Product Modularity:
Conceptualization, Measurement, and Consequences

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Abstract

Customized products help firms creating differentiated value for consumers in highly competitive markets. Modular product designs enable firms to fulfill market requirements for customization while balancing profitability targets. In modular product design, larger systems are broken down into independent sub-components, while the functionality of the entire system is preserved. While product modularity has received great attention from the literature in production and process optimization, research on consumer perceptions of modular products is still in its infancy. The present study develops a two-dimensional scale for product modularity as a basis for an online consumer survey, assessing their perceptions of modular product designs and potential effects of product modularity on product adoption intention. Particular value of this study lies in the application of a consumer research vantage point in the literature field of modular product design.

Keywords: Product Modularity; Product Design; Customization

1. Introduction

Today's consumer goods markets are shaped by intensifying competitive pressure. In order to keep up with competition, many firms constantly expand their product programs, resulting in an unprecedented product diversity and choice complexity for consumers (Salvador, Forza, and Rungtusanatham, 2002). In this complex market setting, the supply of customized products – i.e., products adapted to individual consumer needs or preferences – that help to create differentiating value for consumers is of pivotal importance for the survival of companies (Franke, Keinz, and Steger, 2009). Flexible or so-called modular product designs enable companies to fulfill current market requirements for customization while balancing profitability targets (Sanchez, 1995).

Modular product design describes a hierarchical design principle, breaking a greater system into independent sub-components – referred to as modules – while at the same time preserving the functionality of the system (Baldwin & Clark, 2000; Langlois; 2002; Ulrich, 1995). A modular product design enables an easy assembly into various functional forms, allowing consumers to add or replace individual components as required. For example, the Swedish furniture manufacturer IKEA offers shelving or kitchen systems that build on modular product components (Franke, Keinz, and Schreier, 2008). Consumers can create and assemble individual products from a large pool of standardized components and even adapt products post-purchase.

While modular product design has received great attention from production and process optimization literature, involving research on the simplification of complex products, processes, and organization systems (Bask, Lipponen, Rajahonka, and Tinnilä, 2011; Jose & Tollenaere, 2005), the consumer perspective has been largely neglected in this stream of literature. Yet, the literature acknowledges that an in-depth understanding of consumers' perception of modular product design is crucial for the assessment of the market potential of modular products and, in turn, for the development of a competitive advantage based on customized product offerings (Fiore, Lee, and Kunz, 2004). In order to address this apparent gap in research and to enrich the literature on modular product design, the present study adopts a consumer vantage point and explores consumers' perceptions of modular product designs.

2. Research Background

Recent advances in information and production technology as well as the development of modular manufacturing systems have led to an increase in modular product offerings over the last two decades. From a technical perspective, product modularity comprises both the functional and the physical independence of individual sub-components of a product (Baldwin & Clark, 2000; Gershenson, Prasad, and Zhang, 2003; Sanchez & Mahoney, 1996; Ulrich, 1995). Functional independence is given when a sub-component of a product fulfills exactly one sub-function, independent from other sub-components. For example, most smartphone cameras are functionally independent from other components of the phone. Physical independence describes the interface design of a product, referring to the physical structure of individual sub-components. The apple iPhone serves as an example of a product design that avoids physical independence – sub-components of the phone, such as the camera, cannot be separated from other sub-components.

Traditionally, product modularity has been studied in the context of systems and production research. For example, several authors develop models to determine the optimal number and choice of product components or modules to enhance the performance of modular product designs in manufacturing (Pimmler & Eppinger, 1994; Stone, Wood, and Crawford, 2000).

Others focus on potential cost-savings and synergy effects of modular product designs in manufacturing processes (Lau, Yam, and Tang, 2007; Watanabe & Ane, 2004).

