 3 demonstrates $DIST\_1$ statistics, prices and profits in subsequent stages in all experimental sessions. Experiment Series1_1 shows the results of session 1 stages 21-30, with automatic price fixing, and Series1_2 shows the results of session 1 stages 31-40, with prices fixed by the participants.

Fig. 3 Average product differentiation and company prices and profits in the last 10 stages in individual experimental sessions.



[10] The test statistics comparing the $DIST\_2$ statistic differences in subsequent sessions were Z=3.61, Z=0.841 and Z=1.003, respectively, in the Wilcoxon Test and Z=2.739, Z=1.155 and Z=0.981, respectively, in the Sign Test. The tests statistics that compare the differences in prices in successive sessions were Z=5.122, Z=4.554 and Z=4.457, respectively, in the Wilcoxon Test and Z=5.5, Z=4.725 and Z=4.903, respectively, in the Sign Test.

In Fig. 3, an almost identical $DIST\_1$ variable course is seen in the successive stages of sessions 2 and 3 (Series2 and Series3, respectively). The product differentiation was larger in session 1, both in the case of automatic price regulation and when price was a decision variable. We note that the $DIST\_1$ variable value is smaller in the second case; however, it is nearly four times larger than in session 2 (approximately 80% for the series1_2, with approximately 20% for series2). This result is surprising, as the experiment environment in both cases was identical. The only difference was the experience gained by the participants in the previous stages. The session 1 participants had continuous access to the previous sessions' results records (played with the "Assistant"), which indicated the most profitable strategies based on higher product differentiation. The results from Series2 revealed slight product differentiation. Moreover, in session 1, after introduction of the second decision variable (price), variability increased (the difference between the third and first quartile grew from 26% to 44%), and the average value decreased (the average dropped from 84% to 78%, and the median dropped from 96% to 90%). The experiments performed have shown that the product differentiation layouts did not differ statistically in Series2 and Series3, and the remaining differences were statistically significant.[11] Therefore, the H2 hypothesis stating that increasing model complexity results in a decrease in product differentiation was partially confirmed. The increase in the number of decision variables from one to two caused an increase in model complexity when successive space dimensions were added with no statistically significant changes.

The average prices value in subsequent stages of all experimental sessions is shown in Fig. 3. As for product differentiation, in Series2 and Series3, the prices were defined at a very similar level and were approximately 5,6. In session 1, the price level was approximately three times higher. The price release (Series2) caused a brief growth to a level exceeding the value caused by the Nash equilibrium for maximum product differentiation (the prices were over 20). The competition between the companies caused the market prices to decrease in successive stages, which eventually stabilised at a level slightly lower than in the first part of session 1 (Series1_1) – approximately 16.5. Moreover, the market prices from session 1, in the Series1_1 and Series1_2, have similar average values (16.75 and 16.97, respectively). This variable distribution remained scattered – 25% of the prices in part 2 were over 20, whereas in part 1, there was no such observation. These conclusions are confirmed by the test results[12], which showed a lack of differences between the prices in Series2 and Series3. The U Mann-Whitney test showed a lack of differences between Series1_1 and Series1_2. This test verifies the null hypothesis, showing a lack of significant difference between the arithmetic averages. The most suitable explanation seems to be, however, the results of the Kolmogarov-Smirnov test, which evaluates the zero hypothesis and states that the accumulated frequency layouts of

[11] Test statistics in the K-S test were D=0.133 (comparing Series1_1 and 1_2), D=0.808 (Series1_1 of 2), D=0.816 (Series 1_1 of 3), D=0.77 (Series 1_2 of 2), D=0.791 (Series1_2 of 3) and D=-0.064 (Series2 of 3). The statistics in the M-W test were Z=2.876 (comparing Series1_1 and 1_2), Z=20.463 (Series1_1 and 2), Z=20.112 (Series1_1 with 3), Z=19.444 (Series1_2 with 2), Z=19.125 (Series1_2 with 3) and Z=-0.025 (Series2 with 3).

