Product Architecture and Technology Selection in Dynamic Business Environment

A. Sabaleuski, F. M. Andrade Pires, and P. P. Camanho

Abstract—**The paper presents a product architecture and technology selection model applied to product positioning decision in dynamic business environment. The model underlines the importance of considering potential alterations of endogenous and exogenous market factors, namely changes in market regulations and entry of a new competitor, while making the product positioning decisions.**

Index Terms*— *Business-to-Business; Competitive Analysis; Multi-attribute Utility Analysis; Product Architecture;

I. Introduction

For any firm offering a right set of new products is a key driver of profitability. “Right” products are the ones that are appropriately positioned with regard to the latest market trends and existing or potential competition. Product positioning has been long viewed as a key marketing activity underlining its importance for a firm’s strategy in general [1]. The business environment of every firm is a dynamic system with constantly changing internal and external factors. Thus, a good product positioning decision making should anticipate potential changes and make product architecture (PA) and technology choices appropriately.

From the microeconomic perspective, the resulting market equilibrium differs whenever firms consider product positioning decisions of each other or not [2]. Market analysis, within a new product development, without considering competitive responses, generally leads to profit overestimation and strategic “misses” [4]. Since the beginning of the millennium more and more researchers advocated the importance of considering competitive reactions in a new product development [2-4]. However, the previously published research on the topic is primarily focused on consumer market. Moreover, the majority of papers has a descriptive flavor and can be hardly used in the actual product development scenario supporting the product positioning decisions.

The current work focuses on business-to-business (B2B) market for several reasons. First of all, this is the most suitable environment for “classical” oligopolies. Hence, competitive analysis is of great value in such arrangement. Secondly, most of the companies are SMEs that are in need of a simple and straightforward model. Consequently, the main objective of this paper is to introduce a practical framework to evaluate technology selection decisions in new product development under competitive responses in B2B environment.

The paper starts with research contextualization and proceeds with the model presentation. A case study is presented to illustrate the most important concepts of the proposed model and shows how it can be used in actual decision making scenario. Finally, we discuss how the results of the analysis are related to existing research on competitive interactions.

II. Contextualisation

In this section, we focus on the background of the current research. We realize that there are three interconnected domains that are specific to the model. First of all, we discuss B2B environment and the particular part that we are focusing on. Secondly, we concentrate on the competitors and their relationships both with the buyers and each other. Finally, we explain in detail the link between product position and manufacturing technologies and make the connection between the parts.

A. Market Players, segmentation, value functions and bidding mechanism

The target market is a set of few large OEMs (buyers) that outsource some of the subassemblies from smaller TIER 1 SMEs (suppliers). The subassemblies are then used to manufacture the final product that is sold to a final user (end customers). The total market volume is discretized through individual projects. Thus, there is no continuous stream of production, but rather a sequence of individual projects.

B. Negotiation Mechanism

Negotiation between customers and suppliers occurs in the form of competitive tendering. Each competing supplier is assumed to be an approved bidder by the buyers. Therefore, for every upcoming project each supplier receives Request for Proposals (RFP). Suppliers respond to the RFP with details on how they would satisfy the buyer’s performance requirements and the price they would be willing to accept to do so. They submit their proposals to the customers in the form of sealed bid auction, which is the most common type for projects related to public procurement. That is, the suppliers cannot see the bids of each other and have to anticipate the possible competitive offerings. The buyer evaluates the bids and offers the project to the supplier that submitted a proposal with the

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highest utility for the buyer. We consider that all buyers have similar standardized supplier selection procedures.

C. Buyer Value Function

Typically, the buyer makes multi-attribute evaluation of the received proposals. Together with price, he is looking on product performance over the number of relevant attributes. We realize that there are no two buyers with identical product preferences and each of them sets up product priorities in its own way. It is typically a result of different business strategies and internal product/process policies and constraints. Note that our model focuses on product performance only, i.e. without taking into account other aspects like, payment terms, etc.
In our model, we make use of multi-attribute utility analysis (MAUA) in order to estimate the value function of the buyer. MAUA interviews have to be hold with relevant decision makers inside a buyer, which is typically a complex organization. MAUA is used for that step because of several advantages. First of all, utility analysis measures preference structure rather than imposing one, which is critical in communications with new buyers [5]. Secondly, MAUA takes explicit considerations of decision maker preferences incorporating risk attitudes [6]. Since decision makers within the buyers are professionals in their field, it is easier for them to make more precise utility judgments. Finally, MAUA has been successfully applied in a similar context [7].

