Dynamic pricing models and its methodological aspects

The article deals with dynamic pricing (DP) models methodological aspects, how to model DP in different spheres of services/industries, which factors have a significant effect on the DP formation and what are the benefits of DP application in practice. This paper discusses the concept of dynamic pricing, the dynamic pricing models principles, problems, main methodological assumptions and methods in retail. Therefore the aim of this paper is to analyse the dynamic pricing models principles and problems and to represent the results of DP forming factors evaluated by AHP method.

Keywords: dynamic pricing, revenue management, dynamic pricing model.

Introduction

In the XXI century organizations still face the problem of the optimal price determination search for goods and services in order to maximize their profits. Revenue management were practiced for more than 40 years and have gained the popularity in retail. One such approach is dynamic pricing (hereafter DP), that refers to the process of controlling product prices over the sales season to maximize an expected revenue.

Research on dynamic pricing modelling has been undertaken by economists and operational researchers from a range of perspectives and the benefits of dynamic pricing methods have long been known in airlines, electricity and other industries. In nowadays, there has been an increasing adoption of dynamic pricing in retail sector, where selling a fixed inventory over a short selling season. This paper analyses the dynamic pricing modelling principles,
problems, main methodological assumptions and methods in retail.

The **purpose** of this paper is to analyse the dynamic pricing models and its principles, problems and to represent the results of DP forming factors evaluation by AHP method. The main **problem** is how to model DP and which factors have a significant effect on the DP formation. The main research **methods** include qualitative and quantitative methods. DP forming factors were evaluated by using AHP (hereafter Analytic Hierarchy Process) method. This decision making method was originally developed by T. L. Saaty, allow some small inconsistency in judgment, where the main idea is to derive ratio scales from paired comparisons.

The next section presents a discussion about DP and its models in retail from theoretical standpoint. After that, the expert survey AHP methodology, results and the formulated DP function will be submitted.

**The dynamic pricing and its conception**

What is the dynamic pricing, how to model DP in different spheres of services/industries, which factors have a significant effect on the DP formation, what is the benefit of DP application are the main problems the scientists conducted in their empirical research. DP has been analyzed and tried to be defined in various research areas: *economics* (Philips, 1983; Baker, 2010; Krugman, 2000; and others), *management* (Gallego, van Ryzin, 1994; Haws, Bearden, 2006; Alvarez et al., 2010; Lobo, Boyd, 2003; Siddbri, 2005; and others), *operations control processes researchers* (Belobaba, 1987; Williams, 1999; Zhang, Cooper, 2005; Ziya et al., 2002; Aviv, Pazgal, 2002, 2008; Bodily, Weatherford, 1992, 1995; and others).

Firstly in research papers DP were identified with revenue management. Therefore using DP and revenue management terms scientific literature does not contain strict boundary between conceptions that define these terms (Deksnyte, Lydeka, 2012). This range of problems also reflected in business practice of D. Cary (2004) who stated in his article: “...DP and revenue management act differently in the USA airline area. DP focuses attention on rivals’ actions and the reaction of product supply and demand. Revenue management focuses attention only on models and trends, which are designed on the ground of demand data”. Similarly R. Desiraju and M. Shugan (1999) compared DP to revenue management and regarded them as substantially different practices. The authors of the thesis emphasizes that these concepts should not be identified because DP researches include the determination of optimum product price evaluating supply/demand behavior and the assessment of that reflecting indicators.

Within a context of economic researches in DP is often related to price discrimination: DP is understood as an attempt of a seller to force a customer to pay the highest price he is ready to spend. According to P. Krugman (2000), dynamic pricing is a new practice of old price discrimination. According to him, modern technologies made dynamic pricing useful not only for different areas of industry/services but also for economics. In this context it is worth to mentioning L. Philips (1983). He summarizes a typical attitude of economist towards price discrimination and states that DP is necessary in order to allocate resources in the optimum way in real-life situations. This statement
may sound strange because usual economic analysis states that in the competitive market price is equal to marginal costs and that all that maximizes welfare. However, based on modern true-life situations many sectors of industry such as pharmacy, telecommunications and information technologies experience high fixed costs and less marginal costs. In case of such situation, when prices are set according to marginal costs level, it would be impossible to retrieve initial investment, so in this case DP is assessed positively (Deksnyte, Lydeka, 2012).