[12] The statistics in the K-S test were D=0.172 (comparing the Series1_1 with 1_2), D=0.816 (Series1_1 with 2), D=0.838 (Series1_1 with 3), D=0.789 (Series1_2 with 2), D=0.812 (Series1_2 with 3) and D=-0.077 (Series2 of 3). The statistics from the M-W test were Z=1.164 (with comparison between Series1_1 and 1_2), Z=19.477 (Series1_1 and 2), Z=19.402 (Series1_1 and 3), Z=19.363 (Series1_2 and 2), Z=19.363 (Series1_2 and 3) and Z=0.017 (Series2 and 3).

comparable variables do not differ significantly from each other. It not only compares the average but also the entire layout. This test revealed that differences between the market prices in Series1_1 and Series1_2 are statistically relevant. Therefore, hypothesis H3, stating that increasing model complexity results in market price increases, has been rejected. Similarly, hypothesis H4, which stated that increasing model complexity causes profit growth, has also been rejected. The layout of profits obtained by the participants is not relevantly diversified in Series2 and Series3, in which they were definitely lower than in both parts of session 1. The profits in Series1_2, i.e., after the prices release, were statistically lower than before the release (Series1_1).[13]

The results obtained in this study can be compared to a real situation. In the experiment, the sessions can be divided into two types. The first type consisted of sessions 2 and 3, in which the participants had to make their price and location decisions by themselves. Not knowing the theoretical premises, they chose low-risk strategies, diversifying their products to a small extent. This process helped the participants gain positive profits, although the profits were lower than the potentially attainable profits if the full market potential was used. In the second type of session, there was the first experimental session, in which the participants were familiarised with the simulator for first 30 stages, making the decisions simpler and their consequences more predictable. In Series1_2, the participants had the option to use the experience they had gained. This allowed them to gain higher profits than in the Series2 and Series3. The use of the "Assistant" to define price levels played the role of a market simulator, which helped to predict the results of the decisions made regarding the introduction of a given product type into the market and then resulted in higher profits.

It is interesting to determine if the decisions made by the participants were influenced by their lack of experience and knowledge of the mechanism by which the profits were calculated in the experiment. To explain this observation, hypothesis H6_2, stating that the economics students who have completed microeconomics courses will use strategies closer to the equilibrium model than students of other sciences, which will result in higher profits, has been verified. At the end of the experiment, the participants were given a short survey, which they were asked to complete, e.g. the number of economic courses having passed. It was beneficial to divide the participants into two groups. The first one (Group1) was comprised of economics students who had completed at least two semesters of economic studies. Those students had attended e.g. microeconomics courses in which the Nash equilibrium was taught and the basic Hotelling product spatial differentiation model was explained. The second group (Group2) was comprised of non-economics students, having passed no more than one semester of economics.

The test results (appendix 2) show that in Series1_1 and Series1_2, there were no significant differences in product differentiation, prices and profits between the groups. In Series2, the

[13] The statistics in the K-S test were D=0.228 (with comparison between Series1_1 and 1_2), D=0.814 (Series1_1 and 2), D=0.809 (Series1_1 and 3), D=0.695 (Series1_2 and 2), D=0.69 (Series1_2 and 3) and D=-0.076 (Series2 and 3). The test statistics in the M-W test were Z=4.179 (comparing to Series1_1 and 1_2), Z=19.818 (Series1_1 and 2), Z=19.333 (Series1_1 and 3), Z=16.797 (Series1_2 and 2), Z=16.26 (Series1_2 and 3) and Z=-0.907 (Series2 and 3).

participants with greater knowledge in economics set their prices at a statistically lower level than the participants without an economics education, and in Series3, the participants from Group1 provided less diversified products to the market, choosing locations nearer to the centre of the area, than the Group2 participants. However, there were no relevant statistical differences in the obtained profits. This result means that the theoretical knowledge had a rather small influence on the participants' location-price strategies. This aspect does not explain any discrepancies between theoretical predictions and empirical results. Therefore, hypothesis H6_2 has been then rejected.