D. Market Segmentation

Every buyer sells the final product to one or more end users. Whenever there are few big end users or many small ones that can be effectively clustered, we say that the intersection between a particular buyer and a cluster of end users forms a market segment. The difference between the clusters of end customers can be readily explained through differences in national regulations. Moreover, the end customers that are big enough can have considerable negotiation power and their own restrictions to the products of the suppliers. We assume, without loss of generality, that the number of projects in the analysis period is equal to the number of market segments.

E. Product Architectures

House of Quality is a typical tool that helps to transform market requirements in product functions and evaluate competing alternatives [10]. As shown in Figure 2 any product function can be supported by one or the other manufacturing technology. Various combinations of production technologies provide different PAs. Different sets of initial product functions can deliver unlike architectures, since architecture comprises entities and the structure of relationships and interfaces between them [11]. Thus, we focus solely on high-cost impact and high-market impact functions, which are crucial for the buyers' perception and competitive differentiation.

III. Product Architecture and Technology Selection Model

Figure 1 summarizes the model described in a previous section. It is followed by the mathematical description of the value functions and decision mechanisms.

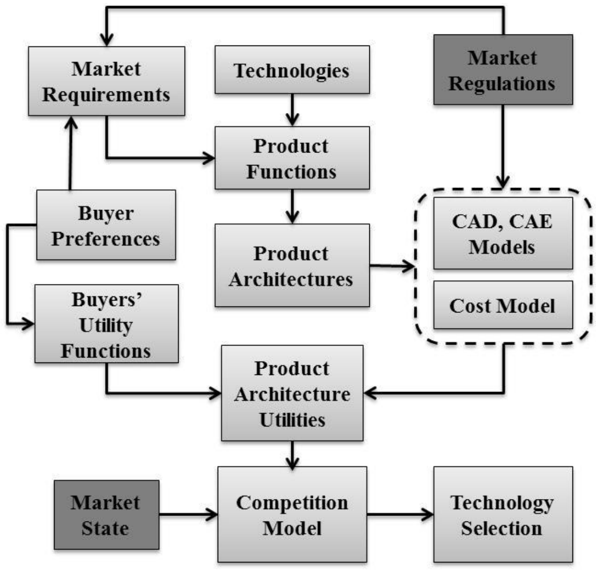

Fig. 1. The product architecture and technology selection model

There are i bidders (suppliers) approved by j buyers on the market. Each buyer is active in n national markets. Suppliers offer different products to the market by investing in certain PAs. Buyers make their purchasing decisions looking to maximize their utility concerning product performance. Both buyers and suppliers are aware of functional requirements in different national markets and make their choices rationally.

A. Buyers' Value Function

Every buyer has product preferences upon y product attributes. Nevertheless, each customer is different from the other customer with regards to its preferences. Let W_{jy} denote the weight of attribute y for the customer j. Each supplier considers finite number of architecture options x. Let A_{xy} denote performance of architecture x on the product attribute y. Subsequently, U_{jn}^{x} represents the utility of architecture A_x for the customer j in market n

$$U_{jn}^{x} = \prod_{y=1}^{k}(A_{xy} \times W_{jy}) \quad (1)$$

Power utility functions help to eliminate options that are out of the product attribute range expected by the buyers. That is, if any of the attributes exceeds the maximum (minimum) required level considered by the buyer, its utility automatically equals to zero.

B. Suppliers' Value Function

Each supplier on the market is looking to select the PA that would maximize his profits π^{i} (single-attribute utility function). The suppliers select PAs from the pre-existing set of

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technology options. Thus, the utility that each supplier offers to the market is the following:

$$U_{jn}^{i} = U_{jn}^{x} \quad (2)$$

When all suppliers make their choices of architecture they form a portfolio that is available for buyers. By choosing a certain architecture, the supplier understands that he will be eventually losing the niches where the chosen architecture performs worse than other competing architectures.

$$\pi_{jn}^{i} = \begin{cases} \pi_m, & if\ U_{jn}^{i} > U_{jn}^{(-i)} \\ \pi_o, & if\ U_{jn}^{i} = U_{jn}^{(-i)} \\ 0, & otherwise \end{cases} \quad (3)$$

Total realized profits in the period by supplier i:

$$\pi^{i} = \sum_{n=1}^{l} \sum_{j=1}^{p} \pi_{jn}^{i}, \quad (4)$$

where l is the number of end customers on the market and p is the number of buyers on the market.