Thus, DP definition has a tendency to show which academic field governs the knowledge of this topic. As it was mentioned at the beginning of DP researches its conception was clearly considered the part of operational management researches (Williams, 1999). In 1999 the authors of the scientific article in the magazine Operational Research Society I. Yeoman et al. (1999) claimed “universally accepted wide definition of DP” sounds like “the allocation of resources and inventory to a suitable client for a suitable price in order to maximize revenue and profitability”. Over the last years demand behavior has also been included into DP researches (Feng and Xiao 2000), whereas the absence of standard DP definition, declared by P. Jones (1999) and others, allowed strain to settle among the disciplines that research this area. Despite the influence of other disciplines operational research still clearly dominates in the literature concerning revenue management. Although today OM researchers recognize that product demand is an integral part of DP researches (Boyd and Bilegan, 2003), the definitions are still concentrated on supply as evidenced by S. E. Kimes and G. M. Thompson’s (2004) definition: Dynamic pricing is the form of resources management where supply is controlled manipulating useful life and price. This is not consistent to the definition of M. Fleischmann et al. (2004): Dynamic pricing is related to price-fixing for perishable resources taking into account demand so that to maximize revenue or profit.

The main problems in DP research and modelling

The lack of uniform DP definition. To define DP solidly is still a complex task for several reasons and the most important are the following: different interpretation of this conception by the representatives of various scientific spheres, the orientation of the DP researchers towards different academic branches.

DP concept analysis suggests that up to now in the literature there is no unanimous and widely used DP definition. To precise and uniform DP definition – still remains a difficult task for several reasons, the most important this paper authors see: the various disciplines, the concept of different interpretations and DP orientation of researchers in different research fields. More discussions on DP theme in various fields of science/industries, gradually formed its conception in various different places. However, it should be noted that the majority of scientists (Belobaba, 1987, Williams, 1999; Zhang, Cooper, 2005; Ziya, Ayhan, Foley, 2004), in their studies do not define DP, they pay more attention on DP modelling, performance monitoring, and thus trying to convey the concept of DP.

This paper defines a dynamic pricing as a dynamic regulation of prices for consumers, evaluating current product demand / supply to maximize revenue. Using dynamic pricing the seller dynamically over
time and in response to parameters such as a product demand, supply – adjust the product prices. This understanding is the opposite of DP definitions in operations management science where demand profile is separated from both the allocation of resources and company’s pricing policy (Netessine, Shumsky, 2004; Talluri, Van Ryzin 2004).

**The lack of DP models applicability in practice.** Most of the DP models are rarely purified in the practice. The biggest part of them remains only on a theoretical level, as well as models with the specificity of complex mathematical algorithms complicates their application. As a result, the authors of this paper argue that DP models should be concluded on the basis of practicality, versatility and simplicity principles (Figure 1).

**The variety of DP determinants and indicators.** An abundance of research in various areas of science has led not only to the lack of a unified concept of DP, but the abundance of the factors forming it.

In the most studies DP is modelled in a specific area and the model is constructed on the basis of factors that are as important only for the particular researcher (recall that DP performed research economics, operations management, management) or specific business areas, resulting in the lack of DP models versatility.

In this context, it is worth to remember W. Elmaghraby and P. Keskinkocak (2003), S. Sibdari (2005) research papers that highlights that before modelling DP it is important to define and evaluate the following characteristics:

- **Replenishment or no replenishment of inventory.** Inventory policy plays an important role in revenue management models. If inventory replenishment is allowed during the time horizon, the retailer should make a joint inventory and pricing decision during the time horizon; if the replenishment is not allowed, the retailer should make the pricing decision based on the given inventory.

- **Dependent or independent demand**
over time. If a retailer has a durable product to sell, the demand for the product might be a dependent function across multiple periods of time. For this type of product, the benefit duration of the product is longer than the time horizon of the sale. On the other hand, if customers’ knowledge about the product plays an important role in their decision to buy the product, the demand would also be dependent over time.

- **Myopic or strategic customers.** The retailers should take into account the purchasing behavior of the customers in order to have an efficient pricing policy. If a customer makes his decision based only on the price he sees when he arrives, we call this customer a myopic customer. On the contrary, we call it a strategic customer.

### Dynamic pricing models overview

**Deterministic dynamic pricing models.**

Deterministic models provide that the seller has the correct information about the demand for the product. This, of course, is a simplified version, especially for those DP application realms where demand is almost not predictive at the beginning of period (season), such as new products or fashion goods. Deterministic models relatively are easy to analyze, since they show a good approximation (approximate value) for practical but complex stochastic models. The second reason is that the deterministic models are usually used in practice.