Motivational determinants of risk

Hypothesis H6_1, which defined the product convergence through stabilisation points at subsequent stages, was verified, and it was confirmed that there is a large difference between the location strategies used by participants in Series2 and 3. It is possible that the choice of product types away from the centre brought higher profits, which also bore higher risk (variability). In this case, the decisions made could be based on risk aversion. Therefore, we propose the following hypothesis:

H7: Risk aversion determines the location strategies. The participants with lower risk aversion (or risk loving) produce more differentiated product types than the ones with higher risk aversion.

To evaluate this hypothesis, the participants from all of the experimental sessions were divided into the three groups with respect to average product distance from the centre of the area (statistics $DIST\_1$). Approximately 1/3 of the participants (33% in Series1_1 and Series1_2, 32% in Series2 and 31% in Series3) with the highest average composed the group: MAX_{DIST}, the same number of participants with the lowest average composed the group: MIN_{DIST}, and the remaining participants found themselves in the group: $REST$. Then, the prices, demands and profits from both extremes were compared. The results demonstrate the large discrepancy between the product location strategies used by the participants in the individual groups. In the group MAX_{DIST}, the average distances from the central type were 100% in Series1_1, 99% in Series1_2, 43% in Series2 and 47% in Series3, whereas in the group MIN_{DIST}, the averages were 62% in Series1_1, 52% in Series1_2, 5% in Series2 and 7% in Series3. The prices, demands and profits in successive experimental sessions are shown in table 1.

Tab.1 Prices, demands and profits divided into the groups MAX_{DIST} and MIN_{DIST} in successive sessions.

		Price		Demand		Profit	
		MAX_{DIST}	MIN_{DIST}	MAX_{DIST}	MIN_{DIST}	MAX_{DIST}	MIN_{DIST}
Series1_1	Average	19.51	14.00	49.65	51.83	9.72	7.22
	StDev	2.31	4.95	1.73	4.44	1.25	2.52
Series1_2	Average	19.05	14.84	45.01	57.31	8.18	7.52
	StDev	5.37	6.69	19.98	27.17	3.77	3.81
Series2	Average	6.99	4.68	47.17	51.89	2.67	2.10
	StDev	4.09	2.49	34.04	36.51	2.12	1.63
Series3	Average	7.64	4.19	39.20	57.21	2.70	2.28
	StDev	4.35	1.49	31.22	36.65	2.31	1.61

In table 1, we can see that in all of the experimental sessions, the profits gained by the participants who located their products far from the centre (group MAX_{DIST}) were higher in general than the profits of participants who chose the location closer to centre (group MIN_{DIST}). Moreover, in Series1_1 and Series1_2, the strategies based on higher product differentiation were less risky, which is demonstrated by the lower standard deviation of the profits. In those experiments, the atypical products were more profitable regardless of the risk aversion of participants. In Series2 and Series3, the wider product differentiation was connected with higher risk (larger standard deviation), which confirms the hypothesis. However, in the sessions with more complex space, the differences in profits between the groups are statistically irrelevant (appendix 3). Therefore, hypothesis H7 has been rejected.

Low price elasticity of demand equalises the opposite effects of demand and price

According to theory, in the spatial models, companies are under the influence of two opposite forces: centripetal force evoked by the demand effect and centrifugal force resulting from the price effect. On the one hand, companies increase their markets shares by launching popular goods and services. On the other hand, these products have close substitutes, which keeps their prices at the lower level. The theoretical equilibria in the analysed models show that the price effect prevails over demand, which results in maximum product differentiation in a single dimension. As the experimental results only showed small product differentiation in the sessions with high spatial complexity, we propose the following hypothesis:

H8: The empirical results, unlike the theoretical predictions, show that demand and price effects are equal.

