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Optimizing differentiation and commonality levels among models in car line-ups: An empirical application of a nature-inspired heuristic mechanism

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ABSTRACT

The product life cycle of cars is becoming shorter and carmakers constantly introduce new or revised models in their lines, tailored to their customer needs. At the same time, new car model design decisions may have a substantial effect on the cost and revenue drivers. For example, although a new car model configuration with component commonality may lower manufacturing cost, it also hinders increased revenues that could have been achieved through product differentiation. This paper develops and illustrates a state of the art, nature-inspired approach, to design car lines that optimize the degree of differentiation vs commonality among models in the line. More specifically, we apply a swarm intelligence mechanism to stated preference data derived from a large-scale conjoint experiment that measures consumer preferences for passenger cars in a sample of 1164 individuals. The proposed two-step methodology is also incorporated into a prototype system, which has been developed in an attempt to facilitate managerial decision making. Our approach provides interesting insights into how new and existing car models can be combined in a product line and identifies the desired balance between differentiation and commonality levels among models within a product line, which elevates customer satisfaction.

1. Introduction

In technology and capital-intensive industries product lines need to constantly evolve in response to market and technology changes. In the automotive industry the process of designing a line of cars is extremely costly and requires extended investments in R&D, whilst product variety within the line is a critical marketing-mix decision that may determine a firm's survival (Jan & Hsiao, 2004).

Industry practice and research to date suggest that product line design decisions in the car industry range between two options, namely, differentiation and commonality. Differentiation among car models in a line enables the manufacturer to charge price premiums, due to greater product variety, but is criticized for escalating product design, development, and manufacturing costs (Heese & Swaminathan, 2006). Commonality and component sharing among car models in the line has been suggested as a means to lower design and manufacturing cost, but is criticized for hindering price premiums and revenues. A product configuration with commonality may distort the perceived value of the product to consumer when the component sharing among products in the line is visible or is known to the consumer (Robertson & Ulrich, 1998). For example, General Motors was negatively criticized for its look-alike car line-up and Honda lost significant market share for its Acura model which was considered to be nothing more than a Honda Accord. Even the best hidden common components will diminish perceived valuation, especially when shared attributes are highly valued by the consumers (Desai, Kekre, Radhakrishnan, & Srinivasan, 2001).

The vast majority of research on commonality vs differentiation in operations management has investigated the cost effects associated with scale economies, risk pooling effects, and reductions in product and process complexity, but has mostly neglected the substantial impact that commonality can have on market shares of a product line (Baker, Magazine, & Nuttle, 1986; Lee, 1996). For a detailed review on the above research streams the interested reader is advised to see the work of Swaminathan and

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Lee (2003). The conventional paradigm in the automobile industry is that, while enabling potentially substantial cost reductions, commonality generally reduces the attractiveness of a car line and, ceteris paribus, leads to lower revenues. However, a manufacturer should also consider commonality decisions in determining optimal product configurations within lines, as a means to reduce escalating manufacturing costs. Evidently, the balance between differentiation and commonality among models in a car line-up represents a considerable dilemma for car manufacturers.

The automobile industry is capital-intensive and has received much attention in the literature. Several topics have been examined so far, both from an administrative and a customer preference perspective, including automobile sales forecasting through network-based fuzzy inference systems (e.g. Wang, Chang, and Tzeng (2011)), customer segmentation in the automobile market through genetic algorithms (e.g. Chan (2008)), automobile price formation through artificial neural networks (e.g. Iseri and Karlık (2009)), product diffusion in the automobile market through agent-based models (e.g. Kim, Lee, Cho, and Kim (2011)), and estimation of customer satisfaction indexes for automobile manufacturers (e.g. Chiu, Cheng, Yen, and Hu (2011)). On the other hand, the issue of designing car line-ups that optimize the degree of differentiation vs commonality among models in the line has received much less attention, despite its importance from a managerial perspective. All existing studies have so far examined the typical optimal product line design problem, which (a) disregards commonality and differentiation design aspects, and (b) considers product attributes which are treated as discrete variables (see e.g. Kuzmanovic and Martic (2012), Lin, Shih, Cheng, and Lee (2011)). Optimizing the degree of commonality vs differentiation among models in a car line-up is an important design problem for every car manufacturer, especially if we also take into consideration that in the automobile industry, most of the car attributes that drive customer satisfaction can take values from a continuous range (e.g. horsepower, fuel consumption, maximum speed, etc). Against this background, the present paper tries to address these crucial design issues through the application of a state of the art, nature inspired mechanism.

