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PRICE PATTERNS IN AN OLIGOPOLY WITH SWITCHING COST AND UNCERTAIN DEMAND

Characteristics of price patterns have been investigated in an oligopoly market with costs for switching a provider. Two regimes of a company's access to information have been considered. In the benchmark scenario, firms make decisions based on perfect information about demand. In the other – more realistic scenario – they conduct market research to estimate an unknown demand curve and therefore face uncertainty regarding their profit function, which in turn leads to suboptimal decision making. The authors inspected how a company's access to information on demand, costs for switching a provider and the rate of market renewal influence price patterns on the market. It has been shown that positive switching cost is a sufficient condition for price dispersion, as well as imperfect information about the company's profit function, e.g. from market research. The average price under the perfect information regime is lower than under market research based price setting, a higher switching cost makes it easier for companies to coordinate their prices and a higher rate of market renewal softens the influence of the switching cost on market price.

Keywords: *price competition, switching cost, agent-based modeling, uncertain demand, price volatility*

1. Introduction

Oligopoly markets are often characterized by repeated purchasing. For instance: the renewal of a contract with a mobile operator or Internet service provider, purchasing updated software, purchasing previously used and familiar food products, or continuing to make savings in a current investment fund. In each period, clients have to make repeated decisions as to whether to continue using the current product or change to another one. In this decision making process, customers take into account both ob-

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jective factors such as price, as well as subjective ones such as an individual's perception of product quality. Still, these are not the only determinants of such a decision. Studies suggest that customers have a significant tendency to maintain the *status quo* and continue their previous consumption of a product, even though another product might be objectively better [14]. The strength of this attachment to a previously used product is measured by the so called switching cost.

Switching cost is the measure of customers' aversion to changing a currently used product for another one. Switching costs may have several causes: cognitive, transactional, contractual obligations to the provider, legal, behavioral, and/or related to the risk of using a new unknown product. These cognitive reasons are associated with the knowledge which has to be acquired by a customer to use a new product, e.g. users of specific software or operating system who decide to switch, must bear the cost of learning to use the new software. Transactional causes of switching costs are associated with the need to terminate the contract with the current provider and sign a new contract with another – this could mean monetary charges and non-monetary costs, e.g. time spent on carrying out formalities, as well as legal consequences. On the other hand, companies often deliberately create switching costs by offering their current customers more favorable conditions. Such actions may include customer loyalty programs at gas stations or programs to collect air miles offered by airlines. Also, mobile phone operators offer favorable conditions to some of their existing customers by introducing retention programs, in order to discourage these clients from switching. This reasoning is justified by the fact that the cost of acquiring a new client in the telecommunications market is 5–8 times higher than the cost of retaining a current customer [8, 23]. Another factor increasing switching costs is the risk of dissatisfaction with a new product, about which initial knowledge is limited [15]. In addition, behavioral economics literature documents a well-known *status quo* bias, which is the tendency to remain at default settings and options proposed by the designers of a system [2, 4, 5, 10, 14, 18].

The subject of switching cost in oligopoly markets was investigated by [25], where the effect of switching cost on price is examined with companies having various lengths of planning horizon. They show that the length of planning horizon is crucial in determining whether switching costs increase or decrease the market price in an oligopoly market. If companies have an infinite planning horizon, i.e. they are driven by the stationary market share distribution, an increase in switching costs decreases the market price. On the other hand, for companies with short-term business planning, such as one period ahead, the impact of switching costs on the market price is the reverse. In this paper, we additionally investigate price dynamics, not only their long term level.

Also [6] demonstrates that switching costs raise the market price in the case of telecommunication companies with short-term planning. In addition, they investigate the influence of customers' rationality on the market price. They show that this impact depends on the level of switching costs. For low switching costs, an increase in customers' rationality lowers the market price. On the other hand, for high switching costs, an increase in customers' rationality surprisingly raises the market price.

The fact that switching costs lower the level of competition in the case of companies with a short-term planning horizon is confirmed by other authors [1, 7, 11]. Under certain conditions, concerning the discount factor, this relationship also holds in [22].

Furthermore, we assume that customers exhibit bounded rationality [3]. There are two sources of bounded rationality, which we include in our approach to model customers' behavior: random errors in choosing the cheapest product due to customers' imperfect perception of the price and customers' myopia. The former of these sources is the difficulty of accurately perceiving the price. This follows from the fact that products offered by companies are often bundled, i.e. multiproduct goods. The exact composition of a product is constructed by each client. These products are priced according to complex price lists that hinder customers' ability to compare the offers of competitors with each other. Moreover, companies often deliberately make these comparisons more difficult by applying so-called price obfuscation [9]. Customers who are not able to evaluate the real cost of a product (which also may be due to uncertain demand, e.g. the number of calls a client will make in mobile networks is not known beforehand), make random errors in the estimation of purchase costs. In our study, we incorporate this type of bounded rationality by introducing the probability of choosing a particular product modeled using the soft-max function [17]. The other source of bounded rationality is customer myopia. In the presence of switching costs, rational clients should predict the future price of products, since today's purchase influences future purchases through the switching cost mechanism. However, we assume that clients are myopic, i.e. they take into account only the present price. This is due to difficulties in predicting future prices.

