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

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A R T I C L E   I N F O

Article history:
Received 13 March 2011
Received in revised form 31 August 2012
Accepted 1 September 2012
Available online 29 September 2012

Keywords:
Component modularity
Interfaces
Auto industry
External innovation
Inter-firm coordination
Buyer–supplier relationships

A B S T R A C T

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.

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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
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 Milder, 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; Fixon, 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
(Campagnolo and Camuffo, 2010; Fixson et al., 2005; Salvador, 2007; Ulrich, 1995), investigating the nature of the interfaces definition process is critical to understand the connection between modularity and component development outsourcing and the integration of external sources of innovation in NPD. Within the modularity literature, Baldwin and Clark (1997) were the first to underline that standard interfaces allow modules to be designed independently and, consequently, “mixed and matched” to create a complete product-system. Hsuan (1999) and Momme et al. (2000) also observe that, in modular design, it is standard interfaces that allow for a range of variations in components to be combined in a product architecture. Salvador (2007) goes even further with his “interfaces standardization approach”, describing how the view of product modularity as interfaces standardization, originated in the computer industry, was developed by the economic literature during the 1980s and became widespread in the strategic management literature with the work of Garud and Kumaraswamy (1993). Finally, Pimmler and Eppinger (1994) emphasized the role of interfaces in the engineering literature, creating specific tools to analyze them, such as the Design Structure Matrix (DSM).

Overall, since interfaces are the coupling protocols among components that ensure that they will work together well, if they are defined ex ante and stable throughout the life of a project, the development of each component can be de-coupled and conducted independently. Consequently, standard interfaces should ease the outsourcing of NPD activities to suppliers, favoring vertical disintegration (Langlois and Robertson, 1992).

Interfaces can be defined in three ways. First, they may result from the adoption of open standard interfaces, i.e. adopting the communication protocols among components widely diffused within a given industry (Fine, 1998). Second, they may be close standard, i.e. a firm designs communication protocols among components that, although firm specific, represent within-firm standard requirements that are replicated across products and projects (Takeishi and Fujimoto, 2003). Third, interfaces may be stable or change over time (i.e. over the time span of the development process). Interfaces are stable if well defined, upfront, at the beginning of the development project. Noteworthy, stable interfaces are not necessarily standard (neither open nor close). They are firm specific, designed to suit the need of a specific development project, and “frozen” once a project starts (Christensen et al., 2002).

Our study draws upon the modularity literature to explore the antecedents and the effects of the interfaces definition process on task and knowledge partitioning between carmakers and suppliers, as well as on vertical inter-firm coordination. In the next section, we briefly outline the state of the art of modularity literature in the automotive industry.

2.2. Product modularity in the auto industry

The last two decades witnessed a steady increase of vehicle development outsourcing and a shift of both product development tasks and knowledge from carmakers to suppliers (Takeishi, 2001). This trend, paralleled by manufacturing outsourcing, led to dramatic de-verticalization processes and a re-definition of the vertical contracting structure of the auto industry toward a tiered configuration with global mega-suppliers (Kenney and Florida, 1993; Sturgeon and Florida, 2004; Whitford, 2005). Therefore, as in many other sectors, to effectively integrate newly designed components inside the car system, the carmakers and their suppliers have developed “hand-in-glove relationships” and started sharing a relevant amount of information (Clark and Fujimoto, 1991).

In this context, the reliance on modularity has been credited of many advantages. Early studies submitted that component modularity should ideally reduce the need for a tight coordination between buyer and supplier during the product development stage also in the automotive industry (Camuffo, 2004; Doran, 2004; Fixson et al., 2005; Ro et al., 2007; Sako and Murray, 1999b). As Sanchez and Mahoney (1996) and Baldwin and Clark (1997, 2000) showed in other industries, also in automotive design and manufacturing the specifications of standardized component interfaces was credited to have the potential to create an information structure that allows coordinating the activities as loosely coupled: the suppliers that design and produce modular components know ex ante the interfaces of the component; this, in turn, reduces the information exchanges needed to design a component that fits the overall product design. Since components’ design and development can thus be isolated and carried out separately by suppliers within a ‘frozen’ product architecture, the need for intense coordination is lowered. Also, standard interfaces, another key feature of modularity, allow increasing the firms’ knowledge specialization and decoupling up to a level where modularity sourcing could be defined as “black-box sourcing” (Lamming, 1993).

MacDuffie (2012) well summarizes the theoretical and potential benefits of component modularity as regards the NPD activities inside the auto industry. First, component modularity should increase the rate of introduction of modular and incremental innovations (Henderson and Clark, 1990). Being modular products conceived as the sum of modules, separated by well-defined and standardized interfaces, products can be innovated adding, upgrading, substituting, or subtracting components (Ulrich, 1995), without changes in the other product components. Second, component modularity, via standard interfaces, provides a form of embedded coordination that reduces the need of high-power integration tools to achieve inter-firm coordination in development processes, thereby making possible the concurrent and autonomous development of components by loosely coupled organization structures (Sanchez and Mahoney, 1996). Third, the concurrent and autonomous development of components speeds the throughput time of NPD activities thus reducing the NPD costs.

Nevertheless, recent empirical evidence shows that, in the automotive industry, modularity has produced disputable benefits (Fournarde and Midller, 2004; MacDuffie, 2012; Zirpoli and Becker, 2011a). A first reason for such limited positive effects is pointed out by MacDuffie (2012): few cars’ components are truly modular and autos are integral products. When the de-verticalization process took place inside the auto industry, while it seemed as if the auto industry would soon mimic the computer industry and converge to a modular configuration, in practice this did not happen. In fact, despite the efforts of some US and European carmakers, modularization has not been implemented successfully, with rare exceptions (Sako and Murray, 1999a, b; Ro et al., 2007; Sako, 2003).

A second and related explanation refers to the object of integration that modularity enables. Zirpoli and Becker’s empirical evidence (Zirpoli and Becker, 2011a) shows that modular product design is not the most appropriate way to deal with the issue of integrating the overall vehicle performance (or functions): for this purpose the assessment of the reciprocal interdependencies between the performances of the different components and systems is difficult ex ante. As a consequence, there are intrinsic limits to the benefits of standardized interfaces among components as this standardization risks not standardize the performance contribution of each single module to the whole. Standardizing

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1 Here we define “black-box sourcing” as an approach in which different subjects/firms can design product’s components independently from one another. A black-box approach allows developing a product’s components without knowing the other components’ technology and working principles. Therefore, in a black-box approach not only the development activities of the diverse components are separated, but even the respective knowledge domains do not overlap.
interfaces does not, therefore, diminish reciprocal interdependencies between component–and system–performances. Building on different evidence, Zirpoli and Camuffo (2009) confirm that in the automotive industry the need for ‘thick’ supply relationships persists, no matter how modular components are. The reason is that product architecture is not the main determinant of task and knowledge partitioning in the observed relationships.