Within this stream of research, the consumer perspective on product modularity remains largely unexplored. This fact is particularly surprising, because modular product designs can serve as valuable means to satisfy consumer needs for product customization. Building on customer value theory (Mazumdar, 1993; Zeithaml, 1988), this study aims to explore the extent to which modular product designs can influence consumers' value perceptions and, in turn, product adoption intention for modular products. In customer value theory, consumers' value perceptions with regard to a specific product are attributed to consumers' assessment of perceived benefits versus perceived cost (or risk) of an adoption transaction (Mazumdar, 1993; Zeithaml, 1988). According to this theory, consumers assess benefits such as simplicity, utility, or customization, whereas they assess the cost dimension along the lines of the financial transaction costs as well as risk perceptions (Lai, 1995; Lapierre, 2000; Mazumdar, 1993; Zeithaml, 1988). As consumers try to anticipate the outcome of an adoption decision, benefits and risk associated with a respective product alternative are carefully evaluated (Taylor, 1974).

In the context of the present research, we expect that product modularity influences both consumers' benefit and risk perceptions. On the one hand, modular product designs allow for customization of products, thereby adding value to a product offering from a consumers' vantage point (Franke & Piller, 2003; Schreier, 2006). On the other hand, more options to choose from can also result in perceptions of complexity, confusion, additional time and cognitive effort, and functional risk perceptions among consumers (Huffman & Kahn, 1998; Jacoby & Kaplan, 1972; Schreier, 2006; Stone & Grønhaug, 1993). To the best of our knowledge, empirical research is lacking on the potential effects of product modularity on consumers' benefit and risk perception and, thus, on their overall value perceptions. Furthermore, there is also paucity of research on the role of product modularity in product adoption decisions.

3. Method

As product modularity had only been studied in the context of systems and production research, the authors of the present study developed a conceptualization and operationalization of the focal construct from a consumer vantage point. First, following established scale development procedures from the literature (Churchill, 1979), the authors of this study conducted a comprehensive review of the relevant literature to develop the aforementioned definition of the focal construct and to identify potential dimensions and indicators of product modularity (Gershenson, Prasad, and Zhang, 2003; Gershenson, Prasad, and Zhang, 2004; Salvador, 2007).

Second, qualitative in-depth interviews with 18 consumers helped to illuminate the consumer perspective on product modularity. Comparing the interview data with the findings from the literature analysis, the authors developed an initial scale with 25 indicators to measure product modularity. Third, this scale was tested quantitatively via means of a paper-pencil consumer survey (n = 48) eliminating redundant indicators and gaining insight into the actual dimensionality of the focal construct. An exploratory and a confirmatory factor analysis of the survey data resulted in a two-dimensional operationalization of product modularity, with eight distinct indicators measuring the functional and physical independence of a product's sub-components and, therefore, reflecting the degree of product modularity (Baldwin & Clark, 2000; Ulrich, 1995).

Having established an adequate scale to measure product modularity in a consumer research context, the authors of this study conducted an online consumer experiment to explore consumers' perceptions of modular product designs. A pretest (n = 52) helped to ensure the validity and the reliability of the study design. The questionnaire for the main study (n = 324) consisted of two sections. The first section briefly introduced the concept of product modularity and randomly assigned one of six product scenarios. These six scenarios differed in both the product category (smartphones and leisure shoes) and the degree of product modularity. Three modularity degrees (MGs) accounted for the functional and physical independence of the product components. MG1 represented an integral standard product, MG2 represented a partially modular product that consumers could customize before purchase (e.g., choosing color or configuration), and MG3 represented a fully modular product, offering customization options even after purchase (e.g., replacing individual components). The second section of the questionnaire assessed consumers' value perceptions with regard to the perceived benefits and perceived risk of the respective product. Furthermore, several questions assessed consumers' individual adoption intention and sociographics (e.g., innovativeness, gender, age, income).