The goal of this study is to examine how switching costs influence price dynamics in an oligopolistic market and how it is influenced by the quality of information about demand and the market renewal rate. This work extends the results obtained in [6, 25]. Unlike those articles, this study explores price dynamics, putting special emphasis on price dispersion and its autocorrelation, as well as on the quality of information about demand and the possibility of market renewal.

In the next section, we present the description of a model of Bertrand type competition. In particular, we present: (1) a customer's decision making process, taking into account his/her bounded rationality and switching costs, (2) formulas for the quantity function and profit function of companies, (3) an algorithm for firms' decision making. In section 3, we present the results by illustrating the characteristics of prices, such as their average, dispersion and autocorrelation. Section 4 concludes.

We implemented simulations based on the model in the statistical programming environment GNU R [13], in which we also perform plots. All the codes are available from the authors upon request.

2. Model

We consider a population of N customers, who repeatedly take a decision to purchase one unit of a product from one of K available suppliers. The demand for this product is inelastic, i.e. each customer purchases exactly one unit of the product regardless of the prices offered by companies. However, the prices influence the clients' choice of supplier. In each period $t \in \{1, ..., T\}$ a proportion r of the customers are replaced by new customers.

2.1. Model of consumer choice

A client's decision is to choose some company j out of K, i.e. $j \in \{1, ..., K\}$. The probability of a client choosing company j depends on the price and its competitors charge, as well as the company i the customer used in the previous period of time. In particular, it is possible that $j = i$. The probability that a customer using supplier i in the previous period will choose supplier j is given by the following soft-max function [17]:

$$s_{ij}(p_j, p_{-j}) = \frac{\exp\left(-\delta\left(p_j + SCI_{[j \neq i]}\right)\right)}{\sum_{k=1}^{K} \exp\left(-\delta\left(p_k + SCI_{[k \neq i]}\right)\right)} \tag{1}$$

where: p_j – price of firm j, p_{-j} – price vector of remaining firms other than j, δ – customers' price consciousness, SC – switching cost, $I_{[\text{condition}]}$ – indicator function of the following form:

$$I_{[\text{condition}]} = \begin{cases} 1, & \text{if condition is true} \\ 0, & \text{if condition is false} \end{cases} \tag{2}$$

The probability s_{ij} expresses the customers' preferences for lower prices and attachment to the supplier they used in the previous period. In particular, if a customer considers changing her current provider ($j \neq i$), she adds the switching cost SC to the price p_j when making a decision. The properties of the choice function (1) are presented in more detail in the following paragraphs.

Firstly, the higher the price of firm i, the lower the probability of a client continuing to purchase the product from it and the higher the probability of switching, *ceteris paribus.* Secondly, the higher the price of competing company j ($j \neq i$), the lower the probability of switching to supplier j. The following results formalize these observations:

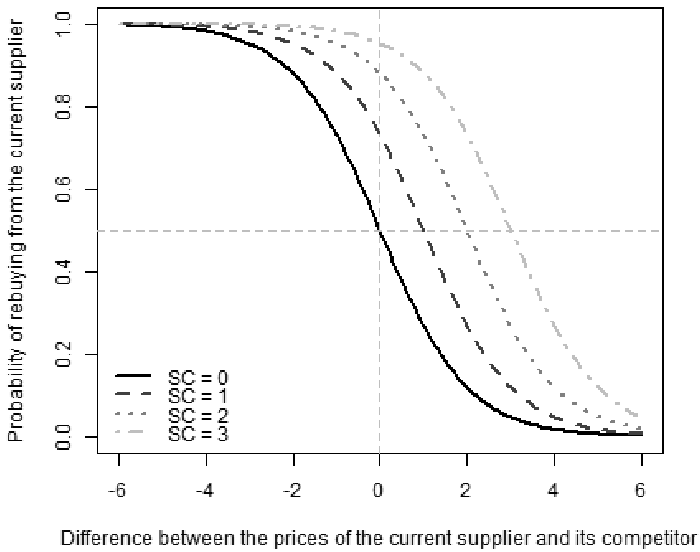

Fig. 1. The probability of repeated buying from the currently used supplier s_{ii} for various values of the switching cost SC as a function of the price difference. Source: authors' own work