These contributions echo similar findings in other industries (e.g. Brusoni, 2005; Brusoni et al., 2001; Prencipe, 2000) and represent a first step in understanding how and to what extent product modularity shapes the allocation of design tasks and interfirm coordination and why modularity might show some limited traction in coordinating the integration of external sources of innovation in the case of complex products. Notably, the file rouge that cut across this literature is an explicit criticism toward the over reliance on the concepts of modularity and standard interfaces, as tools for easing inter-firm coordination.

Although modularity literature considers standard interfaces one of the constitutive elements of modularity and a means for easing design outsourcing, to date, with very few exceptions (Mac Cormack et al., 2010; Zirpoli and Camuffo, 2009) there is a substantial lack of studies that provide empirical evidence on the process through which standard interfaces are defined by OEMs and suppliers and how this process does, or does not, shape the way the OEM integrates external sources of innovation. This study represents an attempt to start filling this empirical gap.

3. Data and method

Our research seeks to shed light on the role of modularity in integrating external sources of innovation and on the reasons of its limited traction within the automotive industry. In order to do so, we focus on the macro and micro dynamics of the interfaces definition process during the NPD activities. We opted for a qualitative method, the multiple case study research design, which is considered an appropriate way to describe and explore puzzling phenomena (Eisenhardt, 1989; Fiss, 2009; Handfield and Melnyk, 1998; Meredith, 1998; Patton, 2002; Yin, 1984). In order to observe the actual role, strengths and weaknesses of component modularity we built, our sample following the principles of experimentation. More specifically, we adopted a “quasi-experimental design” approach (Huberman and Miles, 2002; Romanelli and Tushman, 1986). After selecting one of the most modular components in the car industry, the A/C system (Fourcade and Midler, 2004), we built a research setting in which, keeping constant the variables related to product architecture and technology, and being other things equal, we could observe how and if task and knowledge partitioning and the inter-organizational coordination mechanisms vary in the two observed projects.

In this section, we report on how we chose the component/system object of the study, the specific projects in which we observed the interface definition process, and show the analytical tools that we employed in data gathering.

3.1. Car’s component selection

In order to address our research questions, we decided to focus on a vehicle component that fits as much as possible the above provided definition of modularity.

We followed a two-step procedure. First, we reviewed the outstanding literature on the topic and established the appropriate component/system to study in the light of the car product architecture and its hierarchical structure. Second, we sought confirmation of what the literature suggests, empirically grounding our choice of the object of analysis, through interviews with key informants.

(1) The modularity literature specific to the auto industry offers only sketchy evidence and few insights about the comparative degree of modularity of the key car’s components (Camuffo, 2004; Fixson, 2005; Sako, 2003; Takeishi and Fujimoto, 2001; Zirpoli and Becker, 2011a, b). To overcome this drawback, we followed Takeishi and Fujimoto’s call for analyzing car’s components decomposition at an appropriate level of granularity (Takeishi and Fujimoto, 2003). Only after defining the appropriate level of granularity, i.e. the level of the vehicle architectural hierarchy at which the analysis is positioned, the degree of modularity of diverse components can be meaningfully compared. Literature has devoted much attention to such granularity problems (Doran, 2004; Fixson, 2003; Fourcade and Midler, 2004; MacDuffie, 2012; Miguel and Prieto, 2010; Pimmmer and Eppinger, 1994). More specifically, Fixson (2003) reviews existing literature about product modularity in the auto industry and offers a list of vehicle sub-systems that the literature has classified as modular. These systems are located at the first level of the vehicle product architecture hierarchy and their development is based on involvement of several suppliers facing challenging coordination problems. Fixson (2003) ranks the following car’s components as the most modular: the A/C system, the automotive console, the underbody, the instrument panel, the brake system, and the climate control. Thus, these vehicle sub-systems became the ideal candidates for our analysis.

(2) In order to get confirmation of this literature based ranking, narrow down our options and make our final decision about the object of our analysis, we decided to ask the opinion of automotive experts. More specifically, we needed somebody able to comparatively evaluate and rank the tier-1 vehicle subsystems in terms of degree of modularity. Thus, we resolved to ask the R&D Management of a key global supplier that designs and produces all the car vehicle’s components listed by Fixson (2003) and that would therefore be in the ideal position to assess their comparative degree of modularity. Fortunately, the supplier we intended to analyze, Denso Thermal System (henceforth DNTS), a major global supplier of thermal systems for the automotive industry, is part of the Denso Group, one of the world largest auto supplier that designs and produces a full range of vehicle subsystems. Hence, we leveraged on this and asked several Denso managers to rank the key vehicle’s subsystems according to their degree of modularity applying the above-mentioned definition. All the interviewees converged in indicating the A/C system as the most modular among the vehicle subsystems. These managers, and the DNTS R&D chief engineer in particular, also stated that the A/C system could be considered among the most fully outsourceable vehicle components and pointed to it as the most modular and loosely coupled with the rest of the vehicle. Also, our interviewees confirmed that A/C system interfaces with the other vehicle components can be comparatively more clearly defined and codified by OEMs with regard to performance requirements and technical specifications.

All in all, we chose to analyze the car A/C system because both the literature and our preliminary interviews converged on its comparatively high degree of modularity.

The A/C system has a stable architecture and a mature technological content (Doran, 2004; Fourcade and Midler, 2004). The typical car A/C system architecture, graphically sketched in Fig. 1, is common to the different A/C models offered by suppliers to auto OEMs with regard to:

(a) The functions performed by the A/C system and its inner components;
(b) The function/component mapping and the order/sequence in which components interface.

Such homogeneity was also confirmed by some preliminary interviews we conducted with colleagues of the Physics
Department of the University of Padova, Italy, who have been long involved in international research and technology development with the A/C industry.

DNTS engineers further confirmed this cross-firm homogeneity, explaining that the basic auto air conditioning technology “is old”, and that the conditioning cycle represented in Fig. 1 is standard. According to our industry knowledge and the DNTS’s experts we interviewed, there exist two basic variants of A/C system architecture. Both employ the refrigeration cycle described in Fig. 1, but differ with regard to where and how the A/C system is physically positioned into the car engine compartment. The two architectures are:

- The “centered” architecture, where the A/C system is located in the central part of the engine compartment;
- The “semi-centered” or “epsilon” architecture, where the system is aligned to the back of the engine compartment thus allowing saving space.

The “semi-centered” architecture is the most widespread in the industry because it reduces the size of the A/C system and saves space inside the engine compartment.

### 3.2. Co-development projects’ selection

To set the context for our comparative analysis we selected two similar, if not identical, A/C system development projects carried out by DNTS for two competing carmakers (ALPHA and BETA). Both projects started in 2003 and regarded the development of an A/C system for a light commercial vehicle with a passenger’s use variant. Also, the two projects both derived from a pre-existing platform, shared same similar performance targets, degree of novelty, technologies and both employed a “semi-centered” architecture (see above). The DNTS’s R&D chief engineer, who assisted us in the projects selection, also stated that projects ALPHA and BETA are representative of the usual way DNTS co-develops the A/C systems with these customers.