After completion of the data collection, a confirmatory factor analysis using the covariance-based software package SPSS Amos validated the two-dimensional structure of the product modularity construct. Building on the interpretation of established measures (e.g., Cronbach's Alpha, factor loadings and cross-loadings, Fornell-Lacker criterion, coefficient of determination R^2, standardized path coefficients), the authors ensured the reliability and validity of the measurement instrument. Subsequently, the authors applied the partial-least-squares method (PLS) to analyze the data and to test the research model. A base model including the dependent variable adoption intention, the independent variable product modularity, and the (partial) mediator variables perceived benefit and perceived risk served as a starting point for empirical investigations. Several control variables such as consumer innovativeness, gender, age, income, involvement, or perceived product innovativeness were included in the model. Building on Sobel (1982) and Preacher and Hayes (2008), the authors tested the research model for full and partial mediation of the benefit and risk variables by applying bootstrapping.

4. Empirical Findings

The analysis of the data shows that product modularity has a positive effect on consumers' value perception of consumer goods and, in turn, on product adoption intention. A higher degree of product modularity (MG1 vs. MG2) leads to a higher degree of perceived benefits from the consumer perspective, but also to a higher degree of perceived risk. Yet, a stronger effect of product modularity on perceived benefit versus perceived risk leads to an overall positive effect of product modularity on perceived value and, in turn, on product adoption intention. These findings hold true only for an increase in product modularity from MG1 to MG2. Increasing the degree of product modularity from MG2 to MG3, the positive effect of product modularity on adoption intention diminishes, as unchanged benefit perceptions come along with a further increase in consumers' risk perceptions. It is worth to note that despite increasing risk perceptions, consumers' adoption intention remains at the same high level for MG3 as compared to MG2 due to significantly positive direct effects of product modularity on adoption intention. The findings are robust for both product groups, smartphone and leisure shoes. The (partial) mediation test reveals a full mediation effect of the perceived benefit variable on the relationship between product modularity and adoption intention. In contrast, perceived risk only partially

mediates the effect of product modularity on adoption intention, with a small but significant direct effect of product modularity on adoption intention in the model.

5. Theoretical Contribution

Building on customer value theory, this study explores the effects of modular product design on consumers' value perceptions and its influence on consumers' product adoption intentions. The findings of this study add a consumer perspective to a research field that previously had been characterized by a rather technical focus mostly stemming from production and systems research. Specifically, this study provides two major contributions to existing literature.

First, the present study offers a conceptualization and operationalization of product modularity in the context of marketing research. The development and validation of the two-dimensional scale for product modularity paves the way for future research applying this measurement instrument to shed further light on the role of product modularity in consumers' purchase decisions.

Second, the particular value of these research findings lie in the generation of insights with regard to consumers' benefit and risk perceptions in the context of product adoption decisions resulting from different levels of product modularity. The findings of this study indicate that product modularity has a positive effect on consumers' value perceptions and, in turn, on product adoption intention. However, from a consumer perspective, this study reveals that an increase in product modularity first has a beneficial effect on value perceptions while at high levels of product modularity this effect is diminished. Companies, thus, need to be aware of this diminishing effectiveness of product modularity on consumers' value perceptions.

6. Managerial Implications

While modular product design is a valuable means to satisfy growing consumer needs for customization, managers need to be aware of potential negative effects from increasing risk perceptions caused by high levels of product modularity. In this respect, the findings of this study indicate that the physical independence of individual sub-components negatively impacts risk perceptions, which is why managers should carefully consider an increase in this dimension of product modularity. The physical independence of sub-components evokes consumers' perceptions of an increasing risk of a products' instability and malfunction (Jacoby & Kaplan, 1972; Stone & Grønhaug, 1993). Detailed product descriptions and warranties can mitigate negative risk perceptions, for example, with regard to the functionality and longevity of modular products.

However, the functional independence of product sub-components can help to increase consumers' benefit perceptions if it is implemented to generate a selective, user-oriented choice variety without a confusing extension of the total number of choice alternatives. Managers may adapt the nature and availability of product sub-components to the functional needs of consumers, limiting necessary choices, and present choices in a simple manner.

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