Comparing the average prices and demands between the groups of participants who located their products closer (MIN_{DIST}) or farther (MAX_{DIST}) from the centre (table 1), we can see both the effects of price and demand. These effects are also confirmed by the correlation analysis between the variables, the results of which are found in table 2.

The R Spearman coefficient of correlation demonstrates that in all of the experimental sessions, a positive relationship between the product-centre distance ($DIST\_2$ statistics) and price was observed. Higher prices allowed the participants to gain higher profits. However, the shorter the distance between the product and the centre, the higher demand it evoked. Higher demand also translates to higher profits. All relationships mentioned above (bold letters in table 2) were statistically significant. In Series1_1 and Series1_2, the price effect prevailed, which was demonstrated by the positive correlation between the $DIST\_2$ statistic and the profits. This result explains the wide differentiation of products in this session. In sessions 2 and 3, the correlation between those variables was close to zero and statistically irrelevant. The important conclusion is the following: the participants could not increase their profits by locating their products farther from the centre. Therefore, hypothesis H8 was confirmed in the sessions with complex decision structure.

Tab. 2 R Spearman coefficient of correlation between prices, demands, profits, distance from the centre and product differentiation in successive experimental sessions.

Series1_1

	Price	Demand	Profit	DIST_1
Damand	R=0.074 (p=0.162)			
Profit	**R=0.997 (p=0)**	**R=0.143 (p=0.007)**		
DIST_1	R=0.996 (p=0)	R=0 (p=0.999)	R=0.987 (p=0)	
DIST_2	**R=0.709 (p=0)**	**R=-0.522 (p=0)**	**R=0.664 (p=0)**	R=0.757 (p=0)

Series1_2

	Price	Demand	Profit	DIST_1
Damand	R=-0.441 (p=0)			
Profit	**R=0.315 (p=0)**	**R=0.582 (p=0)**		
DIST_1	R=0.635 (p=0)	R=0 (p=1)	R=0.528 (p=0)	
DIST_2	**R=0.52 (p=0)**	**R=-0.249 (p=0)**	**R=0.181 (p=0.001)**	R=0.727 (p=0)

Series2

	Price	Demand	Profit	DIST_1
Damand	R=-0.43 (p=0)			
Profit	**R=0.134 (p=0.025)**	**R=0.745 (p=0)**		
DIST_1	R=0.465 (p=0)	R=0 (p=1)	R=0.363 (p=0)	
DIST_2	**R=0.322 (p=0)**	**R=-0.196 (p=0.001)**	**R=-0.012 (p=0.842)**	R=0.539 (p=0)

Series3

	Price	Demand	Profit	DIST_1
Damand	R=-0.355 (p=0)			
Profit	**R=0.144 (p=0.021)**	**R=0.816 (p=0)**		
DIST_1	R=0.648 (p=0)	R=0 (p=1)	R=0.382 (p=0)	
DIST_2	**R=0.521 (p=0)**	**R=-0.205 (p=0.001)**	**R=0.029 (p=0.644)**	R=0.653 (p=0)

Interestingly, price and demand effects were mutually neutralised in sessions 2 and 3. It is possible that the participants did not use the option of price competition smoothing by increasing product differentiation. A question remains regarding the empirical relationship between product differentiation and price and its conformity with the theoretical relationship. To explain these questions, the following hypothesis was proposed:

H9: The reason for the failure of theoretical predictions regarding product spatial differentiation is the discrepancy between the empirical and theoretical relationships between product differentiation and price. In this research, price elasticity was lower than what was theoretically predicted.