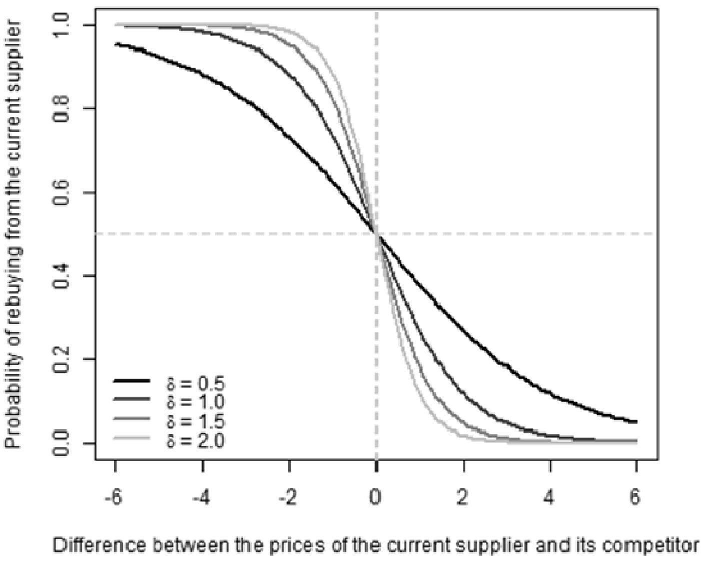

Fig. 2. The probability of rebuying from the current supplier s_{ii} for various values of customers' price consciousness δ as a function of the price difference. Source: authors' own work

$$\forall_{\delta>0}\forall_{i\neq j}\,\frac{\partial s_{ij}}{\partial p_i}>0 \qquad \text{and} \qquad \frac{\partial s_{ij}}{\partial p_j}<0 \tag{3}$$

The above relationships are depicted in Figs. 1 and 2. Both figures show that the probability of rebuying from the same supplier decreases as its price increases in comparison to its competitors.

Secondly, the function s_{ij} expresses (for $SC > 0$) a customers' preference for the supplier currently used, i.e. when two suppliers offer the same price, the probability of choosing the current supplier is higher. More specifically, the higher the switching cost, the higher the likelihood of continuing to buy from the same supplier, *ceteris paribus*. This relationship is shown in Fig. 1. As we can see, the functions corresponding to higher switching costs lay above those corresponding to lower switching costs. The following relationship holds:

$$\forall_{\delta>0} \forall_{i \neq j} \frac{\partial s_{ij}}{\partial SC} < 0 \tag{4}$$

The parameter SC representing the switching cost is a measure of the reluctance to change the currently used supplier. From a customer's perception, the switching cost increases the price of a supplier currently not being used. As shown in Fig. 1, an increase in the switching cost moves the function describing the probability of continuing with the present supplier, s_{ii}, in terms of the price of the present supplier compared to competitors to the right.

The parameter δ determines the degree of customers' price consciousness, i.e. the ability to correctly perceive the differences in the prices offered by companies. Its influence on customer choice is depicted in Fig. 2. In particular, there are two extreme cases:

- For $\delta = 0$, customers make totally random decisions, uninfluenced by price differences. As a result, each supplier is used with equal probability, regardless of its price;
- As $\delta \to \infty$, customers choose the supplier with the lowest total cost, which is the sum of price and switching cost, if any.

Summarizing the interpretation of customers' price consciousness, one can say that the higher the value of the parameter δ, the more often cheaper suppliers are used. Figure 2 shows that an increase in the price sensitivity δ increases the absolute value of the derivative (slope) of the function s_{ii} at the point $x = (p_i - p_{-i}) = 0$. A high absolute value of this derivative means that small changes in price cause a large change in the probability of rebuying from the current supplier s_{ii}.

The uncertainty expressed by the soft-max function in Eq. (1) can be interpreted in two ways. Firstly, the uncertainty about choosing the cheapest product might be associated with the limited ability of customers to perceive correctly the total cost of a product, which might be caused by a complex price list, often induced deliberately by the practice of price obfuscation by companies [9, 16]. Secondly, the heterogeneous distribution of choices could be interpreted in terms of product differentiation, i.e. each client assigns a different base value to different products and as a result this heterogeneity in tastes is translated into heterogeneity of brand choice [19, 20]. Another possible approach to modeling the customer decision making process, besides using the soft-max function, is to assign to each customer an individual random utility value θ_i for each brand i and diminish it by its price p_i. Using such an approach, the surplus of product i is expressed as:

$$s_i = \theta_i - p_i \tag{5}$$

A client chooses the product with the highest surplus:

$$\text{choice} = \arg\max_{\{i:s_i \geq 0\}} s_i \tag{6}$$

This approach is taken in [12, 24]. These formulas would then have to be extended to incorporate a switching cost.

Let us move on to a description of the structure of the consumer population. We assume that a proportion r of the customers are replaced by newcomers in each period. For these new customers, who have not previously used any supplier, the switching cost equals zero ($SC = 0$). The probability of choosing supplier j is as follows:

$$s_j(p_j, p_{-j}) := s_{ij}(p_j, p_{-j}, SC = 0) = \frac{\exp(-\delta p_j)}{\sum_{k=1}^{K} \exp\left(-\delta p_k\right)} \tag{7}$$

2.2. Model of a company's behavior

Our model considers two scenarios describing how companies can use predictions of demand: (1) the use of perfect information about the true demand function and (2) estimates resulting from conducted market research.