This research design created the conditions for a meaningful study of cross-OEM variation as it allows us to compare the two OEMs’ approaches in defining the interfaces as well as their patterns of coordination with suppliers referring to two co-design projects that are very similar among them.

We collected the data, from 2007 to 2009, via structured and semi-structured interviews and by analyzing several company documents. We decided to interview both the projects’ sales and marketing managers, responsible for the commercial relationship with the OEM from the pre-offer phase until the end of the project (two interviews of about 2 h each) and the R&D chiefs of projects A and B, responsible for component technology and system development (one interview of about 2 h and 30 min with the R&D chief engineer for ALPHA and two interviews of overall 3 h and 30 min with the R&D chief engineer for BETA). Also, we interviewed the R&D chief engineer three times (4 h and 30 min) and two times the R&D chief for ALPHA assistant (3 h and 30 min). Overall, we conducted 12 interviewees for a total amount of 18 h. We did not interview the carmakers’ managers because we were interested in triangulating data on two projects that only DNTS’ managers could meaningfully compare. Confidentiality issues also did not allow us to contact the OEMs’ sourcing and engineering departments.

### 3.3. The analytical tools employed in data gathering

The characteristics of our study are such that a prevalent focus on interfaces is justified. Indeed, as above explained, the maturity of the technology, the architectural stability of the car A/C system, and the cross-company homogeneity of the product render the A/C component functions and the A/C function-component mapping similar across the two firms and vehicles (and, as showed above, across the industry as a whole).

For each dyad (DNTS-ALPHA and DNTS-BETA), we framed the data gathered during the interviews (1) using the framework presented in Table 1, which represents a tool specifically designed to analyze the interfaces between the A/C system and the car’s components with which it interacts; (2) using a purposely designed visual representation tool.

In line with our research questions, in this paper we used an analytical tool designed to describe how the two carmakers and DNTS set the interfaces between the A/C system and the other vehicle systems with which the air conditioning interacts. For each firm, we gathered the data using a table, see Table 1, structured as follows: the car’s components with which the A/C system interacts are reported in the rows, while columns contain the indication of the type of interfaces (i.e., spatial, informative, energetic, material) that exist between the A/C system and the vehicle components (listed in rows). Building on the DSM literature, i.e. a literature at the cross-road of the managerial and engineering literature which focuses on the interfaces analysis, and particularly following Pimmel and Eppinger’s approach (Pimmel and Eppinger, 1994), we analyzed four types of interactions between the A/C system and the car’s components: (a) spatial (e.g. physical adjacency, alignment, orientation); (b) energetic (e.g. heat, vibration, electricity); (c) material (e.g. air, oil, fluids, flows); and (d) informative (e.g. signals, controls transfers). Indeed, we analyzed the interfaces as follows. First, for each component with which the A/C system interacts we identified the kinds of interaction (spatial, material, energetic, informative). Second, for each kind of interaction we checked if it represents an open standard (O-S) (i.e. the interface is a standard used by companies operating in the industry), or closed standard (C-S) (i.e. the interface is a standard within the OEM projects), or non standard (N-S) interface. Finally, either if the interface was standard or not we checked for its stability over time (i.e. across the project lifecycle) employing a 1–5 point scale where 5 stands for “frozen interface from the start of the project” and 1 stands for “unstable interface that often changes during the project”. In order to...
reduce the subjectivity of the interfaces characterization and to ensure results comparability, we assisted the R&D chief engineers of Project-A and Project-B in the interfaces analysis and in the compilation of the tables so that the interfaces would be analyzed accurately and consistently across the two projects. Also, once the tables were compiled, we organized a meeting with the two engineering chiefs and the DNTS’s R&D Chief engineer, to compare the results, improve cross-rating reliability, and fine tune the cross-project analysis. This meeting allowed to surface and to take into consideration language, perceptual and cognitive differences the two project managers might have applying the interfaces analysis, and more specifically the ambiguities about such concepts as interface, standardization and stability. This process ended up with the final release of Tables 2 and 3 (one for Project A and another for Project B) that summarize and allow to compare the interfaces between the two projects. Each table took about two hours to be completed and other two hours to be discussed and fine tuned in the final meeting. These tables are reported in the findings section.

After collecting data about A/C system interfaces via Table 1, we framed the data gathered through the interviews using the visual representation tool illustrated in Fig. 2. We designed this visual device to provide a compact representation of how the OEMs manage the relation with the supplier in NPD. It also allows to compare how the OEMs integrate external sources of innovation in vehicle development providing, at a glance, information about task partitioning, knowledge partitioning and interorganizational coordination with regard to: (a) the design of a component/system performance parameters and its engineering solutions; (b) the definition of a component/system interfaces; (c), the choice of the inner components/subsystems (within the component/system); and (d) the overall component’s/system’s inner engineering solutions (such as the interfaces among the inner components and their performance parameters).

This representation tool allows to visualize not only the different types of design activities but also how they are allocated between
the actors involved (who performs them). Each design activity is represented by a graphic icon/specific shape, while the motives that fill these areas show who performs these activities. The main rectangle (Fig. 2) delimited by the rectangular frame represents the system interfaces (between the analyzed subsystem – in our case the A/C – and the vehicle), the smaller rectangles represent the inner A/C system sub-components, and the big oval the overall A/C system performance parameters and engineering solutions. The area between the main rectangle and the smaller ones represents the level of the OEM’s intrusiveness in defining how the system is internally designed (i.e. the inner components and their performance parameters).

The colors that can be used to fill these shapes are white and black. The black color identifies the carmaker’s contribution to designing the corresponding areas (i.e. the big oval, main rectangle, smaller rectangles, and the area between the main rectangle and the smaller ones). If the icons/shapes (corresponding to design activities) are solid black, it means that the carmaker completely defines its design. If the icons/shapes (corresponding to design activities) are white with black spots, the higher is the density of black spots the higher is the carmaker’s contribution to designing it. On the contrary, fully white icons/shapes represent design activities fully and exclusively performed by the supplier.

As above mentioned, this compact representation allows to visualize and compare the OEMs’ approach to the A/C system design. A larger presence of darker shapes, icons and lines indicates that the OEM takes on a larger share of the task of defining the various A/C system design elements. Below, in Figs. 3 and 4, we apply to Project A and B the visual representation tool presented in Fig. 2.

4. Findings

In this section, after illustrating the genesis of DNTS’ relationships with ALPHA and BETA, we break down the presentation of our findings articulating them into four sub-sections: the first reports on how design and engineering tasks were partitioned between DNTS and the carmakers in the two projects; the second draws the implications of between-firm task partitioning on the architecture of the A/C system; the third describes the performances of the two projects; and the fourth expands on the cross-case differences with regard to the application of inter-firm coordination tools.

