Linkages between product modularity and integration strategies: a conceptual framework to determine competitive capabilities

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Abstract—Existing streams of literature are integrated to propose a conceptual framework that highlights the effect of product modularity on competitive performance with three integration strategies as potential mediators. The framework aims to provide insights into the influence of product modularity on multiple dimensions of competitive performance.

Keywords- product modularity, competitive performance, integration strategy, manufacturing

I. INTRODUCTION

Rapid changes in manufacturing technology coupled with an increasing demand of customized products has seen many firms to look at implementing product modularity (PM) strategy as a means of gaining competitive advantage. Since the pioneering work on modular design theory by Ulrich and Tung (1991), a stream of research has emerged on this topic. Much of the literature on PM deals with features of product components and the extent to which modules are independent or separate; the extent to which components are specific; the extent to which modules are transferable or reusable within the production process; and cost saving benefits of PM (Baldwin and Clark, 2000; Schilling, 2000).

Extant literature has considered PM to be an effective approach for mass customization and cycle time reduction (Duray et al., 2000), enabling manufacturers to improve strategic flexibility (Worren et al., 2002; Sanchez, 1995). Numerous studies have reported on the benefits of PM at a firm level (Sanchez and Mahoney, 1996). However, the impact of PM beyond the firm in strategic terms such as external integration and their impact on competitive capabilities have only begun to be explored (Antonio 2009; Howard and Squire, 2007; Gadde and Jellbo, 2002; Worren et al., 2002; Rosenzweig et al., 2003).

Choosing sample from the automotive sector, a more recent examines the relationship between product modularity and competitive performances with supplier integration, design integration, and manufacturing integration as mediators (Jacobs et al, 2007). Given that there are fundamental differences in the industry dynamics, market structures, and customer needs between developed and developing countries of the world, the larger aim of this study is to develop a conceptual framework and after testing the framework further empirically examine the effects of product modularity on competitive performances of the manufacturing sector in a developing and emerging market. In this paper, a conceptual framework is proposed to linkages between PM and the domains of competitive capabilities, that is cost, quality, flexibility and cycle time. The framework also attempts consider the test the mediation effect of integration strategies (supply, design, and manufacturing integrations) between PM construct and each of the competitive performance outcomes (Figure 1).

II. PROPOSED CONCEPTUAL FRAMEWORK

A. Proposition 1-Potential Linkage Between Product Modularity And Cost

There is broad consensus that PM reduces product cost (Jacobs et al. 2007). Costs reductions in modular product design arises due to increasing economies of scale (Ulrich and
Proposition 1: Product modularity will have a positive effect on cost performance.

Proposition 2- Product Modularity and Flexibility

Flexibility during production process can lead to competitive advantage (Yusuf et al., 2004; Worren et al., 2002). Because of advantages of flexibility, firms try to set up manufacturing systems that are flexible. But a system ability to be flexible and handle variety is ultimately determined by the product architecture (Ulrich, 1995).

Product modularity has an impact on flexibility in a variety of ways. Firstly, production mix flexibility is increased with the use of product modularity (Lorenzi and Lello, 2001). This means that set-up times that the number of similar components or subassemblies.

Another study reports cost benefit arising from engineering and operational efficiencies attributable to modularization (Collier, 1981). Finally, firms can also benefit through a reduction in investment costs (Fisher et al., 1999). Given that PM enables standardized production process, costs associated with tooling, engineering, testing, and support services are all reduced by using standardized components and sub-assemblies (Fisher et al., 1999).

In contrast to the general consensus, one study reports a contrast finding indicating that product modularity does not necessarily lead to cost reductions (Kuttnet, M., Nachtsheim, C., Neter, J. and Li, W., 2005). This study conclude that PM process actually leads to increase in spare parts costs due to a higher failure rates of modules vis-a-vis components. However, a limitation of this study is that there is no comparison between the cost of spare parts required by modular products and that for integrated products.

We therefore offer the following research proposition:

Proposition 3: Product modularity will have a positive effect on quality improvements.

Proposition 4-Product Modularity and Cycle Time

PM leads to reducing cycle time (Sherman et al., 2000; Lorenzi and Lello, 2001). As PM enables manufacture of modules in parallel and assembles them based on order requirements, cycle time is reduced (Novak and Eppinger, 2001; van Hoek and Weken, 1998). Improved component
availability also reduces cycle time (Jacobs et al., 2005). Lee and Tang (2007) report that system service levels improve with modular architectures and contribute to cycle time reduction. Modular product design is considered to be an effective approach for mass customization and cycle time reduction (Ro et al., 2007).