In the former case, companies endowed with perfect information, they know the customers' decision making process exactly, and forecast the quantity sold in an unbiased and exact manner. Given the current volume of clients belonging to each company, they are able to calculate an unbiased expected quantity sold in the next period t:

$$q_j^t\left(p_j, p_{-j}\right)\sum_{i=1}^{K} q_i^{t-1} s_{ij}\left(p_j, p_{-j}\right) \tag{8}$$

Having this expected quantity, firm j can calculate its expected profit at time t:

$$\pi_j^t\left(p_j, p_{-j}\right) = q_j^t\left(p_j, p_{-j}\right)\left(p_j - MC\right) \tag{9}$$

where: p_j – price of firm j, p_{-j} – price vector of remaining firms other than j, MC – marginal cost.

In the latter case, firms do not possess perfect information and conduct market research on a small sample of customers, in order to try to infer customers' behavior. Given this estimation procedure, companies set an optimal price. The estimated quantity sold by firm j is given by the following random variable:

$$Q_j^t\left(p_j, p_{-j}\right) = \sum_{i=1}^{K}\sum_{n=1}^{q_i^{t-1}} s_{ij}\left(p_j, p_{-j}\right) \tag{10}$$

where:

$$s_{ij} = \begin{cases} 1, & \text{with probability } s_{ij}\left(p_j, p_{-j}\right) \\ 0, & \text{with probability } 1 - s_{ij}\left(p_j, p_{-j}\right) \end{cases} \tag{11}$$

As a result, the profit of firm j is a random variable as well:

$$\Pi_j^t\left(p_j, p_{-j}\right) = Q_j^t\left(p_j, p_{-j}\right)\left(p_j - MC\right) \tag{12}$$

Having specified the objective functions of the companies as a profit function, each company with probability ρ sets a price in period t, $t \in \{1, ..., T\}$ that maximizes profits under the assumption that competitors will continue with the same prices as in the period before. This decision making process is called best-response [21].

Firms change their price by a multiple of the parameter Δ, for instance prices in UK are multiples of one penny. The parameter m specifies the maximum multiplicity, e.g. $m = 10$ means that in any period a company cannot change its price by more than 10Δ, i.e. by no more than 10 pence. This ensures that companies do not introduce large changes in prices, which is also observed in reality. Consequently, a new price p^t is selected from the discrete decision set:

$$p^t \in \left\{p^{t-1} - m\Delta, ..., p^{t-1} - \Delta, p^{t-1}, p^{t-1} + \Delta, ..., p^{t-1} + m\Delta\right\} \tag{13}$$

The implementation of the described price setting mechanism is explained with the use of pseudo-code in Table 1.

Table 1. *SetPrice* procedure

```
Function SetPrice(pj, p-j, PI, Δ, m)
     BestProfit := -∞
     For each iÎ{-m, -m+1,..., 0,..., m-1, m}
          If(PI = TRUE) then
               newProfit := πj(pj + iΔ, p-j)
          else
               newProfit := Πj(pj + iΔ, p-j)
          End If
          If (newProfit > bestProfit) then
               bestProfit := newProfit
               bestPrice := pj + iΔ
          End If
     End For each
     Return bestPrice
End Function
```

Source: authors' own work.

Because the model described in this section is complex (it includes a consumer choice function, procedure for estimating demand, price setting mechanism), we apply simulation to investigate its properties. The parameters used and their ranges of variation in the simulations are shown in Table 2.

The choice of the investigated ranges of parameter values is dictated by both the research problem in question and computational constraints. We employ the experimental design of grid search, thus the number of simulations to be run grows exponentially with the number of parameters investigated. Because of this, we perform a sensitivity analysis with regard only to those parameters that are crucial in answering our research questions. As a result, we do not investigate the impact of the following parameters: customers' price consciousness δ, as it is investigated in [6, 25], the marginal cost *MC*, since it is of little interest, as it enters the formula for the equilibrium price additively and is investigated in [25], the number of customers *N* is a measure of demand uncertainty, since the lower the market research sample size *N* is the higher the demand uncertainty. Because the impact of demand uncertainty is captured and investigated by the regime type parameter *PI*, we do not assess any further the impact of *N*. It is worth noticing that when the regime type parameter *PI* is set to TRUE, i.e. under the perfect information regime, this is equivalent to the number of customers surveyed going to infinity, i.e. $N \to \infty$. The parameters that are investigated are discussed below.

Table 2. Parameters of the model and their values

Parameter	Values	Meaning
	Customers	
SC	[0, 3]	Customers' switching cost
δ	{2}	Customers' price consciousness
	Firms	
MC	{1}	Marginal cost
ρ	{10%, 100%}	Probability of setting a new price
PI	{TRUE, FALSE}	The regime of Perfect Information
Δ	{0.01, 0.1}	Minimal price change
m	{100, 500}	Maximum multiplicity of price change □
	Oligopoly market	
N	{1000}	Number of customers
K	{2, 3}	Number of firms
r	[0%, 25%]	Market renewal rate
	Technical parameters	
T	{40, 2000, 5000}	Number of periods simulated
$T_{\text{burn-in}}$	{10, 100, 1000}	Number of burn-in periods

Source: authors' own work.