The profit that the supplier realizes after winning a project in each market segment is the difference between the price and variable and fixed product costs:

$$\pi_{jn}^{i} = P_{jn}^{i} - vc_{n}^{x} - fc^{x} \quad (5)$$

where P_{jn}^{i} represents the price of product offer of supplier i; vc_{n}^{x} – variable costs of the architecture x supplied to national market n; and fc^{x} defines the fixed costs of architecture x. Fixed costs have two components: product development costs and production fixed costs. Product development costs are assumed to be equal for all alternative product architectures. Secondly, production fixed costs are realized only after the decision is made and a supplier has been offered a project. Thus, we disregard fixed costs since they do not play a strategic role in the PA selection problem.

We employ margin to operationalize the dependence between profit, price and variable costs. Thus, we re-write the profit and price functions in the following manner:

$$\pi_{jn}^{i} = vc_{n}^{x} \times m_{jn}^{i} \quad (6)$$

$$P_{jn}^{i} = vc_{n}^{x} \times (1 + m_{jn}^{i}) \quad (7)$$

where m_{jn}^{i} denotes the margin level selected by the supplier i. The supplier can select either monopoly or oligopoly level margin for each market segment.

C. Value Maximization Mechanisms

The profits are characterized by the differences in utility values of different PAs for different buyers. The oligopoly profits in this scenario are equal to oligopoly profits in Scenario 1. However, monopoly profits now depend on the utility difference between our choice of architecture and competitive offer.

$$maximize\ \pi^{i}(A_x)\ subjected\ to\ m_o\ and$$

$$m_{jn}^{i} = \frac{P_{jn}^{i}\left(U_{jn(min)}^{i}\right)}{vc_{n}^{x}} - 1 \quad (8)$$

$$U_{jn(min)}^{i} = U_{jn}^{(-i)} (when\ m_{jn}^{(-i)} = m_o)$$

We take first-order condition and optimize the profits of each individual competitor subjected to its own PA decision and PA decisions of its competitors.

$$maximize\ \pi^{i}(A_x, A_{-x})\ subjected\ to\ \pi^{-i}(A_x, A_{-x}) \quad (9)$$

The game is at Nash equilibrium (NE) when no player has a better strategy to play given the strategies of the other players. In general, monopoly profits are higher than oligopoly profits, and market players will tend to establish local monopolies through the choice of PA in the first stage of the game [12]. We assume that all market suppliers are rational decision makers, maximizing their profits. Thus, the equilibrium predicted by the model is stable in new circumstances. Note that we change only input data on market regulations and the number of competitors to find out potential equilibria in new circumstances.

IV. The Evaluation Case Analysis

The case study presented builds up on the ongoing collaboration with a Portuguese SME looking for a sustainable market position in European railway interiors market. The target market has two key buyers that are selling to three end customers each operating in a different national market. The national markets are different in terms of regulations applied to product performance (Figure 2). Thus, there are six business segments on the market.

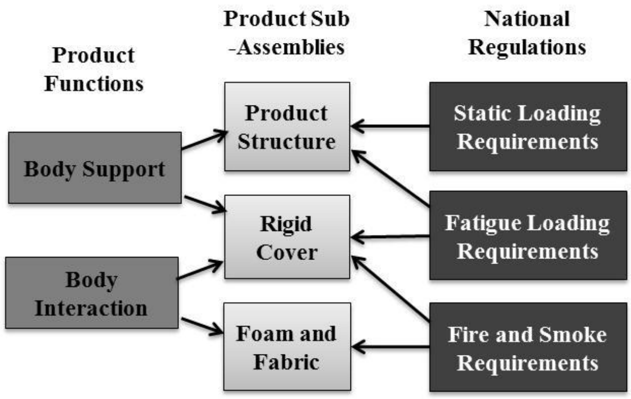

Fig. 2. Technology options and market regulations applied to product sub-assemblies based on functional analysis.