K. T. Talluri, G. J. van Ryzin (2005) in their work present a simple deterministic pricing model expression when the initial inventory level \( x(0) = C \), the selected price series \( p(t) \) (which promotes demand volume \( d(t, p(t)) \)), for purpose to maximize company revenue. The optimal scope were expressed:

\[
\max \sum_{t=1}^{T} r(t,d(t)) \tag{1}
\]

\[
\sum_{t=1}^{T} d(t) \leq C
\]

\[
d(t) \geq 0
\]

where: \( f(t,d) = \frac{\partial}{\partial d} r(t,d) \) – expressed as marginal revenue, \( \pi^* \) – Lagrange multiplier, then the conditions for optimal revenue volume \( d^*(t) \) and multiplier \( \pi^* \) is:

\[
f(t,d^*(t)) = \pi^*.
\]

The complementary condition says that the opportunity costs can not be positive if there are excess reserves. If the opportunity cost is zero \( (\pi^* = 0) \), then, if we maximize the income (revenue) without constraint at each period (by setting a price where marginal revenue is equal to zero), we do not expend potential supply.

A. Rajan and R. Steinberg (1992) focus on the price changes that occur in the order of execution cycle when a seller sells a perishable goods such as fresh food. The deterministic demand for the product is a descending function of the age (ie, the elapsed time from order execution cycle) and cost. The problem facing the seller is to determine the optimal price sequence order execution cycle, the optimal cycle time \( T \) and the optimal order size \( Q \), in order to maximize its average profit (income) over time (assuming that discount will not be available). A. Rajan and R. Steinberg (1992) believe that a) the optimal price to be determined at time \( t \) after the last order was made, ie, \( p^*t \), is independent of \( T \), and b) the optimal sequence of prices \( p^*t \) is unique. In addition, the optimal price may increase, decrease, or to
increase or decrease in order execution cycle time \( (t) \). When \( t \) increases, increases and general comparative costs despite of depreciation, which could lead the price increment.

S. Smith and D. Achabal (1998) examined the case where the demand intensity is dependent on the product prices and inventory level, \( \lambda(p;C; t) \). The authors assume that the demand decreases, when the inventories have been exhausted. Buyers have less chance to find the desired product (eg, size, color, quality, etc.) when the levels of stocks are low. In this context, the authors derive the optimality conditions for price and provide solutions for this special case: \( \lambda(p;C; t) = k(t), y(C)exp(-\gamma p) \).

S. Biller et al. (2000) presents a dynamic pricing model that can be applied to the production of combining performance constraints and maintenance costs. According to the author: (1) a profit on a dynamic pricing can be significant, (2) the dynamic pricing is a useful lever to reduce demand variability, (3) the potential benefits of dynamic pricing depends on the type of demand variability, (4) price changes can be up to 10% of the fixed costs, and (5) a few price changes may affect the profitability of the organization. In spite of the fact that the seller provides excellent demand for the same period, it has the capacity restrictions on the number of items it can produce in each period. Seller task again is to determine the optimal sequence of prices of goods sold in each period and the production during the \( T < \infty \) periods.

Usually only one product is analyzed in deterministic models, several products case has attracted much less attention. The main reason of this problem identified by the G. J. van Ryzin (2001, 2005) is quite difficult to consider several products, especially when need to describe the correlation of demand and product substitution cases.

**Stochastic dynamic pricing models.** Pricing policies in stochastic demand are more complex and more difficult to assess than the deterministic analogs. On the other hand, stochastic models are more appropriate to describe real-life situations where demand and inventory behavior is unpredictable. The simplest way of solving this type of problem is to use a stochastic dynamic programming (SDP) method. In case of stochastic demand, and in the context of a single product, the easiest way to find the optimal price is a fixed price for a pricing decision whole period \( pt = p; t \in [0, T] \). This method is applicable to products that have at least one of the following: short selling horizon, the high prices of replacement costs and regulatory requirements on prices. In spite of the fact that prices can change, firms often prefer fixed-price policy for its simplicity.

E. P. Lazear (1986) provides retail trade model for one product \( (C = 1) \), and potential users \( (N) \). Selling horizon is divided into two periods. The main goal of the seller is to determine the price of goods of the first and second periods of time, \( p_1 \) and \( p_2 \), respectively. Lazear model is with incomplete information. If the product is not sold during the first period by price \( p_1 \), then the retailer can adjust his initial calculation \( R \) to \( p_2 \). In this context, Lazear shows that the price monotonically decreases over time, \( p_1 > p_2 \). It can be concluded that the high demand commodities adapt more quickly to the marketplace in which the product remains unsold.