The range of the switching cost parameter *SC* is from 0 to 3. The minimum value of 0 is an evident benchmark scenario for a market with no switching costs. The maximum value of 3 corresponds to a switching cost equal to three times the marginal cost, i.e. $MC = 1$. The range between 0 and 3 was also investigated in [6, 25] which makes our analysis comparable to those papers. Also, in [6, 25] we investigated the case in which companies immediately adjust their prices to opponents' moves, which corresponds to the parameter describing the probability of setting a new price ρ being equal to 100%. In this research, we also examine the case in which companies exhibit some delay in the adjusting process by setting the probability of setting a new price ρ to be equal to 10%.

The choice of *m* and Δ is dictated by constraints on computational burden. The parameter Δ is the minimal price change allowed to companies and determines the precision of the price equilibrium derived, so we would like to have Δ as small as possible. The parameter *m* is the maximum multiplicity of the price change Δ and it increases the number of simulations to be performed and therefore the computational burden, so we would like to have *m* small. On the other hand, both Δ and *m* define the width of the price space covered, which is the product $2m\Delta$ and we would like this to be large. Summarizing, high precision requires small Δ and small computational burden requires small *m*, but high coverage of the price set requires large $2m\Delta$. Therefore, based on our needs we employ two pairs of (Δ, m), i.e. Δ = 0.01, m = 500 and Δ = 0.1, m = 100 which result in the width of price set coverage being equal to 10 and 20, respectively.

Finally, in order to determine the influence of the market renewal rate, we perform a sensitivity analysis based on the parameter r by sampling its values from the range of 0% to 25%. The maximum value of 25% is dictated by the fact that for the mature and saturated markets that we consider, the renewal rate should not exceed 25%.

The technical parameters T and $T_{\text{burn-in}}$ are selected based on trial and error depending on each application of the model, so that the required summary statistics are precisely calculated and stable.

3. Results of the simulations

The following section presents the characteristics of price patterns in an oligopolistic market. Especially, we focus on the following characteristics of prices: average, dispersion and autocorrelation. We also examine the market shares of companies.

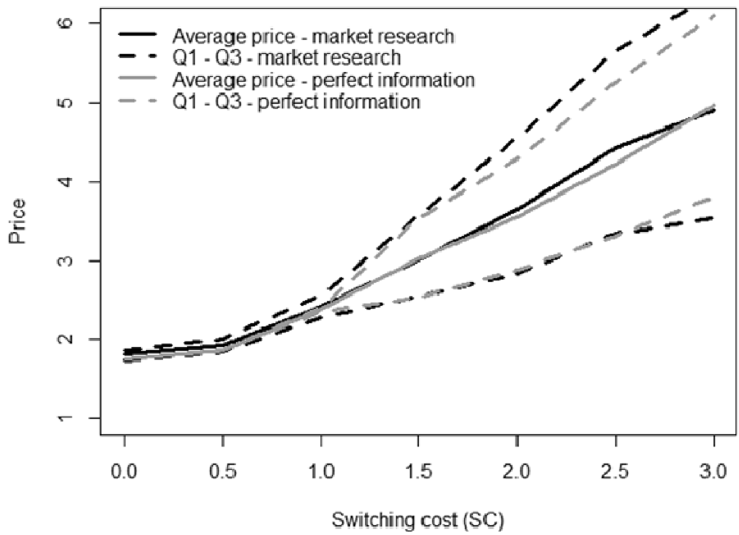

Fig. 3. The impact of the switching cost on price level and dispersion in regimes of perfect information and market research or the following remaining parameter values: $\delta = 2$, $MC = 1$, $\rho = 0.1$, $\Delta = 0.01$, $m = 500$, $N = 1000$, $K = 3$, $r = 0\%$, $T = 5000$, $T_{\text{burn-in}} = 100$. Source: authors' own work

Figure 3 depicts the relationship between the market price and switching cost for the two regimes considered: perfect information, and uncertain demand, which might be estimated by conducting market research. We can observe that a higher switching cost results in higher prices. This result is consistent with previous research on companies with a short planning horizon [1, 6, 7, 11, 25]. Under certain conditions concerning the discount factor, this result is also consistent with [22]. The slope of the average price line (both for the regime of perfect information and uncertainty) in Fig. 3 is approximately equal to 1, which means that the switching cost is fully internalized into the price. As a result, although clients want to avoid incurring switching costs by their implicit loyalty to a specific brand, they actually incur this cost each time they buy the product, as they pay a higher price. Companies are aware of the presence of switching costs and exploit this fact in the following manner. Companies that have a certain customer base could increase their price by the level of the switching cost without any fear of losing customers. As a result, customers pay more. Lower switching costs or customers behaving as if there were no switching costs would result in lower prices in the market. However, from an individual customer's point of view, it is optimal to minimize all costs, including the switching cost. Hence, this problem is analogous to the prisoner's dilemma [21].

In addition, Figure 3 shows that prices are higher under the regime of uncertain demand than under the regime of perfect information, *ceteris paribus*. These price differences are statistically significant (p-value < 0.001). Finally, we can observe in Fig. 3 that higher switching costs result in a greater dispersion of prices. For small values of the switching cost ($SC \leq 1$), price dispersion is driven mostly by the uncertainty in estimating demand. For higher values of the switching cost ($SC > 1$), price dispersion grows rapidly and is smaller under the regime of perfect information than under uncertain demand.