The target product is a seat for regional rail transportation. Product sub-assemblies are defined by product functions such as supporting the body and interacting with the body providing comfort to a passenger. The design of each product sub-assembly is affected by at least one national standard (Figure 2). Each sub-assembly can be manufactured out of few possible

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technology options (Table 1). Foam and Fabric sub-assembly is assumed to be identical for all possible PAs. There are two technology options for Product Structure and Rigid Cover forming four possible PAs.

TABLE 1
PRODUCT ARCHITECTURES IN CASE STUDY

Rigid Cover	Product Structure	
	HSS Laser Cutting	Aluminum Extrusion
Mild Steel Stamping	Architecture 1	Architecture 3
GFRP Hand Lay-out	Architecture 2	Architecture 4

The structural performance of each PA has been verified through finite element simulation in ABAQUS®. The Fire and Smoke data is a courtesy of the collaborating company. The above data was feed into the cost model. Costs were estimated based on the cost data of the collaborating company and information received from the potential technology suppliers. Typical business data, such as margin levels, structural costs, and interest rates, was obtained through the interviews with the buyers and prospective competition. Due to differences in the regulations between national markets of end customers each PA can have different performance (Figure 3).

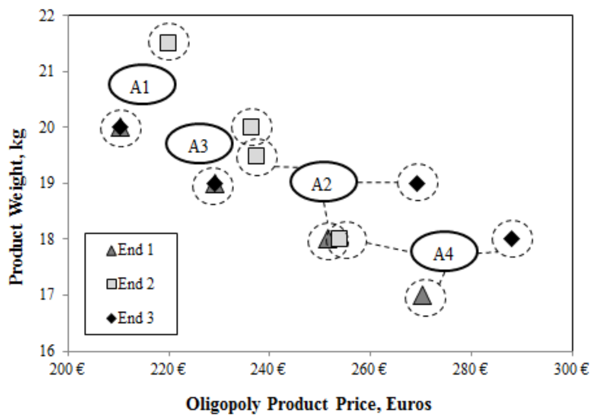

Fig. 3. Performance of technology options before new regulations.

The national market of end customer 2 has the strictest Static and Fatigue Loading Requirements, while national markets of end customers 1 and 3 are stricter in terms of Fire and Smoke Requirements with end customer 3 being the strictest.

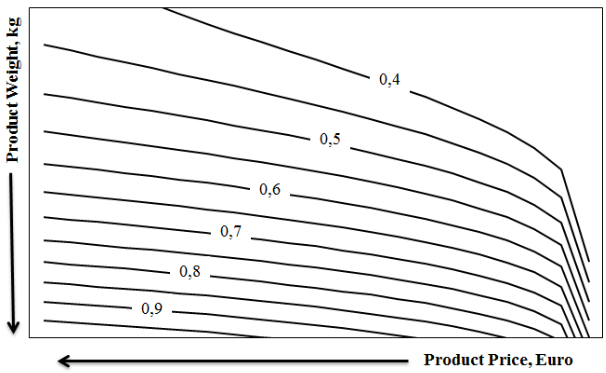

Fig. 4. Iso-utility curves of Buyer A.

Two buyers have diverse product preferences with regard to the two most important product attributes: product weight and product price. Due to internal restrictions Buyer A (Figure 4) is much more concerned with product weight than Buyer B (Figure 5). Thus, Buyer A is willing to pay more for a unit of weight reduction than Buyer B. Iso-utility curves were acquired from the MAUA interviews with the buyers. Finally, the shares of the market segments in a study period were given by the Marketing department of the collaborating company.

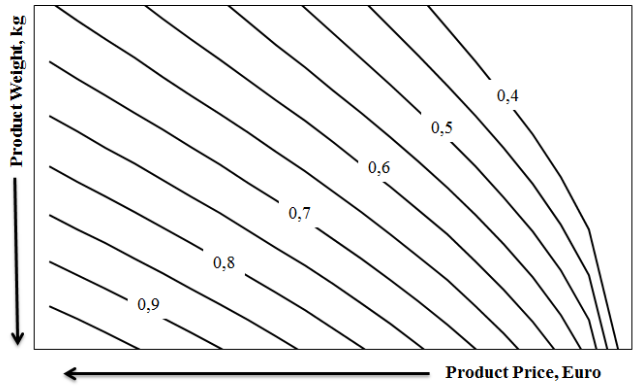

Fig. 5. Iso-utility curves of Buyer B.