The hypothesis presented above was verified based on results obtained in Series1_2 and Series2, which were performed in an identical experimental environment; the differences in strategies used by the participants resulted only from the experience gained in previous stages. The relationship between product differentiation ($DIST\_1$ statistics) and price was examined. The empirical results on the theoretical results background are shown by Fig. 4. In section 1, the point graphs demonstrating the empirical relationships are presented, and they demonstrate an increasing tendency with a large spread. In Series1_2 (Fig. 4, Part 1), the line dependence between the analysed variables explains approximately 30% of the variability (adjusted $R^2 = 0.2984$), and the function form is shown by the equation: $Price = 6.8093 + 13.074 * DIST\_1$.[14] A positive absolute term means that the participants, who provided

[14] The variable (test statistics: $t = 12.34$) and constant ($t = 7.83$) parameters of the $DIST\_1$ are significantly different from zero, and the function form is correct (Durbin-Watson statistics: $DW = 1.83$).

completely homogeneous products to the market, do not compete as strongly as it is predicted by theory, therefore avoiding the Bertrand paradox. The increase in product differentiation resulted in the smoothing of the price competition, despite the slower rate of price growth, than what was theoretically predicted.[15] The market prices were more rigid than predicted based on the model. In Series2 (Fig. 4, Part 2), the line model explains 21% of the variability (adjusted $R^2 = 0.0209$), and the function form is expressed by the equation: $Price = 3.9956 + 8.5456 * DIST\_1$.[16] The companies were then able to avoid the Bertrand paradox by selling the homogeneous products for positive prices, even though the price competition was stronger in that case than it was in Series1_2. Moreover, in this session, the market prices reacted to the even weaker differentiation increase, which demonstrated their smaller elasticity, than in the Series1_2. This result means that the participants did not use their market opportunities to smooth the price competition and gain higher profits as the result of strategies based on product differentiation.

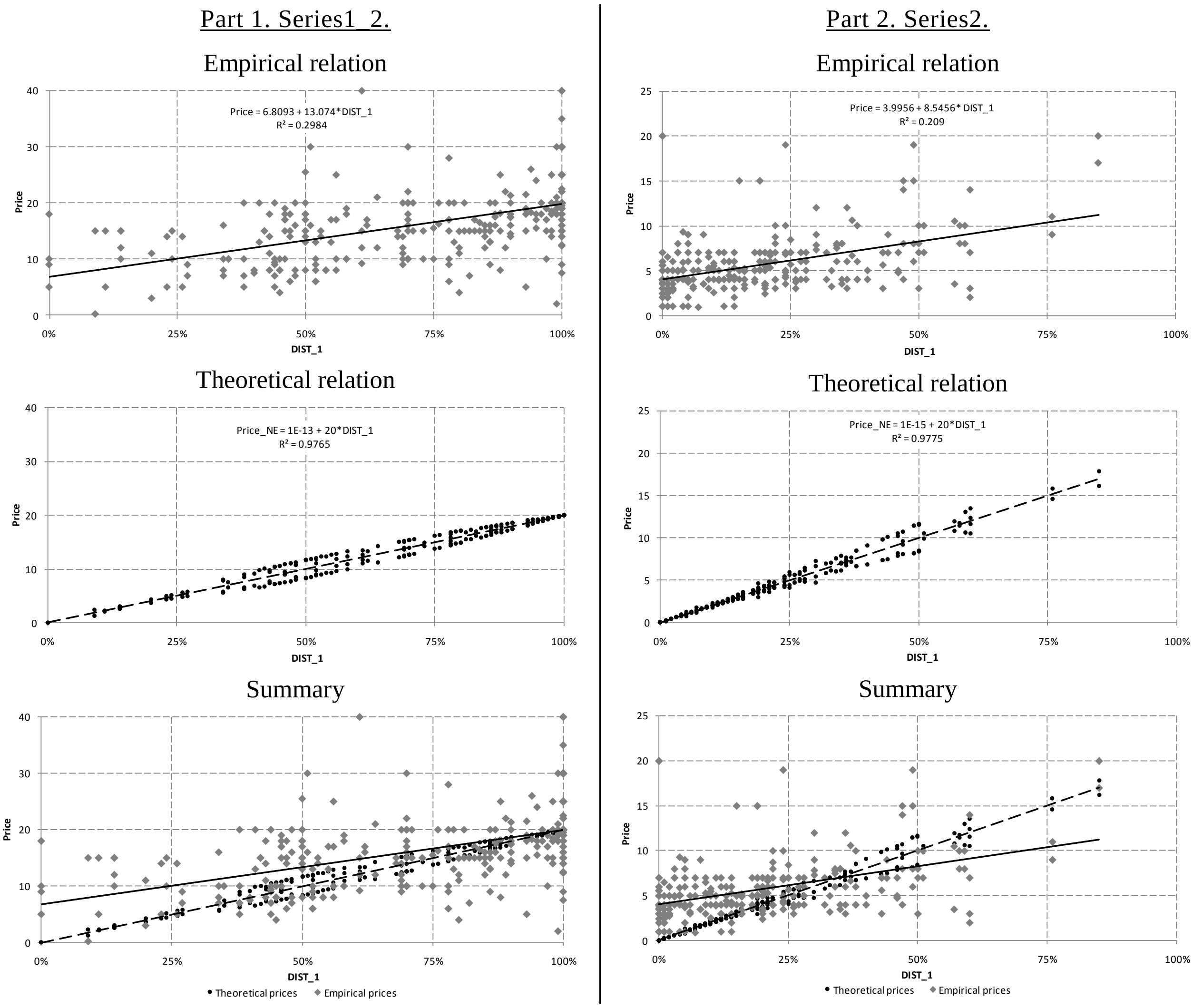
Fig. 4 shows the equilibrium prices for the individual locations in Section 2. Slight differences in the equilibrium prices for the values of the $DIST\_1$ statistic result from the asymmetrical product location. The observations located below the dashed straight line indicate that the analysed product was located farther from the centre, and the observation above the straight line shows the opposite situation. For this reason, the adjusted R^2 statistics is slightly smaller than 1 (it is above 0.96 in both sessions).