The price dispersion is the result of switching costs, since switching costs make the optimal price dependent on the market share being stochastic. Customers move partially at random between various brands. These customer flows are described by a transition matrix [25]. Therefore, various market shares result in different behaviors by the companies, depending on whether it is beneficial to the company to attract new customers or to exploit old ones. In summary, the presence of switching costs and random customer flows between brands is a sufficient condition for price dispersion, regardless of the quality of available information, i.e. whether it is a perfect information regime or uncertain demand regime.

The decision making of firms under the regime of uncertain demand is prone to random errors in setting the optimal price. As we can see in Fig. 4, the profit function is convex and flat around the maximum point. Therefore, a small error in the estimation of the objective function results in a random price around the optimal value.

In summary, based on Figs. 3 and 4, we conclude that either positive switching costs or uncertainty in the estimation of the profit function are sufficient conditions for the presence of price dispersion in the market. However, it should be noted that switching costs have a greater influence on the level of dispersion.

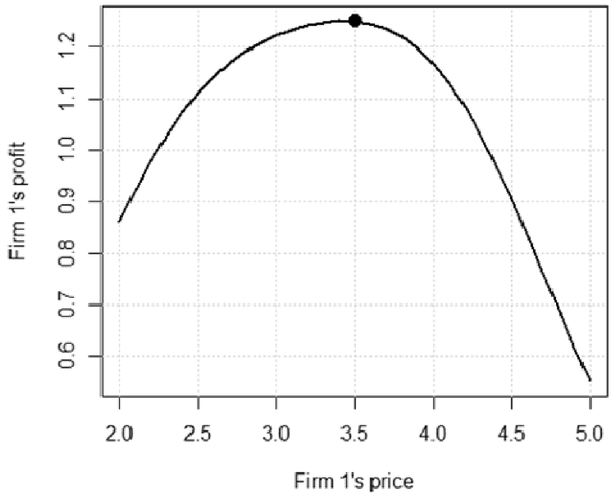

Fig. 4. Profit function of firm 1 when its competitor's price equals 3.5, market share equals 50% for the following remaining parameter values: $SC = 1$, $\delta = 2$, $MC = 1$, $K = 2$, $r = 0\%$.
Source: authors' own work

Figure 5 depicts the dynamics of prices and market shares for various values of the switching cost, i.e. $SC \in \{0, 1, 2\}$, under the regime of perfect information, i.e. *PI* = TRUE. This shows how the switching cost induces price dispersion. We can observe in the top-left plot that when there is no switching cost ($SC = 0$), the price is constant. This is due to the fact that in the absence of a switching cost, companies do not possess any locked-in customers and consequently they compete more for both new and current customers by offering competitive prices. As a result, the market share from the previous period does not have any impact on the current price. This is observed in the bottom-left plot. We can see random market shares caused by partially random flows between brands, even though the price is fixed. The equilibrium price p^* in this case is given by the following formula:

$$p^* = MC + \frac{2}{\delta} \tag{14}$$

On the other hand, even a small switching cost ($SC = 1$) induces a price increase, as shown in Fig. 5. This follows from the fact that companies, being aware of the switching cost incurred by clients, try to exploit their current customer base by setting a higher price. As a result, the optimal price in a given period depends on the company's market share in the previous period. Therefore, fluctuations in market share translate into fluctuations in price, as seen in Fig. 5. Moreover, we can observe that in the case of a positive switching cost, market shares fluctuate in a more systematic way than with no switching cost, i.e. $SC = 0$.