For a study period, the markets of end customers 1 and 2 are slightly bigger than the market of end customer 3. Furthermore, Buyer A has a lead over Buyer B in the market of end customer 1 and vice versa for the market of end customer 2.

TABLE 2
PRODUCT ARCHITECTURES IN CASE STUDY

Market share of the Buyer for each end customer	End Customer 1 (35%)	End Customer 2 (35%)	End Customer 3 (30%)
Buyer A	60%	40%	50%
Buyer B	40%	60%	50%

The market is rather homogenous with the highest market share of 21% for segments 1A and 2B and the lowest market share of 14% for segments 1B and 2A. Note that target markets account for about 75% of European railway interiors market.

The model has been implemented in MS Excel® to predict the strategic interactions between the players. The model returns a strategic form game with a pay-off structure for every instance of the game, which helps to estimate the best response function for every competitor. Table 3 shows the NE for the case of national regulations and 2 competitors. The pay-offs in the table are profit per product taking into consideration shares of different market segments. The pay-offs of the Competitor One are in the first column; the pay-offs of the Competitor Two are in the second column.

We did not consider specific relations of each competitor with any of the buyers for the current analysis. Therefore, there are two NE in the game (A3,A2) and (A2,A3) that are symmetric. That is, in such circumstances, competitors prefer to invest in PAs 2 and 3.

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TABLE 3
STRATEGIC FORM GAME FOR THE CASE OF NATIONAL MARKET REGULATIONS AND 2 COMPETITORS

Strategy of Competitor One	Strategy of Competitor Two			
	A1	A2	A3	A4
A1	(8 ; 8)	(14,4 ; 24,5)	(10,7 ; 23,1)	(12,9 ; 18,2)
A2	(24,5 ; 14,4)	(9,4 ; 9,4)	(19,4 ; 18,5)	(12,7 ; 15,2)
A3	(23,1 ; 10,7)	(18,5 ; 19,4)	(8,7 ; 8,7)	(18,3 ; 18,6)
A4	(18,2 ; 12,9)	(15,2 ; 12,7)	(18,6 ; 18,3)	(10,1 ; 10,1)

Next we present how the market equilibrium alters when the market regulations are changing and the number of competitors is increased. For the purpose of the paper, the resulting market equilibria are analyzed qualitatively and compared to the “Best Value” case, which shows PA with the highest utility for each market segment when a supplier charges oligopoly price.

A. National Smoke and Fire Regulations

There is no dominant PA in the game. That is, each PA possesses the best utility for at least one market segment (Table 4). The game with two competitors has the equilibrium with PAs 2 and 3 in equilibrium as shown before. If the current market situation changes marginally PAs 3 and 4 can also be played in equilibrium. When a new competitor enters the market all market players diversify more with PAs 1, 3 and 4 played in equilibrium. Thus, the order of PAs for the new market entrant is {A4; A1; A3}. Note that the second-mover from existing competitors has an advantage over the last-mover. On contrary, the existing competitors can preoccupy the most profitable PAs 1 and 4. However, this strategic move would still not deter the entry.

TABLE 4
GAME EQUILIBRIA FOR THE CASE OF NATIONAL MARKET REGULATIONS

Market Segments		PA choices for market segments in equilibrium											
		The Best Value				2 Competitors				3 Competitors			
PAs		1	2	3	4	1	2	3	4	1	2	3	4
1	A				X		X						X
1	B	X					X			X			
2	A				X			X					X
2	B		X				X						X
3	A			X				X				X	
3	B	X						X		X			
		2	1	1	2		3	3		2		1	3

B. European Smoke and Fire Regulations

New European Fire and Smoke Regulations impose the same requirements for each national market. Thus, the only difference would be in Structural Performance of different PA. When the regulatory differences are removed away from the market, only the difference between utility functions of two market buyers distinguishes the market segments (Table 5). Hence, there are only two PAs 1 (“the cheapest”) and 4 (“the lightest”) that return the highest utility values for both buyers. Nevertheless, two competitors would prefer to invest in PAs 1 and 2. This is due to the fact that the profit returns of PA 4 are limited by the maximum price limit (Figure 6) and competitors would prefer to invest in PA 2 instead. When the new market player enters the set of PAs, played in equilibrium, changes. Now there is one supplier that acquires a monopolistic position in three market segments with PA 1 and two suppliers investing in PA 4 and obtaining oligopoly profits in the remaining market segments.

