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Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry

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ABSTRACT

In the last two decades, the auto industry has shown a steady increase of vehicle development outsourcing and a shift of both product development tasks and knowledge from carmakers to suppliers. This trend has increased the interest toward product modularity as a tool to ease the integration of external sources of innovation but there is contradictory evidence concerning the benefits of modularity in inter-firm coordination in the automotive industry. Moreover, although modularity literature considers standard interfaces one of the constitutive elements of modularity and a means for easing design outsourcing, very few studies have analyzed the genesis and the micro-dynamics of the interfaces definition process. In order to fill this research gap, this paper focuses on how assemblers and suppliers define the component-vehicle interfaces in component co-development projects. This study adopts a "quasi-experimental design approach" comparing two similar vehicle component co-development projects carried out by the same first-tier supplier with two different automakers. Under the ceteris paribus *conditions* defined by the research design, the empirical evidence derived from the analysis of the two projects shows that, differently from what modularity theory claims: the interface definition process is neither technologically determined nor the mere result of product architectural choices; the OEMs and the supplier's capabilities, degree of vertical integration, knowledge and strategic focus drive the partitioning of the design and engineering tasks, the interfaces definition process, and the choice of the inter-firm coordination mechanisms. Furthermore, while component modularity and design outsourcing are considered as complements in modularity literature, our findings suggest that they may work as substitutes and are rather difficult to combine.

1. Introduction

The integration of external sources of innovation has become a problem that more and more firms need to address (Chesbrough, 2003). Inter-organizational integration mechanisms (co-located project teams, integrators, resident-engineers, collaborative technologies, IT infrastructures, etc.) are by now a classical topic in organization theory and a large body of research has analyzed their ability to sustain supply relationships capable of spurring inter-firm innovation (Clark and Fujimoto, 1991; Helper and Sako, 1995; Parmigiani and Rivera-Santos, 2011). In this respect, product modularity has received much attention and has been credited of many advantages.

For example, modularity supporters claim it can improve the management and the outputs of the new product development (NPD) activities by: (a) allowing firms to easily de-couple both the design and the manufacturing of the components that constitute a product; (b) ensuring an easy and well performing integration of the externally supplied components into the final product architecture. Overall, modularity is believed to help firms manage outsourcing efficiently and effectively thus facilitating the integration of external sources of innovation (Baldwin and Clark, 1997, 2000; Langlois and Robertson, 1992; Sako and Murray, 1999a).

The features and advantages of product modularity have been investigated by both the managerial and engineering literatures. Industry studies show that the average degree of component modularity varies across industries (Fixson and Park, 2008; Fixson et al., 2005; Galvin and Morkel, 2001; Sturgeon, 2002). More specifically, while some industries as electronics (Baldwin and Clark, 2000) and

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bicycles (Galvin and Morkel, 2001) show high levels of component modularity others, as autos, stick to prevalently integral product architectures.

As far as the automotive industry is concerned, the vehicle development outsourcing trend has increased both the practitioners and scholars interest toward product modularity as a tool to ease the integration of external sources of innovation. In the last two decades, several studies have analyzed how and to what extent carmakers design modular cars and suppliers provide component modularity (Camuffo, 2004; Fourcade and Midler, 2004; Frigant and Talbot, 2005; Fujimoto and Dongsheng, 2006). Interestingly, these studies offer contrasting empirical evidence on the diffusion and use of modularity in the car industry and question the benefits and feasibility of this strategy. Other contributions also offer controversial results. For example, Lau et al. (2007) and Jacobs et al. (2007) provide some empirical evidence that modular product architectures are usually associated with cooperative buyer–supplier relations while Ro et al. (2007) describe how the North American auto industry has attempted to move to modularity documenting a significant, though seldom successful, impact of modularity on outsourcing, product development and supply chain coordination. In a comprehensive study MacDuffie (2012) claims that cars remain overall integral products and shows that there is not conclusive evidence about the role of modularity in shaping the vertical contracting structure and inter-firm coordination of the auto industry.