The third section Fig.4 shows the comparison between the empirical and theoretical results. It shows that in Series1_2, the participants fixed their average prices at higher levels than the theoretical prices at each of the differentiation levels, even though this difference was decreasing with the increase of the $DIST\_1$ statistic. In Series2, one can clearly see that for the small differentiation, the empirical prices exceeded the theoretical ones, and the opposite relationship was seen for this large differentiation. This observation explains the process of grouping the products around the central types during the session. The companies did not get any benefit from providing the peripheral types to the market because they could not use monopolistic power, which appeared as a result of the introduction of peripheral types. This situation did not occur in Series1_2, in which the market prices were higher than the theoretical prices for any product differentiation – from minimal to maximal. Regarding the relatively low price elasticity that was also observed in this case, some of the participants located their products inside of the tested area, providing only partially differentiated product types to the market.

[15] The theoretical relationship is expressed with the equation: $Price = 0 + 20 * DIST\_1$.

[16] In this case, the model parameters are significantly different from zero. The test statistic values are $t = 8.57$ for the variable parameter of $DIST\_1$ and $t = 15.32$ for the constant parameter; the function form is also correct, which is confirmed by the Durbin-Watson statistics ($DW = 1.86$).

Fig. 4 The empirical and theoretical relationship between the product differentiation ($DIST\_1$) and the price level in Series1_2 and Series2.



In summary, the reason for the failure of the theoretical predictions regarding the spatial distribution of products was the discrepancy between the empirical and theoretical relationship between the product locations and their price levels, which means that hypothesis H9 has been confirmed.