We therefore offer the following research proposition:

**Proposition 4:** Product modularity will have a positive effect on reducing order cycle time.

**E. Proposition 5: Role of supplier integration as a potential mediator between PM and competitive performance**

The concept of integrating suppliers has received attention since the initial surge in exploring Japanese manufacturing practices (Parker et al., 2008). Early studies focused on finding the competitive advantage that Japanese manufacturers enjoyed over their U.S. and European counterparts (Clark, 1989; Clark and Fujimoto, 1991; Womack, Jones and Roos, 1991).

Jacobs et al. (2005) identify three facets of supplier integration from the perspective of the buying organization, supplier development; just in time purchasing; and supplier partnering. Antonio et al. (2010) specifically identify three organizational processes that integrate supply chain with PM, namely, information sharing, product co-development and organizational coordination. Past studies indicate that PM has a positive influence on supplier integration as it builds a cooperative relationship by increasing the level of trust through the improved forecasts brought about by product modularity (Petersen et al., 2005). Supplier integration is also enhanced by reducing communication barriers through the creation of a common language (Lorenzi and Lello, 2007; Galvin and Morkel, 2007).

Studies have also indicated that supplier integration has a positive effect on firm performance (Antonio et al., 2007; Carr and Pearson, 1999); cost, quality, and cycle time, (Landeros and Monczka, 1989); increase in innovation and a decrease in cost and cycle time (Lewis, 1995).

We therefore offer the following research proposition:

**Proposition 5:** Product modularity will have a positive effect on

(a) Supplier integration; and

(b) Cost, quality, flexibility, and cycle time through supplier integration.

**F. Proposition 6: Role of design integration as a potential mediator between PM and competitive performance**

Modularity defines components that are designed independently but still function as an integrated whole (Baldwin and Clark, 1997). Designing for PM attempts to achieve high levels of simplification and standardization in product modularity. Methods used to solve the same modularization problems have different results, clearly indicating the impact of the extent of design integration (Holtha and Salonen, 2003).

Research on PM and design integration address a variety of concerns that include assembly line design (He and Kusiak, 1998); decomposition of manufacturing systems (Kusiak, 1990; Kim et al., 1993); modular work cell design (Chen et al., 1999) product platform and family design (Erens and Verhust, 1997; Gonzalez-Zugasti et al., 2000; Muffatto and Roveda, 2000; Sanderson and Uzumeri, 1995) and assembly line design (He and Kusiak, 1998).

Apart from the effect of product modularity on key elements of design integration, an effect of design integration has been found to affect competitive performance (Jacobs et al., 2005). Design integration resulted was also reported to reduced product cost (Sharma, 2004). Another study based on a case analysis found that design integration constructs enables faster production thereby giving more time to market products (Mabert et al., 1992). Reduction in production cost, improved reliability of product leading to better financial performance of firm was reported as benefits through design integration (Parker, 1997).

Thus, there is support in the literature that modularity and design integration are related and affect competitive performance. We therefore offer the following research proposition:

**Proposition 5- Role of supplier integration as a potential mediator between PM and competitive performance**

Given the global competitiveness, successful product development can only be achieved if the firm effectively integrates internal functions including manufacturing (Kahn, 2001; Sherman et al., 2000).

A number of studies have shown that manufacturing integration has a positive impact on performance. Sohal et al. (2001) report that manufacturing integration techniques resulted in overall improvements for the study firm, aside from other contributory factors. In a different setting and employing a different methodology, a case study of a manufacturing firm concluded that, integration techniques were found to reduce costs (Collett and Spicer, 1995). Another work, based on a simulation study comparing cellular manufacturing and job shop layouts concluded that the cellular approach decreased WIP and cycle time (Shafer and Charnes, 1993).

Thus, we propose:

**Proposition 7:** Product modularity will have a positive effect on

(a) Manufacturing integration; and

(b) Cost, quality, flexibility, and cycle time through manufacturing integration.

**III. RESEARCH IMPLICATIONS**

The proposed framework establishes a starting point for empirical investigation of the mediation effect of integration
strategies and competitive performance outcomes on PM. This paper develops a framework and is part of a larger study which seeks to empirically examine the proposed relationships. Empirical verification could focus on one or more links at a time. Furthermore, extensive longitudinal study could test the framework over periods of time. Measurement scales are available in the literature for all the constructs in this framework, which could be adapted to suit settings in developing nations. Sample for an empirical study could be drawn from similar organizations within an industry or across manufacturing industry. The model could be tested as a whole or in parts by employing appropriate statistical procedures to verify the validity of the proposed framework.

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