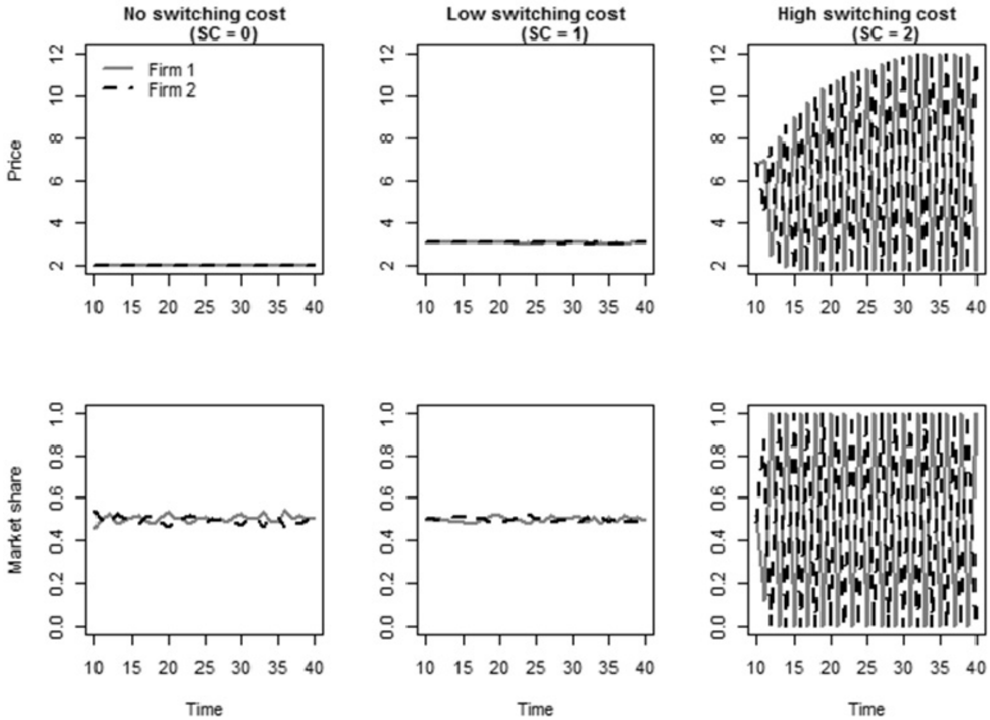

Fig. 5. Duopoly price patterns for various values of the switching cost ($SC \in \{0, 1, 2\}$) for the following remaining parameter values: $\delta = 2$, $MC = 1$, $\rho = 100\%$, PI = TRUE, $\Delta = 0.1$, $m = 100$, $N = 1000$, $K = 2$, $r = 10\%$, $T = 40$, $T_{\text{burn-in}} = 10$. Source: authors' own work

In the case of a high switching cost, the price dynamics are different. As shown in Fig. 5, firms set low and high prices alternately. Consequently, market shares also change in this fashion, since the firm setting a high price loses its market share at the expense of the company which sets a low price. Such dynamics are caused by both the high switching cost and myopic companies, i.e. companies, which assume that its competitor's price from the previous period will remain unchanged. Consequently, in order to compete for customers with a low price company, the company with a higher price has to significantly lower its price, because the existence of a switching cost makes it difficult to drag customers from an opponent and a company assumes its opponent's price will be low in the next period. On the other hand, the company with a lower price raises its price significantly in order to exploit its customers, because due to the switching costs it thinks that customers will continue purchasing its products and it assumes that the competitor's price will be high in the next period. As we see, a high switching cost strengthens such pricing patterns.

Summarizing, we conclude that the high switching cost, short planning-horizon of firms and the assumption that the competitors' price remains unchanged from the previous period, results in a strong dependence between the optimal price and market share (Fig. 5). Consequently, we observe alternations between high and low prices. The strength of this coordination depends on the switching cost, as shown in Fig. 5.

Figure 5 depicts how a high switching cost (SC = 2) makes companies set alternately high and low prices. The difference between the high and low price is a measure of customer exploitation and, as it is seen in the figure, this depends on the switching cost. A good measure of customer exploitation is the difference between the prices as perceived by a client who does not incur the switching cost, e.g. a new client to the market. The probability of a newcomer choosing supplier j, i.e. s_j, is equivalent to the probability of a client switching from any other company to company j when the switching cost is zero and is defined by Eq. (7).

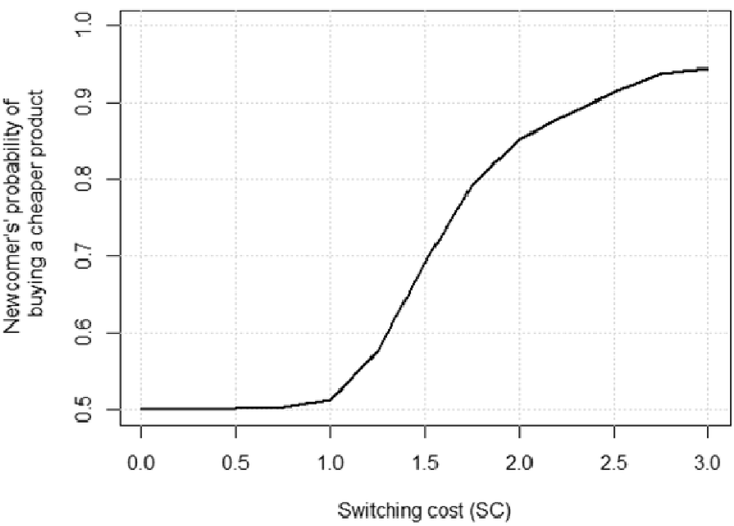

Fig. 6. Influence of the switching cost on price coordination in a duopoly market with the following remaining parameter values: $\delta = 2$, $MC = 1$, $\rho = 10\%$, PI = TRUE, $\Delta = 0.1$, $m = 100$, $N = 1000$, $K = 2$, $r = 10\%$, $T = 10000$. Source: authors' own work

The measure of price coordination attachmentStrength is presented in Fig. 6 and is defined as the maximum value of s_j over j $(j \in \{1, ..., K\})$

$$\text{attachmentStrength} := \max_{j\in\{1,\dots,K\}} s_j\left(p_j, p_{-j}\right) \tag{15}$$

The value of attachmentStrength can be interpreted as the probability of a client who is new to the market buying the cheapest product, since the minimum of s_j over j is associated with the company setting the lowest price.