During our fieldwork the interviewees confirmed that the two projects were fully representative of the “usual” division of labor and coordination mechanisms employed in the relationship between DNTS and the two analyzed carmakers.

4.1. The genesis of DNTS’s relationships with ALPHA and BETA

Project A was started by DNTS for ALPHA in 2003 from an existing product platform. Denso was the only supplier for both projects. ALPHA launched the Request for Quotation (RFQ) of project A in 2003 and a handful of suppliers (Behr, Valeo, and DNTS) replied to the request within 3–4 months. According to the sales and marketing manager that had the commercial responsibility of the project, DNTS acquired the business for three main reasons. First, ALPHA positively evaluated the type of mixture air system proposed by DNTS. Second, DNTS developed the prototype with the highest performance levels. Third, DNTS, being the only supplier co-located with ALPHA (DNTS opened a new production site closed by ALPHA’s assembly plant) was able to offer a particularly interesting price. This observation is convergent with the geographic analysis of modularity, which suggests that the diffusion of the modular production in the automotive industry has reinforced the need for proximity between auto-makers and parts-makers (Frigant and Layan, 2009). DNTS won the RFQ in 2003 and was selected by ALPHA 48 months before the expected production start and ramp-up.

Project B was developed by DNTS for BETA. DNTS was the only supplier for the analyzed project. The project was derived from a pre-existing platform developed by DNTS’s competitor. In 2003 BETA launched the RFI (Request for Information). As usual, during this step BETA involved five competing suppliers (DNTS, Valeo, Behr, Delphi, and Calsonic) providing them with business information among which volume forecast for the A/C system. The suppliers were asked to suggest the best technical solution and the price. Once this phase was completed, BETA chose the best technical solution and launched the RFQ. DNTS won the RFQ at the end of 2004. The development of the A/C system took about two years. The BETA’s production started in 2007. According to the sales and marketing manager that had the responsibility of the project, DNTS was able to acquire the above business thanks to its superior technical knowledge, its cooperative approach, and its price. He also told that, although price was an important variable, only suppliers that have high technical capabilities could participate to the BETA’s RFQ. In fact, BETA employs a complex supplier’s evaluation system and certification procedure (i.e., suppliers have to pass a strict exam every 5–6 years). Thus, first BETA selects the suppliers on the basis of their competences, and then pushes the price competition.

Overall, DNTS’s relationships with ALPHA and BETA are long-lasting, collaborative, and solidly grounded on the technical knowledge and price competitiveness. Consequently, DNTS knows well both carmakers, their procedures and their technical competences.
4.2. Design and engineering task partitioning in Project-A and Project-B

4.2.1. Interfaces definition

This section reports in detail how DNTS, ALPHA and BETA, respectively, partition their design and engineering tasks. In line with our research questions, we start describing how the two carmakers and DNTS set the interfaces between the A/C system and other vehicle systems with which the air conditioning interacts, respectively, in Project A and Project B.

4.3. Project-A

Table 2 reports the results obtained for Project A’s interfaces analysis.

Table 2 shows that all the interfaces analyzed were defined upfront and “frozen” from the beginning of the project and that 10 out of 18 interfaces were either open or closed standard. Our interviewees were unanimous in stating that ALPHA defined the product’s architecture and the interfaces in great detail. All the managers we interviewed stressed ALPHA’s ability in well defining all the specifics early in the project (interfaces, functions, performance levels, etc.). This data is confirmed by the R&D Chief Engineer of Project-A who reported to us that ALPHA freezes the specifics after the avant phase (48 months before the ramp up) and “ALPHA is a strict OEM that does not change its specifics: once the specifics are set, these do not change for all the suppliers involved in the car development”. ALPHA well defines the A/C system interfaces, included in the main set of specifics, because first designs the architecture of the vehicle components with which the A/C system interacts and, once these architectures are stable, sets the A/C system interfaces. Notably, the managers claimed that the specifics constitute one of the main coordination tools used by ALPHA. In fact, R&D Chief Engineer of Project-A explained that “ALPHA has a main set of specifics for the A/C system that is articulated in dossiers, one for each component. The main set of specifics contains the general requirements and standards for the system. Indeed, the architecture is completely defined ex ante by ALPHA while the supplier has the task to design and engineer most of the inner components of the A/C system, respecting the detailed specifics given by ALPHA”. Of course, DNTS’s managers noted that the higher the numbers of “frozen” interfaces, the higher the constraints they face and the lower the design’s degrees of freedom left to DNTS.

Moreover, ALPHA defines some A/C system’s inner components. According to the Chief of Project-A “ALPHA defines these components to better control the A/C system’s architecture and to control those components whose performance has the higher impact on the passengers’ comfort”. Notably, the interviewee stressed that “ALPHA does not define these components only to achieve higher levels of commonality among different platforms. […] Interfaces standardization is not aimed at improving the modularity level of the A/C system per se but as a mean to better control the overall A/C system performance”. ALPHA’s ability in defining the A/C system architecture and specifics was fully acknowledged by DNTS. The engineering managers reported to us that when they tested the A/C system on the car the results were totally positive. DNTS’s managers also said that, during Project-A, they were highly confident that the test results would have been good as “their specifics were clear, easy to follow and did not change”. Fig. 3 sketches ALPHA’s approach in defining the A/C system architecture. ALPHA fully specified all the interfaces (the main rectangle is solid black) and the performance parameters, as well as the engineering solutions (the area between the big oval and the main rectangle is white with a high number of black spots).

ALPHA is also quite “intrusive” in defining how the system is internally designed (the area between the main rectangle and the smaller rectangles is white with some black spots) and some of the inner active components (the black boxes inside the A/C system boundaries).

4.4. Project-B

Table 3 summarizes the analysis of Project-B interfaces (BETA company).

Twenty out of 23 interfaces were either closed or open standard. But, interestingly enough, only 12 out of 23 interfaces had a stability level equal or lower than three and eight interfaces were standard with a stability degree equal or lower than 3. As previously explained, an interface may be standard but it is unstable when substituted by another standard interface during the project development. According to Project-B’s R&D chief engineer, during the project BETA allows all component suppliers to suggest component interface changes if this improves the component performance and/or the vehicle development. This data is consistent with one of our interviewees’ statement that “BETA started Project-B with hypotheses that had to be defined in more details with the suppliers involvement”. Indeed, during Project-B the initial A/C system architecture changed and evolved, and DNTS was involved in these architectural changes. This drove Project B’s lower interfaces stability.