G. Bitran et al. (1996, 1997) found optimality conditions for cases where the transfer of inventory between warehouses (stores) are (are not) allowed. A set of rules
drawn up by using planning indicators by which each decision point of the price is calculated by assuming that this is the last time when it is being reviewed. Author experiment show that this type of rules works well enough with an average error of 2% - 3%. The article also includes experiments that were performed using actual data from a network of retail stores.

Multi-product case in stochastic dynamic pricing models have attracted much less attention too. The case of trade networks were examined in dynamic pricing models by G. Gallego and G. van Ryzin (1994). In this case, optimality condition is described:

\[
\frac{\partial V_t(C_t)}{\partial t} = \sup_p \{ \sum_{i=1}^{n} \lambda(p)[p_j - (V_t(C_t) - V_t(C_t - A_j))] \}
\]

where \( \lambda(p) \) is demand intensity of product \( j \) for price vector \( p \).

**Evaluating DP forming determinants**

*Methodology.* Forming the DP model, firstly need to select and justify determinants and their reflective indicators (Figure 2). For this purpose expert survey was selected as instrument to obtain judgments from experts about the importance of DP forming factors. This questionnaire was directed to get the priority weight of the each factor used for ranking DP forming factors. The methodology used is Analytic Hierarchy Process (AHP). The factors here should be rated by method of a pair-wise comparison where the preference of a factor over the other is given a numeric value (scale 1–3–5–7–9).

The method brings the possibility the qualitative evaluation to be transformed into quantitative evaluation. The comparison result is a square matrix \( P = || p_{ij} ||(i, j = 1, \ldots, m) \).

Comparison matrix mathematical expression:

\[
P = \begin{pmatrix}
p_{11} & p_{12} & \cdots & p_{1m} \\
p_{21} & p_{22} & \cdots & p_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
p_{m1} & p_{m2} & \cdots & p_{mm}
\end{pmatrix}
\]

Fig. 2. DP determinants measurement process
Results. More than 10 international experts were interviewed in 2012 December – 2013 April. The first phase was carried out in a pilot study to determine the adequacy of the study and verify measuring instruments adapted procedures. The second phase was carried out for the re-trial of the 10 experts. The survey data were computed by “Make It Decision Rational Tool” program.

The second stage was carried out to eliminate all the factors on both the supply and demand side groups with the significance in a comparative assessment scale is ≤ 5%. Government policy, the number of sellers in the market related prices, price level of competitors were eliminated from the supply-side, the type of product, buyers income, buyers expectations, consumer behavior, fair price perception, fashion trends, and the number of buyers in the market - the demand factor group. And in the third stage experts were asked to evaluate only significant factors by using AHP method.

The final DP function was formulated:

\[
DP_{it} = y_1(\beta_1 f_n + BrAssort_{it}) + \beta_2 PLC_{it} + y_2(\beta_3 SEASw + \beta_4 COO_{it} + \beta_5 PD_{it} + \beta_6 QA_{it} + \beta_7 Brand_{it})
\]

\[
DP_{it} = 0.44(0.53(f_n + BrAssort_{n}) + 0.47PLC_{it}) + 0.56(0.27SEASw + 0.20PD_{it} + 0.14QA_{it} + 0.18 Brand_{it})
\]

where, \(f_n\) – inventory level, \(BrAssort_{n}\) – partial assortment effect, \(PLC_{it}\) – product lifecycle, \(SEASw\) – seasonality, \(COO_{it}\) – country origin, \(PD_{it}\) – product discount, \(QA_{it}\) – product quality, \(Brand_{it}\) – brand attractiveness.

Conclusions

In the research literature and organizations practice more and more attention is paid to the formation of the current product demand and supply situation reflective pricing - dynamic pricing. What is dynamic pricing, how to model DP in different spheres of services/industries, which factors have a significant effect on the DP formation, what is the benefit of DP application are the main problems the scientists conducted in their empirical research were analyzed in this paper.

Dynamic pricing refers to the process of controlling product prices over the sales season to maximize expected revenue. To define DP exactly and solidly is still a complex task for several reasons, the most important of which are the following: different interpretation of this conception by the representatives of various scientific spheres, the orientation of the DP researchers towards different academic branches.

DP concept analysis suggests that up to now in the literature there is no unanimous and widely used DP definition. To precise and uniform DP definition - still remains a difficult task for several reasons, the most important this paper authors see: the various disciplines the concept of different interpretations and DP orientation of researchers in different research fields.
Most of the DP models are rarely purified in the practice. The biggest part of them remains only a theoretical level, as well as models with the specificity of complex mathematical algorithms complicates their application.