Several alternative heuristic procedures that could potentially handle such highly complex optimization problems have been proposed in the literature, including Dynamic Programming (Kohli & Sukumar, 1990), Beam Search (Nair, Thakur, & Wen, 1995), and Lagrangian Relaxation with Branch and Bound (Belloni, Freund, Selove, & Simester, 2008). Recently, nature-inspired approaches have been also introduced, including genetic algorithms (Steiner & Hruschka, 2003) and Ant Colony Optimization (Albritton & McMullen, 2007). For the latest review, see Tsafarakis and Matsatsinis (2010). Contrary to existing approaches, our mechanism can assist manufacturers in designing car lines that optimize the degree of differentiation vs commonality among car models in the line, whilst allowing product configurations to take on any value from a continuous design solution space. Evidently, the contribution of this study is twofold and resides in both the managerial problem and the research methodology.

The present study follows a two-step methodology: First, consumer preferences for car attributes have to be determined. To do that, stated preference data are derived from a large conjoint experiment involving preferences for automobiles. In the second stage, the derived measures of individual preferences are utilized to predict the valuation for any new concept car configuration that was not originally assessed by the respondents. The nature of the problem demands product attributes to vary over both a continuum range of values and a set of predetermined discrete levels. To deal with this issue we apply Particle Swarm Optimization (PSO), a state of the art optimization algorithm inspired from natural intelligence, which has excellent compatibility with continuous, nonlinear functions, and thus can simultaneously handle both continuous and discrete data. The proposed mechanism, which is also integrated into a prototype system, provides important implications for managers in the automotive and other capital-intensive industries who attempt to reduce manufacturing and design costs, whilst maintaining their ability to charge price premiums through variation in key product characteristics.

The rest of the paper is organized as follows. In the next section, we provide an overview of the literature on product variety, with a particular emphasis on the studies focusing on the automotive industry. Section 3 illustrates the conjoint experiment which was carried out to analyze consumer preferences for car attributes. Section 4 provides an overview of the Particle Swarm Optimization algorithm and introduces our approach to the car market. Section 5 discusses the empirical results, whilst in Section 6 a prototype system is presented, which supports the proposed two-step methodology and facilitates decision making. Finally, a concluding section summarizes the paper and provides useful implications for managers and researchers.

2. Theoretical background

2.1. Research on product variety: Insights into the automotive industry

Enhancing product variety is a trend in many industries and as a result, several aspects of the topic have been examined in the literature. For example, Ramdas and Sawhney (2001) focused on the dimensions of product variety by examining how an assembled product manufacturer can use components to differentiate and variegate its products. Krishnan and Gupta (2001) focused on the broad topic of product architectures and tried to identify the design resources that must be shared across product platforms. In the same direction, Ulrich and Ellison (1999) examined the factors that drive different degrees of customization within a single industry, whilst Bhattacharya, Krishnan, and Mahajan (2003) tried to examine how to time the introduction sequence for related products. Finally, Singhal and Singhal (2002) examined the impact of product variety on manufacturing operations, whilst Randall and Ulrich (2001) examined the impact of supply chain structure on product variety management (see also Ramdas (2003), for a detailed review of the literature on product variety).

Cars are very complex products, and thus, this sector has attracted considerable attention in the literature of product variety. The aim of these studies is to examine how variety in a car-line can be best managed. For example, Pil and Holweg (2004) explored the link between external variety (i.e., the variety offered the customer) and internal variety (i.e., the variety involved in creating the product), and found that these two dimensions can be independent of each other. Scavarda, Schaffer, Schleich, Winkler, and Hamacher (2007) and Schleich, Schaffer, and Scavarda (2007) examined product variety on the basis of the different variants offered by car manufacturers, whilst Scavarda, Schaffer, Schleich, da Cunha Reis, and Fernandes (2008) attempted to describe the development of an automobile product variety analysis, by also taking into consideration platforms, models and dealer fitted options. Finally, Stäblein, Holweg, and Miemczyk (2011) proposed and empirically tested a set of novel measures of product variety (i.e., the average repetition ratio and a specification Pareto curve), in an attempt to enhance the understanding of product variety.

Most of the product variety literature in the automotive sector has long emphasized the fact that reduced product variety may decrease manufacturing costs, but also reduces revenues by limiting the range of options in the marketplace (Pil & Holweg, 2004). In the automotive domain, although some manufacturers are beginning to build vehicles tailored to customer orders, such a transition is extremely costly, and thus, the issue of product variety becomes