Moreover, Project BETA R&D chief engineer explained that the components with which the A/C system interacts, such as the flame damper, are strictly related to the car’s design and style and are modified in every car model. Consequently, “every time the cockpit supplier suggests changes in the cockpit style, these require changes in the A/C system”. In this case, defining upfront and “freezing” A/C system’s interfaces would negatively affect the cockpit design innovativeness and/or performance. A black-box approach was not pursuable for BETA. DNTS extensively shares information and data with BETA because “only through opening the black-box DNTS can help BETA” in evaluating: (a) the BETA’s requirements and (b) the impact that changes required in other vehicle components might have on the A/C functioning and performance.

The same interviewees stressed the evidence that BETA and DNTS have different bodies of knowledge, but since they do not develop isolated tasks, they need to integrate their knowledge domains to effectively integrate the car’s components.

Fig. 4 sketches the BETA approach in defining the A/C system architecture. BETA sets the A/C system main concept and architecture but allows, and in some cases asks for, DNTS’s suggestions about how to improve the system performance parameters as well as its engineering solutions (the area between the big oval and the main rectangle is white with some black spots). BETA is not intrusive in defining how the system is internally designed (the area between the main rectangle and the smaller rectangles is almost white) and does not define the A/C system inner components (there...
is no black box inside the A/C system boundaries). Also, BETA co-develops the interfaces with DNTS (the main rectangular frame balances white and black spots). The white zones are those fully managed by DNTS.

4.5. A comparative analysis of Project A and Project B

We observed that the two A/C systems, despite the similarities in terms of characteristics and performance, were developed by DNTS on the basis of interfaces that were defined by ALPHA and BETA in two substantially different ways. Tables 2 and 3 show that while the two analyzed A/C systems interact exactly with the same other car’s components via four different types of interfaces (i.e., spatial, material, informative, and energetic interfaces), such interfaces are different between the two OEMs in three ways.

(a) Type 1 difference: the characteristics of the interfaces (i.e. spatial, informative, energetic and material interfaces) that connect the A/C system with other car’s components may differ in the two projects. An example of the type 1 difference is the instrument panel (mechanics) that has an informative interface with the A/C system in the BETA project but not in ALPHA. During our interviews, we contemporarily met both the R&D chief engineers for the ALPHA and BETA projects and we specifically asked them an explanation for the instrument panel (mechanics) differences in informative interfaces. The BETA R&D manager explained that this component exchanges only a few data with the A/C system but he decided to check this entry because, in BETA, the instrument panel (mechanics) is part of the electrical wiring that exchanges data with the A/C system. When specifically asked, the ALPHA manager explained that, in ALPHA, there is no data exchange between the instrument panel (mechanics) and the A/C system.

(b) Type 2 difference: the nature and degree of interfaces’ standardization (i.e. the interfaces can be open, closed standard or non-standard) may differ in the two analyzed projects. Tables 2 and 3 show that the engine cooling system has, in both projects, open standard material and energetic interfaces. The engine cooling system is connected with the A/C system via tubes and valves that are standard at the industry level for their sizes, the heat and vibration they have to support, and finally for the fluid exchanges they regulate (both the size and temperature of the fluid are standard). But, with regard to spatial interfaces, BETA relies on standard interfaces, while ALPHA on non-standard interfaces. In ALPHA the spatial interfaces are always non-standard because they strictly follow the car’s style that ALPHA defines and freezes ex ante. ALPHA, which has an in-depth knowledge of the A/C system, is able to define ex ante the A/C system spatial interfaces even if these interfaces do not follow specific standards. Also, in the BETA case the spatial interfaces follow the car’s style, but BETA, due to a lack of A/C system in-depth knowledge, does not univocally define the spatial interfaces that remain fluid even when the A/C system development starts. To balance the project instability deriving from the inability of ex ante freezing these interfaces, BETA employs standard spatial interfaces that are represented by a standard range (space) inside which the spatial interface has to be placed.

(c) Type 3 difference: the level of interfaces stability during the project development (i.e. the extent to which the diverse interfaces change over time during the development process, which is scored on a 1–5 scale) may differ in the two analyzed projects. For example, most of the material interfaces BETA employs are subject to change in late stages of the project because they need to adapt to changes in the layout of the A/C system components that, in turn, is contingent on the style of the vehicle (which BETA changes during the development project). It is worth noting that, according to our interviews, the decision to rely on stable and detailed interfaces (i.e. the ALPHA’s approach) vs. fluid and changing ones (i.e. the BETA’s approach) was not linked to intrinsic technological characteristics of the system under development, but derived from deliberate choices of the OEMs. Such choices, in turn, were grounded on the amount of component-specific knowledge owned by the OEM and its current involvement in component design (i.e. vertical scope).

ALPHA designs stable and detailed interfaces. According to our company informants this approach worked because ALPHA had developed an in-depth knowledge of the A/C system architecture and components. This seems to point to the fact that a better and more effective definition of standard and stable interfaces co-varies with the OEM’s vertical scope (i.e. the OEM holds component-specific knowledge). The main drawback of the ALPHA approach was the impossibility to tap into the supplier’s knowledge because of the limited supplier’s freedom to suggest new and original architectural solutions. Also, DNTS’s engineers claimed that interfaces standardization did not eliminate the need for frequent and intense information sharing due to the existence of complex functional interdependencies between the A/C system and other vehicle components: ALPHA’s interfaces standardization level is high but, from an architectural perspective, did not manage to achieve a complete functional isolation (i.e. some functions of the A/C system remain shared with other vehicle components). Consequently, ALPHA, in order to control some of the residual functional interdependencies, had to be involved in the definition of some A/C system’s inner components becoming “intrusive”. The ALPHA approach is captured and visually represented in Fig. 3 that shows how ALPHA does not rely on DNTS to define the interfaces but, at the same time, it is intrusive and defines some inner engineering solutions and active components.

In the second case, BETA provided some directions regarding the interfaces between the system and the rest of the vehicle almost in a “black box sourcing” fashion, i.e. without specifying the A/C system architecture and the inner components’ features. However, since the OEM knew little about the interdependencies and interactions between the components within the system and the rest of the vehicle, it had to be prepared to revise and adjust systemati- cally the A/C system architecture and component features through intense mutual adjustment and information sharing with DNTS, during the project. Fig. 4 captures and visually represents the BETA approach to the relation with the supplier, to the integration of external sources of innovation in vehicle development and to task partitioning, knowledge partitioning and interorganizational coordination. Fig. 4 is prevalently characterized by lighter or white areas, which indicate a substantial DNTS’s contribution to designing the A/C system. Comparing Fig. 3 with Fig. 4 it clearly appears that BETA outsources more design tasks than ALPHA. According to DNTS’s engineers, this approach facilitated the introduction of important innovations and improvements. DNTS had the possibility to suggest innovations at the A/C system’s inner components level as well as at the system interfaces level. But this approach also increased the project instability and complexity. In fact, in order to tap into the suppliers’ ingenuity and integrate their knowledge into the vehicle development project, BETA allowed DNTS, as well as all those suppliers that produce vehicle subsystems that interact with the A/C system, to suggest changes in the subsystem interfaces during the project development.