An abundance of research in various areas of science has led not only to the lack of a unified concept of DP, but the abundance of the factors forming it. Forming the DP model, firstly need to select and justify determinants and their reflective indicators. For this purpose was selected expert survey to obtain judgments from experts about the importance of DP forming factors and finally DP function was formulated. The function will be used for future research dynamically adjust product prices in retail practice.

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DINAMINĖS KAINOS NUSTATYMO MODELIAI IR JŲ METODOLOGINIAI ASPEKTAI

Santrauka

XXI amžiuje tinkamos kainos nustatymas vis dar išlieka itin sudėtingas uždavinys: organizacijos susiduria su optimalios prekių ir paslaugų kainos nustatymo paieškos problema tikslu maksimizuoti peln. To pasekoje straipsnio autoriai siekia išanalizuoti dinaminės kainos nustatymo modelių principus, problemas ir pristatytı AHP metodu nustatytus DK formuojančius veiksnius.

Straipsnyje dinaminės kainos nustatymas autorijų apibrėžiamas kaip dinamiškas kainų vartotojams reguliavimas, įvertinant dabartinę produkto paklausą/pasitęsios būseną siekiant maksimizuoti organizacijos pajamas. Taikant dynaminę kainodarą pardavėjas dinamiškai laikui bėgant bei reaguojant į tokius rodiklius kaip produkto paklausą, pasiūlos galimybės, koreguoja kainas.

Straipsnyje autoriai apžvelgia deterministinių bei stochastinių modelių specifiku, Deterministiniai modeliai numato, kad pardavėjas turi tiksliai informaciją apie produkto paklausą. Tai žinoma yra supaprastintas variantas, ypač toms DK taikymo sréms, kur paklausą yra beveik neprognozuotina
laikotarpio (sezono) pradžioje, pavyzdžiui, nauji produktai ar mados prekės. Deterministinius modelius gana nesunku analizuoti, kadangi jie parodo gerą aproksimaciją (apytikslę reikšmę) praktiškesniems, bet sudėtingiems stochastiniams modeliams.

Dinaminės kainos nustatymas esant stochastinei paklausai yra sudėtingesnis ir sunkiau įvertinamas nei jo deterministiniai analogai. Iš kitų pusės, stochastiniai modeliai yra tinkamesni, kad būtų galima nusakyti realias situacijas, kur paklausos ir prekių atsargų elgsena yra nenuspėjama. Paprasčiausias sprendimo būdas tokio tipo problemoms spręsti – naudoti stochastinio dinaminio programavimo (SDP) metodą: parduotuvės menedžmentas tyrimo metu informaciją apie dabartinę atsargų būklę ir parduotuvės nustato produktų parduotuvės kainas.

Moksloje literatūroje pateikiami gana plati dinaminę kainodarą formuojančių veiksnių įvairovės. Tyrėjai vieningai sutaria, kad nėra vieningos bei visuotinai priimtos dinaminę kainodarą formuojančių veiksnių klasifikacijos bei vieningai pagrįstos jų tarpusavio sąveikos. Minimos tik prielaidos, kuriomis remiantis galima išskirti bei sisteminti DK formuojančius veiksnius. Tyrimuose, atsižvelgiant į DK sąvokos daugiaaspektiškumą, pripažįstama, kad vienas ar keli veiksniai neatspindi DK tyrimų problematikos. Pastebėta, kad DK tyrėjai dažnai remiasi tik keletu veiksnių, kas sąlygoja modelių netikslumą bei ribotumą.

Siekiant gauti kompleksinį praktiniam taikymui tinkamą skirtingų DK formuojančių veiksnių svarbos įvertinimą, autoriai pasirenka ekspertinio vertinimo metodą. Šis metodas suteikia galimybę nustatyti vieno lygio hierarchijos rodiklių svarbą (reikšmingumus) aukščiausio lygio galiu. Eksperimento tyrimo metu buvo identifikuoti svarbiausi DK nustatymų sąlygojantys veiksnius. Gautoji funkcija – DK funkcija, pasirinktinu laikotarpiu identifikuojanti kainos korekcijos būtinių. Funkcijos taikomumas paremtas tuo, kad sėkmingai pasirinkti DK nustatymą lemiantys rodikliai gali tiksliai ir laiku signalizuoti apie prekės perkainojimo būtinių.