This paper intends to shed light on how assemblers and suppliers define the component-vehicle interfaces (that in the case of modularity are supposed to be standard) in component co-development projects. In fact, even if standards are a constitutive element of modularity (Baldwin and Clark, 1997; Galvin, 1999; Hsuan, 1999; Momme et al., 2000; Sanchez and Mahoney, 1996; Ulrich, 1995), very few studies have analyzed the dynamics of their definition process. In order to fill this research gap, this paper focuses on how auto assemblers and suppliers define the component-vehicle interfaces in component co-development projects. We do so by analyzing the process through which interfaces are defined in two projects concerning the co-development of air conditioning systems (A/C systems), which is a major vehicle component. The two projects were carried out by Denso Thermal System, a major Japanese first tier supplier, with two European carmakers. We designed our research following a "quasi-experimental" logic. We selected two similar development projects, almost identical with regard to the most relevant economic and technological dimensions (A/C system architecture, degree of technological complexity, vehicle market segment, degree of carry-over from previous projects, project cost, duration, and performance). This research design allowed us to observe *how* the vehicle-component interfaces emerged, to *what extent* they were standardized in the two projects, and the effects of such process on task and knowledge partitioning between the car makers and the supplier, as well as on vertical inter-firm coordination. We observed that the interfaces definition process is neither technologically determined nor the mere result of product architectural choices; the OEMs and the supplier's capabilities, degree of vertical integration, knowledge and strategic focus drive the partitioning of the design and engineering tasks, the interfaces definition process, and the choice of the inter-firm coordination mechanisms. Furthermore, while component modularity and design outsourcing are considered as complements in modularity literature, our findings suggest that they may work as substitutes and are rather difficult to combine.

The study is organized as follows. The next section provides a review of the literature and presents the research questions. Section three describes the data and method. Section four and five, respectively, present and discuss the empirical findings. Section six concludes the study and offers research and managerial implications.

2. Literature review

2.1. Modularity and the key role of interfaces standardization

Products are complex systems in that they comprise a large number of components with many interactions between them. The scheme by which a product's functions are allocated to its components is called its "architecture" (Ulrich, 1995). Modularity refers to the way in which a product design is decomposed into different parts or modules.

While authors developed so far a variety of modularity concepts, they agree that "modules" are characterized by independence across and interdependence within their defined boundaries (Campagnolo and Camuffo, 2010; Gershenson et al., 2003; Fixson, 2007; Mikkola, 2003; Salvador, 2007; Ulrich, 1995). This independence is achievable through the adoption of interfaces that decouple the development and the inner working principles of a product's components (Baldwin and Clark, 2000; Sosa et al., 2004).

There are different types of modularity-in-design. Ulrich and Tung (1991) propose a classification based on how the final product configuration is built. Their typology distinguishes between component-swapping, fabricate-to-fit, bus and sectional modularity, and captures different possible approaches to combining modules. Ulrich's typology (Ulrich, 1995) relies on the nature of the interfaces among components as the classification criterion and distinguishes between slot, sectional and bus modularity. Salvador et al. (2002) complement these typologies introducing the notion of combinatorial modularity as a sub-type of slot modularity and contrasting it with component-swapping modularity. In combinatorial modularity, each product component is a variant within a component family and each component family interacts with a subset of other component families. The interactions are ensured by standardized interfaces that may differ depending on the combination of families they connect but are independent of the component variant chosen, so that "all component families are allowed to vary while the interface between specific pairs of component families is standardized" (Salvador et al., 2002: 571).

Despite the differences in approaches, definitions and emphasis, scholars converge in identifying three main features of modules: they are *separable* from the rest of the product; they are *isolable* as self-contained, semi-autonomous chunks; and they are *re-combinable* with other components. Separability, isolability, and re-combinability are properties deriving from the way functions are mapped onto the components and from how components interact, i.e. from their interfaces. In what follows we delve into these concepts.

Ideally, a perfectly modular product is made of components that perform entirely one or few functions (1:1 component/function mapping), with interfaces among them well known, defined, and codified (Ulrich, 1995). If these interfaces – i.e. the communication protocols among components – are widely diffused within a given industry, these components have open standard interfaces. However, if the protocols are designed specifically to suit a certain firm's requirements, i.e. they are firm specific, these protocols are closed and non-standard, unless we consider closed interfaces as proprietary standards used by a single firm or a specific network of firms (Fine et al., 2005). Interestingly, modular products are characterized by standard interfaces among components, but the other product's features and attributes – including technologies – may change. Thus, a modular component is not necessarily standard.

Therefore, since the modularity literature converges in identifying standard interfaces as a core technical attribute of a module