7. Conclusions

The aim of this study was to analyse the influence of model complexity on the participants' location-price decisions. We found that the structural complexity of the model has a significant influence on the participants' behaviour in the market. However, changes in behaviour were not gradual, as was expected; instead, the changes were more discontinuous. Addition of a second decision variable causes complete product differentiation inversion, which influenced prices and profits. In one-dimensional space, the participants behaved as was predicted by the theory – they provided maximally differentiated products to the market, gaining relatively high profits. In two- or multi-dimensional models, the situation was the opposite. The participants provided the products that appeared different. In this case, the price competition was not as strong as was predicted by the theory (the companies fixed higher prices than had been defined in the theory for a given product differentiation); however, the market price levels were unquestionably (almost three times) lower than in the session with a simple model structure. This result was the participants' reaction to their uncertainty. They used the safest strategies based on providing well-known, popular, highly demanded product types. Because the products offered in the market differed slightly, the companies were forced to run a strong price competition policy, which had a negative impact on their profits. Increasing the companies choice space by adding the next decision variable did not have any statistically significant influence on the market.

Regarding the failure of the theoretical predictions, we have attempted to explain the discrepancies with experimental findings. It has been proven that lack of experience and coordination problems could not account for this phenomenon. The main reason for the low level of product differentiation may be the low price elasticity in relation to product diversity. The empirical relationships were definitely weaker than the theoretical relationships, which resulted in neutralising the effects of demand and price on the two opposite spatial models. The companies were then unable to gain greater-than-average profits using strategies based on product differentiation. The location strategies used by the participants were, to some extent, determined by risk aversion as well.

In the real world, product decision space complexity is very high, and the results of companies' decisions are associated with a high uncertainty level. In such cases, the experimental results indicate insignificant (illusionary) product differentiation in many mutual dimensions, which seems to confirm the research hypothesis. The companies were not able to stop increasing price competition between the products, resulting in much lower profits than possible. The results of the research show that the problem of failure of theoretical predictions regarding spatial product models results mainly from assumptions about the participants decision-making mechanisms and not from assumptions about the environment. In complex circumstances, companies do not take advantage of opportunities for high profits that could be gained by diversified products, which results in a higher rigidity of prices with respect to product differentiation. The strategies based on product differentiations are then less profitable in practice than it is assumed in theory.

The conclusions of this research are extremely important for explaining the effects of the commonly observed phenomenon of increasing the quantity of product dimensions. In the modern world, we observe the introduction of new features for products and services by companies to achieve differentiation. It may seem that this process is motivated by a desire adapt the product to customers' needs. However, analysis of the products on the market reveals that they are extremely similar to each other. The results of this research explain this phenomenon. The participants' reaction to the growing environmental complexity was that they were forced to make decisions of increasing risk due to an inability to predict the results of the decisions. Therefore, the safest strategy is to produce the verified and most highly demanded types of products. The increase in the dimensions of product differentiation is therefore unfavourable both for the producers (dropping profits) and for the consumers (smaller real product differentiation with increased complexity, complicating the choice of the most preferable products).

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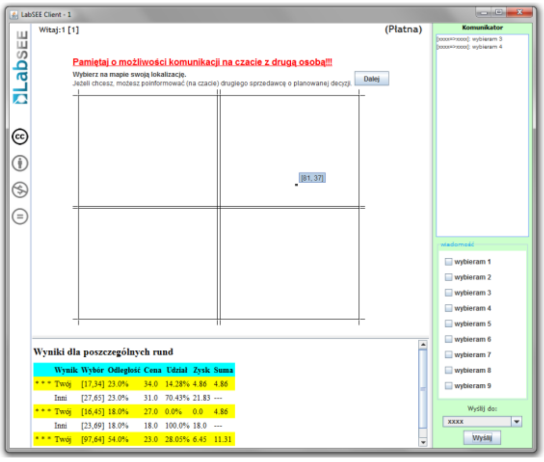
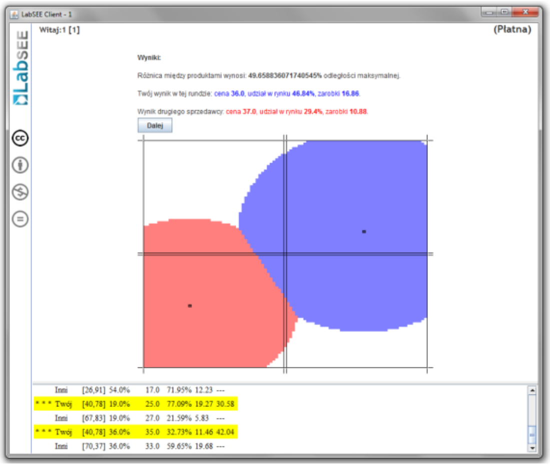
Appendix