4.5.1. Functional isolation

After the interfaces analysis, we studied the two A/C systems’ level of functional isolation directly interviewing the R&D
chefs of the ALPHA and BETA projects. Our interviews highlighted that – in both cases – the A/C system shares several functions with other components. Indeed, carmakers have to manage such functional interdependencies.

On the one hand the R&D chief engineer of Project-A explained that “the integration issues are all managed by ALPHA that defines the A/C system performances and interfaces knowing the interdependencies with the other car components”. On the other hand, the R&D chief engineer of Project-B explained that BETA managed the A/C system integration into the vehicle relying on DNTS competences. DNTS helped BETA understand how the A/C system would have performed given the specifics of the components with which the A/C system shares its functions.

Hence, our data highlights noteworthy differences between ALPHA and BETA. ALPHA’s in-depth technological knowledge of the A/C system enabled the carmaker to manage all the key interdependencies. The R&D chief engineer of Project-A stressed that ALPHA’s level of architectural knowledge was higher than DNTS’s while ALPHA’s knowledge about the A/C system’s structural and functional coordination with the main components of the A/C System was similar to DNTS’s. The Project-A sales and marketing manager explained that ALPHA has enough competences “to develop the components inside the A/C system” because it directly cooperates with the main second tier suppliers. Indeed, ALPHA is increasing its level of integration to be more competitive as regards the A/C system technology. Back to the results shown in Table 2, DNTS’s interviewees maintained that thanks to its technical knowledge ALPHA was able to define all the A/C system interfaces so neatly. ALPHA’s high competences on the A/C system technology put the company in the position of designing interfaces between the A/C system and the rest of the vehicle and, consequently, to address most of the A/C system’s functional interdependencies upfront. BETA, vice versa, lacked the necessary component-specific knowledge thus being neither able to develop and provide technical specifications to the supplier nor to address functional interdependencies upfront. Consequently, it hinged upon fluid interfaces and needed a higher contribution from DNTS in the definition of the A/C system components.

We also took the opportunity to ask DNTS managers, on the basis of their experience, acquaintance with ALPHA and BETA, and knowledge of the industry, what were the main determinants of such different A/C systems co-development approaches between ALPHA and BETA. The explanation they provided goes back to the priority attached by ALPHA and BETA to the A/C system performance. While ALPHA explicitly considers the A/C system performance a key feature of its vehicles, which its customers perceive as a distinctive characteristic of their brands, BETA, historically, does not put such an emphasis on the A/C system performance. This can be a reasonable explanation of why ALPHA has kept a tighter control on the A/C system technology. In fact, the interviewees also clarified that ALPHA pursues modularity, defined as interfaces standardization, mainly to increase its component control.

In this section we have shown that the same A/C system (same product, same architecture, same complexity, similar vehicles targeted to the same market segment) was co-developed according to a different conceptual definition of the interfaces as well as to different design and task partitioning schemes. In the following sections we first focus on the projects’ performances to understand if a specific conceptual definition of the interfaces, coupled with a specific design and task partitioning scheme, is associated with a superior project’s performance and then, in Section 4.4, we analyze if the two different approaches in defining the interfaces, and the two task and knowledge partitioning schemes, are reflected on the organizational side.

4.6. Project performance

During our interviews, we gathered DNTS managers’ evaluations of Project-A and Project-B outcomes, which were similarly good. The interviewees were satisfied with both the A/C systems, and the project development targets (time, cost, quality) were met in both cases. In absolute terms, Project-A had more ambitious technical specifications (perceived quality of air conditioning by the final customer) but, overall, the performances of the two projects were definitely similar.

Also DNTS considered ALPHA’s and BETA’s approaches to knowledge and architectural management as consistent because they were well integrated. ALPHA couples high level of component-specific knowledge with the ex ante definition of the A/C system architecture, while BETA couples lower levels of component-specific knowledge with a higher reliance on the supplier’s competences to modify and adjust the A/C system architecture. As the concept of consistency ran the risk to remain vague, we also asked DNTS managers for a counter example (inconsistency), i.e. an example of OEM that pursues an incoherent strategy of supplier involvement in vehicle design. DNTS’s managers provided the example of an A/C system development project with GAMMA, another European OEM, whose approach was inconsistent because GAMMA wanted to define upfront all the interfaces but lacks the necessary know-how to do so. Thus, GAMMA’s approach created a lot of problems for DNTS when working with those interfaces that inevitably had to change when unexpected trade-offs came out and DNTS had to do a lot of re-design during the component development process. The project was late and more expensive than expected.

Finally, we explicitly asked DNTS engineers their perception about modularity, what they meant by “modularity” and what they expected to gain from a modular approach. The engineers told us that modular designs would allow reducing the interactions with the carmakers during the development phase: the carmaker would ex ante define the components’ specifics while the suppliers might interpret these autonomously and find the best technical solution. Particularly, DNTS views modularity as a property that gives to the OEM the task to design the interfaces and performances, while it leaves to the supplier the freedom to decide how to meet the performance targets. But when we asked to refer back to the “real world” practice we were told that in the auto industry nobody, yet, has this approach. The R&D chief engineer of project A claimed, “OEMs need more experience. ALPHA is near the modularity approach but they are intrusive, they should make a step back…” because they need further competences to modularize the A/C system without contemporarily providing the specifics of its inner components. ALPHA has a modular approach in defining the interfaces but “to fix the product architecture, their specifics go inside the A/C system”.

The DNTS R&D chief engineer, when asked to comment on this point, acknowledged that “product modularity might allow employing a pure black-box approach but product modularization requires a high knowledge about the components to modularize”. Consequently, we asked whether DNTS prefers customers (OEMs) that define the architecture and the specifics leaving the supplier the freedom to develop the component in a black-box fashion, like BETA, or customers with an approach such as that of ALPHA. On the one hand the DNTS’s R&D chief acknowledged that the BETA approach leaves more space to the supplier. On the other hand, the manager specified that ALPHA, being intrusive, limited the DNTS’s potential contribution to component innovation. Finally, the same manager admitted that ALPHA’s clear and stable interfaces and specifics facilitated the DNTS’s design tasks.
4.7. Inter-firm coordination mechanisms

ALPHA and BETA managed their relation with DNTS using two completely different task and knowledge partitioning schemes. These schemes were associated to a fundamental divergence in how the interfaces between the A/C system and the rest of the carmakers’ systems were defined and set. These differences reflect on the organizational side. ALPHA and BETA coordinated with DNTS using very diverse inter-firm coordination mechanisms.