In the case of a duopoly (K = 2), the attachmentStrength measure ranges over the interval [0.5, 1]. In the absence of price coordination and equal prices, the chances of attracting a client new to the market are the same for both companies, i.e. equal to 0.5, hence attachmentStrength = 0.5 as well. On the other hand, in the case of price coordination, one company has a greater chance of gaining a customer new to the market and so attachmentStrength is larger. Figure 6 shows that for a high switching cost (SC = 3) it is even 95%. On the other hand, a low switching cost does not cause systematic differences in companies' prices, which is also seen for the case of SC = 1 in Fig. 5.

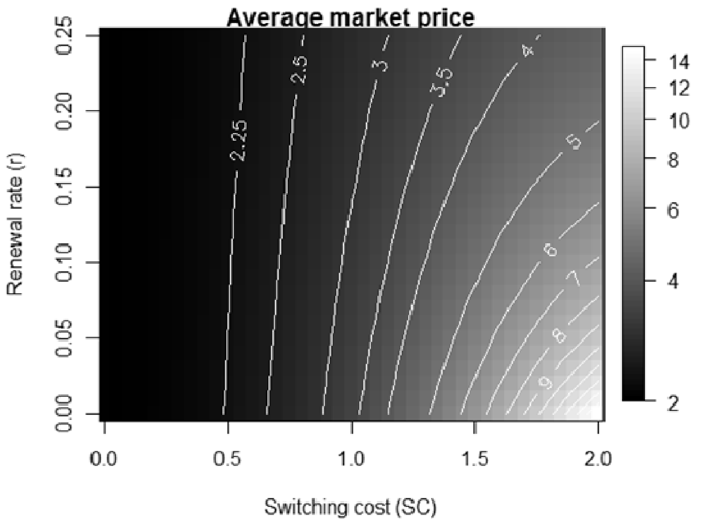

Fig. 7. Heat map of the average market price conditional on the switching cost (SC) and market renewal rate (r) with the following remaining parameter values: δ = 2, MC = 1, ρ = 100%, Δ = 0.01, m = 1, N = 1000, K = 2, T = 2000, $T_{\text{burn-in}}$ = 1000. Source: authors' own work

The switching cost increases market prices, as seen in Fig. 3 and confirmed by earlier research [6, 25]. Figure 7 confirms this dependence but also shows how it interacts with the variable determining the rate of market renewal, i.e. the proportion of clients who are replaced each period by new clients. We see in Fig. 7 that the higher the market renewal rate r, the less detrimental to customers is the switching cost. An increase in the market renewal rate r decreases the market price and this effect becomes stronger as the switching cost increases. When there is no switching cost ($SC = 0$), the market renewal rate has no impact on price, because new and existing clients are treated equally by companies – the contour lines in Fig. 7 are vertical for a low switching cost. For a high switching cost, the impact of the market renewal rate r on the decline in prices is clear – the lines in Fig. 7 run more horizontally. This is due to the fact that the switching cost makes it profitable to exploit clients attached to the company. In the case of a high percentage of newcomers r, companies compete for new customers with lower prices.

4. Conclusions

The switching cost is a measure of customers' aversion to change a currently used product for another one. This reluctance to change might be driven by both financial reasons, such as transactional costs, and non-financial reasons, e.g. cognitive, behavioral or legal. The importance of switching costs has been already documented in the field of behavioral economics [2, 4, 5, 14, 18]. In this paper, we show the significance and influence of switching costs on price patterns and their dynamics in an oligopolistic market.

This work confirms the result that switching costs are detrimental to competition and increase market price in the case of companies with a short-term planning horizon [1, 6, 7, 11, 25]. We show that the switching cost is almost entirely internalized into the price of the product. As a result, even though customers try to avoid incurring the switching cost, which can be described as implicit loyalty, they in fact incur this switching cost each time they purchase a product. Customers behaving as if there were no switching costs would reduce the market price. However, for each client, it is individually optimal to take into account both costs: price and the potential switching cost. That is why this problem is analogous to the prisoner's dilemma, see [21].

Moreover, we show that positive switching costs make a firm's optimal price dependent on its market share from the previous period. Since market shares are stochastic, this leads to the randomness of prices, which we define as price dispersion. Such price dispersion is the result of the introduction of random elements into a firm's decision making process. The first possibility is a random market share, which in the case of a positive switching cost ($SC > 0$) translates into a random price. The second possibility is uncertainty in estimating the demand curve, which results in uncertainty about the objective function leading to decisions fluctuating around the optimal price.

High switching costs result in price coordination between firms. Companies set alternately a high price to exploit current customers and a low price to acquire new customers. We demonstrate that the higher the switching cost the stronger this price coordination.

Finally, we show the importance of the market renewal rate, i.e. the proportion of current customers replaced by new ones in each period. The higher the market renewal rate, the less detrimental the effect of switching costs on competition. In the case of a high market renewal rate, companies compete for newcomers by lowering their prices.

Further research requires the thorough examination of the parameter space, in particular concerning: customers' price consciousness (δ), the number of firms (K) and the companies' feasible set of prices (the parameters Δ and m).

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