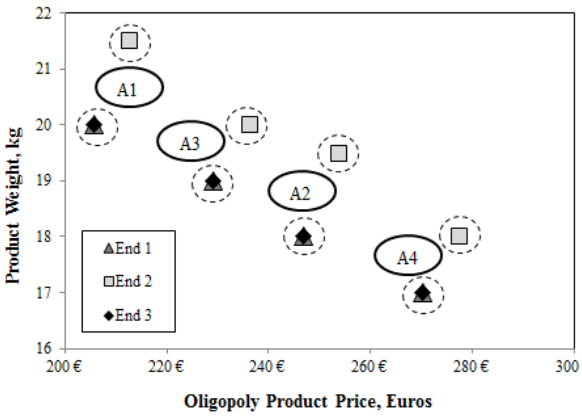

Fig. 6. Performance of technology options after new regulations.

TABLE 5
GAME EQUILIBRIA FOR THE CASE OF EUROPEAN MARKET REGULATIONS

Market Segments		PA choices for market segments in equilibrium											
		The Best Value				2 Competitors				3 Competitors			
PAs		1	2	3	4	1	2	3	4	1	2	3	4
1	A				X		X						X2
1	B	X				X				X1			
2	A				X		X						X2
2	B	X				X				X1			
3	A				X		X						X2
3	B	X				X				X1			
		3			3	3	3			3			3

C. PA Recommendations for Changing Business Environment

Finally, decision support guidance for the existing supplier can be obtained (Figure 7). We are able to predict the best choice of PA strategy in light of two potential events in the decision situation: the entry of the new competitor and new European regulations. When there is no entry, the best choice is PA 2 since it returns monopoly profits from three market segments irrespectively of changes in regulatory environment (c.f. Tables 4 and 5). However, the entrance of the new market

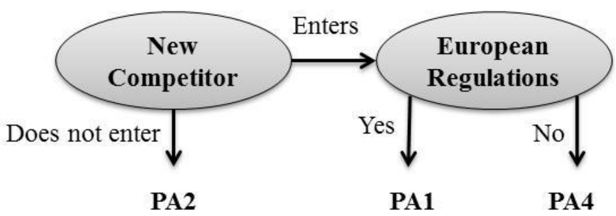

Fig. 7. Decision support “tree” for the existing supplier.

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supplier (change of endogenous market factor) considerably changes the prospective market equilibrium and now the attention should be paid whether or not the regulations are changing (change of exogenous market factor). In this case PA4 is the best choice when the regulations are not likely to change and PA1otherwise.

To summarize, the case study presents the scenario when the change in external market factor does not alter the respective market equilibrium. Yet, when internal market conditions are changing together with external factors it is greatly affecting the resulting market equilibrium.

V. Discussion

The problem with a current set of parameters returned pure-strategies NE. Still, this is not always the case and the problem might be solved only with mixed-strategies equilibria [13]. Moreover, sensitivity analysis can be useful in order to check the robustness of the obtained solution and define the range of the parameters for which the solution holds. The latter is advantageous in case the decision maker is uncertain about the possible state of the market.

Although MS Excel® can be readily applied to more complex problem set-ups; its application is limited when the complexity of the problem increases. The most critical in this case is the increase in the number of competitors. Recent research suggested that such problems can be solved with: linear programming [3], genetic algorithms [14], and discrete selection and iterative optimization [15]. Most of the models were implemented in MATLAB®. The selection of the exact method depends on the problem at hand.

The results of the analysis are well aligned with previous research on competitive interactions. First of all, the market players always choose to position their products as far away as possible from the competition and establish local monopolies [12]. Secondly, more competition increases the "social welfare" of the market and leads to better served market segments [16]. However, we show that abolishing the barrier between market segments (implementing the same product regulations across the markets) does not necessarily lead to closer product positioning and intensified price competition. This is the case of remaining heterogeneity between the buyers, which is sufficient to avoid fierce price competition between the suppliers.