As described above, ALPHA provided to DNTS detailed and stable specifications and interfaces. However, contrary to what mainstream modularity literature assumes, this fact did not reduce the need for intense information exchange during the project. Even in the case of Project-A information sharing between DNTS and ALPHA, both formal and informal, remained high. The formal information exchange took place in the form of a joint monthly meeting to plan the activities, and through two other bi-weekly joint meetings aimed to solving technical issues. Moreover, the DNTS’s chief engineers kept systematically in touch via e-mail or telephone calls with the corresponding ALPHA chief engineers. These interactions were more frequent (daily interactions) and intense during the concept development and the preliminary design phases, while they were less frequent after that. The daily contacts usually aimed at solving problems that might stop the project. In fact, even if ALPHA well defines the interfaces and the specifics upfront, not all the issues driven by the interdependencies between the A/C system and the car are solved. In this respect, as the R&D chief engineer for project A suggested, daily contacts are needed to verify that DNTS have correctly understood the ALPHA’s requirements as well as when DNTS needs the carmaker’s help. Moreover, DNTS rented a space nearby ALPHA. In fact, despite the intense and frequent interactions with the carmaker via e-mails, telephone calls, and meetings, daily face-to-face communication was unavoidable.

With regard to Project-B and the relationship between DNTS and BETA, our data clearly shows that BETA really co-developed the A/C system with DNTS and that it heavily delegated design and engineering tasks to DNTS. The interviews confirmed that co-development was not aimed at increasing BETA’s knowledge about the A/C system, but at improving the NPD efficiency. As seen above, BETA did not heavily invest in the A/C system’s knowledge and this had noteworthy consequences on how BETA managed the relationship with DNTS. As opposed to ALPHA, in fact, BETA cooperated with DNTS without sharing the same knowledge base concerning the A/C system. To do so BETA has set up a sophisticated reporting system that stores all the relevant information concerning the cost of the components and the quality issues (defects) that the A/C systems reported on the market. The cross comparison of cost details and technical and functional problems allowed BETA to guide DNTS’s choices without an in depth technical knowledge about the A/C system’s inner components. BETA was known for having rigid systems and procedures to analyze the costs of the A/C system’s components and asked many details about the costs of the components that DNTS purchased. In this respect, BETA required ad hoc meetings to analyze the components chosen by DNTS, and sometimes imposed restrictions about the second tier suppliers and also preferences about their nationality.

Moreover, often DNTS managers stressed BETA’s emphasis on the codification of co-development practices into standard procedures. BETA controlled the project status through formal procedures and a series of detailed milestones and meetings. BETA had a specialist for each project milestone. Moreover, BETA had several inspectors that supervised DNTS’s activities and progress. Nevertheless, DNTS believes that the competences held by the OEMs’ staff, more than the procedures themselves, ensure a robust engineering approach to problem solving. Moreover, the heavy use of procedures at times slows and renders the process bureaucratic.

Overall, BETA relied on intense and frequent information sharing with DNTS.

5. Data interpretation and discussion

Our description of the two projects shows that the OEMs developed with DNTS the same A/C system (same product, same architecture, same complexity, same market segment) following a different interfaces definition process and applying different organizational solutions.

ALPHA decided to rely on stable and detailed interfaces while BETA employed fluid and changing ones. As shown above, such interface definition process was not linked to intrinsic technological characteristics of the system under development, but derived from the amount of component-specific knowledge owned by the OEMs and their current involvement in component design (i.e. vertical scope).

On the one hand ALPA that had developed an in-depth knowledge of the A/C system architecture and components, was able to set standard and stable interfaces between the A/C system and the rest of the vehicle. In theory, this may make us think of an orientation toward modularity and “black box sourcing”. In practice however, despite the high level of interfaces standardization, ALPHA, in order to control some of the residual functional interdependencies, remained involved in the definition of some A/C system’s inner components (and, hence, of second tier suppliers) becoming “intrusive” and losing the chance to take advantage of the coordination benefits that the modularity literature usually attaches to the definition of standard interfaces (i.e. reduction of coordination and control costs). Interestingly, this approach did not allow ALPHA to tap into the supplier’s knowledge. Interfaces clarity, standardization and stability, coupled with “intrusiveness” about the A/C system inner components, limited the supplier’s freedom to contribute with new and original solutions at the component level.

On the other hand BETA provided directions regarding the A/C system interfaces in a “black box sourcing” fashion. Also in this case, this may make us think of an orientation toward modularity. In practice however, BETA’s lack of component-specific know-how led to a co-development process in which BETA and DTNS had to continuously and systematically revise the A/C system architecture and components features through intense mutual adjustment and information sharing. Contrary to the case of ALPHA, DNTS significantly contributed to the A/C system’s development suggesting innovations that spanned from inner components to interfaces. But this approach, apparently consistent with the idea that with modularity suppliers may better contribute to product design thanks to knowledge encapsulation, in reality increased the project complexity and instability due to continuous design changes even at late development stages.

As reported above, BETA tried to compensate its lack of component knowledge with intense mutual adjustment and information sharing with DNTS during the project. Also, BETA applied more sophisticated and structured inter-organizational procedures that ALPHA that, instead, being more in control of the technical interdependencies, relied more heavily on standard and stable interfaces that were complemented with systematic and intense information sharing but less formal coordination.

DNSTS evaluated both relationships as successful and OEM’s behaviors as “consistent”. ALPHA and BETA were considered as consistent by DNTS because their strategic approaches, knowledge depth and scope, capabilities and organizational structures were in line with the task partitioning scheme with DNTS and the relational strategies and practices employed. In our view, such internal consistency and substantial differences between the two projects is a
central finding of our study and allow us to address our research questions.

In fact, through the analysis of the interface definition process, its antecedents and consequences, our cases offer new insights on the role of modularity in integrating external sources of innovation and, also, some evidence about why, today, cars are still integral products (MacDuffie, 2012). While the modularity literature builds on Sanchez and Mahoney’s hypothesis (Sanchez and Mahoney, 1996) that product architecture drives organizational architecture – the so called “mirroring hypothesis” (Colfer and Baldwin, 2010) – with modular products being developed by loosely coupled organizations, we found that OEM’s strategy drives the investments in the A/C system knowledge that, in turn, determine how NPD activities are managed. Sanchez and Mahoney (1996) wrote ‘although organizations ostensibly design products, it can also be argued that products design organizations’. Instead, our study supports the proposition that the way in which a firm designs its product and taps into other firms’ knowledge is determined neither by product technology nor by product architectural choices. Rather, it is driven by the firm’s strategic orientation, its level of vertical integration, and the scope of its knowledge domains. Within this setting, modular design does not substitute for high-power interorganizational coordination mechanisms.

Standard and well-defined interfaces may work as coordination devices, but they neither eliminate the need of high-powered interfirm coordination mechanisms nor shape the allocation of NPD activities between firms per se. Also, standard and stable interfaces do not necessarily lead to black-box sourcing. What eases buyer–supplier coordination through interfaces stability is the level of knowledge held by the OEM and its ability to predict the technical interdependences characterizing the design of the product over the life of the project (as the DNTS-ALPHA case shows). As Principe (2000) argued studying the aircraft engine control system, manufacturers need a deep understanding of components’ inner functioning to specify, assess, test and integrate components externally supplied. The OEM’s lack of component-specific knowledge prevents the OEM from being able to envision and address upfront all the possible coupling problems.