Appendix 1. Computer screens

Location decision	Results
	

Appendix 2. Tests of the significance of differences in $DIST\_1$, $DIST\_2$, prices and profits between the groups with larger (Group1) and lower (Group2) theoretical knowledge in particular experimental series.

Kolmogorov-Smirnov test

	DIST_1		DIST_2		Price		Profit	
Series1_1	**D=0.078**	**(p>0.10)**	**D=0.113**	**(p>0.10)**	**D=0.088**	**(p>0.10)**	**D=0.079**	**(p>0.10)**
Series1_2	**D=0.063**	**(p>0.10)**	**D=0.045**	**(p>0.10)**	**D=0.098**	**(p>0.10)**	D=0.172	(p<0.05)
Series2	**D=-0.149**	**(p>0.10)**	**D=-0.053**	**(p>0.10)**	D=-0.201	(p<0.05)	**D=-0.156**	**(p>0.10)**
Series3	D=-0.246	(p<0.025)	D=-0.256	(p<0.01)	**D=-0.099**	**(p>0.10)**	**D=-0.156**	**(p>0.10)**

U Mann-Whitney test

	DIST_1		DIST_2		Price		Profit	
Series1_1	**Z=0.415**	**(p=0.678)**	**Z=1.088**	**(p=0.277)**	**Z=0.315**	**(p=0.753)**	**Z=0.27**	**(p=0.787)**
Series1_2	**Z=0.187**	**(p=0.851)**	**Z=0.591**	**(p=0.554)**	**Z=0.613**	**(p=0.54)**	**Z=1.824**	**(p=0.068)**
Series2	**Z=-0.215**	**(p=0.83)**	**Z=-1.764**	**(p=0.078)**	Z=-2.393	(p=0.017)	**Z=-0.673**	**(p=0.501)**
Series3	Z=-3.362	(p=0.001)	Z=-3.316	(p=0.001)	**Z=-0.844**	**(p=0.399)**	**Z=-1.635**	**(p=0.102)**

Appendix 3. Tests of the significance of differences in prices, demands and profits between two extreme groups (MAX_{DIST} and MIN_{DIST}) in relation to average product distance from the centre of the area (statistics $DIST\_1$) in particular experimental series.

Kolmogorov-Smirnov test

	Price		Demand		Profit	
Series1_1	D=0.792	(p<0.001)	D=-0.65	(p<0.001)	D=0.792	(p<0.001)
Series1_2	D=0.425	(p<0.001)	D=-0.3	(p<0.001)	D=0.208	(p<0.025)
Series2	D=0.333	(p<0.001)	**D=-0.144**	**(p>0.10)**	**D=0.167**	**(p>0.10)**
Series3	D=0.6	(p<0.001)	D=-0.363	(p<0.001)	**D=0.175**	**(p>0.10)**

U Mann-Whitney test

	Price		Demand		Profit	
Series1_1	Z=11.82	(p<0.001)	Z=-5.999	(p<0.001)	Z=11.666	(p<0.001)
Series1_2	Z=6.118	(p<0.001)	Z=-3.616	(p<0.001)	**Z=1.867**	**(p=0.062)**
Series2	Z=4.306	(p<0.001)	**Z=-0.858**	**(p=0.391)**	**Z=1.571**	**(p=0.116)**
Series3	Z=7.641	(p<0.001)	Z=-3.077	(p=0.002)	**Z=0.454**	**(p=0.65)**

Faculty of Economic Sciences
University of Warsaw
44/50 Długa St.
00-241 Warsaw
www.wne.uw.edu.pl