Finally, the decision maker is advised to carefully integrate the framework into the decision process and take into account that in real life the competitors might play more aggressively [17].

VI. Conclusion

Successful market positioning of new products is an important factor that drives the profitability of the company. Effective models that assist on product positioning decisions should account for appropriate representation of the market product preferences and differences among the various buyers on the market. The model should also take into account competitive reactions of other market players in pursuit of sustainable position. Moreover, a good product positioning decision making should anticipate potential changes and make PA and technology choice appropriately.

The paper presented an approach to incorporate the knowledge on potential market alterations together with prospective competitive reactions into the actual product development scenario. On-going research continues to enrich the model in few directions we believe are relevant for the actual business environment. In certain situations non-product related attributes (e.g. reputation and quality records) are also taken into account while making purchasing decisions and building relationships with the suppliers. We believe that the proposed model will enhance the communication between product development and marketing teams and general management within SME while making product positioning decisions.

References

[1] Y. J. Wind, Positioning Analysis and Strategy. Working Paper, Wharton School, University of Pennsylvania, Marketing Department. Issue 88, Part 29, 1988, 88 p.
[2] J. Hauser and S. Shugan, Defensive Marketing Strategies. Marketing Science, 1983. 4 (2): p. 319-360.
[3] C.-S. Shiau and J. Michalek, Optimal Product Design under Price Competition. Journal of Mechanical Design, 2009. 131 (071003): p. 1-10.
[4] J. Michalek, P. Papalambros, S. Skerlos, A Study of Fuel Efficiency and Emission Policy Impact on Optimal Vehicle Design Decisions. Journal of Mechanical Design, 2004. 126: p. 1062-1070.
[5] A. Ansari, N. Economides, and A. Ghosh, Competitive Positioning in Markets with Non-uniform Preferences. Marketing Science, 1994. 13 (3): p. 248-273.
[6] J. Hauser, Competitive Price and Positioning Strategy. Market Science, 1988. 7 (1): p. 76-91.
[7] F. Field, R. Kirchain, and R. Roth, Process Cost Modeling: Strategic Engineering and Economic Evaluation of Materials Technologies. Journal of Metals, 2007. 49 (10): p. 1543-1581.
[8] R. Roth, F. Field, J. Clark, Materials selection and multi-attribute utility analysis. Journal of Computer-Aided Materials Design, 1993. 1: p. 325-342.
[9] R. L. Keeney, G. L. Lilien, A Utility Model for Product Positioning. Working Paper #777-75, Sloan School of Management, Massachusetts Institute of Technology, 1975, 19 p.
[10] J. Hauser, D. Clausing, House of Quality. Harvard Business Review, 1988, 13 p.
[11] E. Crawley, O. de Weck, O., S. Eppinger, C. Magee, J. Moses, W. Seeting, J. Schindall, D. Wallace, and D. Whitney, The Influence of Architecture in Engineering Systems. Engineering Systems Monograph, Cambridge, MA, March. 2004, pp. 1-29.
[12] S. Roy, "Strategic Segmentation of a Market", International Journal of Industrial Organization, vol. 18 (2000): pp. 1279–1290.
[13] R. Deneckere, D. Kovenock, "Price leadership". Review of Economic Studies, vol. 59 (1992): pp. 143–162.
[14] H. Rhim, L. G. Cooper "Assessing Potential Threats to Incumbent Brands: New Product Positioning Under Price Competition in a Multisegmented Market," Int. J. Res. Mark., 22 (2), 2005: pp. 159–182.
[15] L. Luo, P. K. Kannan, and B. T. Ratchford, "New Product Development Under Channel Acceptance," Mark. Sci. Providence R.I., 26(2), 2007: pp. 149–163.
[16] D. Fudenberg, J. Tirole, "The fat-cat effect, the puppy-dog ploy and the lean and hungry look". Papers and Proceedings of the American Economic Association, vol. 1, 1986: pp. 361–366.
[17] U. G. Marks, S. Albers, Experiments in Competitive Product Positioning: Actual Behavior Compared to Nash Solutions. Schmalenbach Business Review, 2001, 53: p. 150 – 174.

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