Despite modularization efforts, cars’ components share a number of functions and are interdependent. This requires keeping in house or having the ability to get access to specific knowledge, and this calls for specific investments.

Our findings, thus, add to the literature that questions the possibility to narrow the scope of the knowledge of the OEM, rely on the component-specific knowledge owned by suppliers and use product architectural choices (knowledge encapsulation within standard interfaces) to coordinate multiple firms’ design efforts. Our findings confirm that firms’ knowledge necessarily have to span these boundaries (Brusoni, 2005; Principe, 2000; Steimmueller, 2003; Zirpoli and Becker, 2011a) and only carmakers that know more than they do can leverage modularity (Takeishi, 2001; Brusoni, 2005; Zirpoli and Camuffo, 2009).

Our findings also support the studies that have surfaced the limits of modularity in explaining distributed innovation processes in the car industry (Camuffo, 2004; Fourcade and Midler, 2004; MacDuffie, 2012) and suggest that cars are complex systems, not nearly decomposable in nature à la Simon (1962): the A/C system, one of the most modular car’s component, shares a number of interfaces and functions with other subsystems. This points to the many organizational challenges and sizable costs implied by the modularization of such complex products (Ethiraj, 2007; Zirpoli and Becker, 2011b).

First, our findings highlight a trade-off. The ability to design a highly modular A/C system is contingent upon an in-depth knowledge of both the A/C system architecture and its inner components. Given cars’ architectural complexity, only OEMs with high levels of direct involvement in components development can design a more modular system and experience the benefits of this architecture, as coordination and control mechanism. But this is a paradox, since one of the hypothesized benefits of modularization is to economize on component-specific knowledge by decoupling OEMs’ and suppliers’ design activities, i.e. by making them separable, isolable and recombinable.

This paradox confirms that whether and how good modular designs may be achieved in the face of complexity is an important question (Ethiraj and Levinthal, 2004). The contrapositions of the case of ALPHA and BETA suggest that, at least in the auto industry, component vehicle modularity, defined as the use of upfront defined “frozen” interfaces, can be achieved only if the OEM has a strategic interest in controlling the component performance via direct and intense investments in component-specific knowledge.

Second, our study shows that modularity (at least in the form of interface clarity, standardization and stability) has limited traction in easing the integration of external sources of innovation. High-powered interorganizational coordination mechanisms remain necessary to ensure effective and efficient product development. The implicit assumption of mainstream modularity literature that if you can modularize then you can outsource is mistaken, at least in the context we study. Modularity per se does not ease interfirm coordination. On the whole, our findings suggest that a variety of strategies regarding task partitioning and inter-firm coordination may be equally consistently pursuable and effective (Cabigioso and Camuffo, 2012), adding further evidence against the technological determinism that has been so pervasive in innovation studies (e.g. Sanchez and Mahoney, 1996).

Third, the two in-depth case studies provide empirical evidence on the conditions that make a modular strategy viable. In this respect, MacDuffie (2012) describes the case of the Chinese carmakers (see also Yong et al., 2009): they usually design more modular cars because, contrary to ALPHA, they almost completely rely on external suppliers to design the car’s systems. Once the suppliers have designed the car’s systems, the Chinese OEMs preserve these architectures that, otherwise, they would not be able to fully manage. Overall, our study complements the MacDuffie’s (MacDuffie, 2012) examples supporting the idea that non-univocal relationships exist between modularity and inter-organizational relationships.

Finally, our analysis suggests that further modularization processes in the A/C system would not necessarily lead to interorganizational loosely coupled relationships between OEMs and suppliers. However, although we do not expect that higher levels of modularity will modify the inter-organizational relationships per se, the A/C system technology, after having experienced an era in which diverse architectures were available and compete, may eventually converge to a single dominant design (Anderson and Tushman, 1990). This may lead to the definition of further standard interfaces that will increase the A/C system modularity level within the vehicle product architecture. In turn, we believe that this scenario still remains less likely because the A/C system constraints the car’s style and eventually the vehicle architecture (via power train and electrical requirements, fuel efficiency, etc.). Today, almost all carmakers use platforms to develop their models: different car models share a high number of underskin components (i.e. the platform) and are mainly differentiated leveraging on the car’s style (i.e. the hat). To achieve such component sharing among different models, carmakers impose many design constraints to NPD teams. These constraints are firm specific (i.e. are “closed standard”). Changing the idiosyncratic interfaces after the diffusion of an industry “open standard” might induce a high “propagation cost” (i.e. the cost of changing the design of all the interrelated components, MacCormack et al., 2010) at the firm level. Such propagation cost is usually high in integral products such as
cars (MacDuffie, 2012), proprietary software (MacCormack et al., 2012) and airplanes (Brusoni and Prencipe, 2011), and might offset the benefits of standardization (of one component interface).

Indeed, higher A/C system modularity levels may not be compatible with the necessity of differentiating cars' styles and, hence, may not be pursuable by OEMs.

6. Conclusion

This study analyzed two cases of integration of external sources of innovation focusing on the dynamic process of components’ interfaces definition (Baldwin, 2007; Sosa et al., 2004). We addressed our research questions relying on a “quasi-experimental design”: we built a research setting in which, keeping constant the variables related to product architecture and technology, and being other things equal, we could observe how and if task and knowledge partitioning and the inter-organizational coordination mechanisms were driven and shaped by component modularity.

Our results show that interfaces diverge significantly in the two cases and that their definition process was neither technologically determined nor the mere result of product architectural choices. In both cases, the OEMs and the supplier’s capabilities, degree of vertical integration, knowledge scope 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.

Our findings provide evidence against the “mirroring hypothesis” (Colfer and Baldwin, 2010), and more generally a deterministic view linking the engineering structure of a product and the related organizational structure (Sanchez and Mahoney, 1996). First, we show that the inherent complexity of automobiles reduces the chances of modularity to be effective as a functional equivalent of high-powered inter-firm coordination mechanisms (Cabigioso and CamUFFO; MacDuffie, 2012; Zirpoli and Becker, 2011a, b). Second, we highlight that carmakers, in order to increase vehicle components’ modularization and to take advantage of the associated benefits, need to heavily invest in components-specific knowledge. In the observed cases, modularity and design outsourcing are inversely related.

These findings have straightforward managerial implications. First, it clarifies under which conditions modularity-in-design may become a feasible strategy to harness external sources of knowledge and innovation in product development processes. Indeed, we found that modularization requires component-specific knowledge and, consequently, some kind of investment to remain in that knowledge domain. Modularity may constraint the supplier’s innovative contribute, but can also increase the control over the component performances and the supplier’s substitutability. Alternatively, firms may opt for lower levels of modularity thus reducing the depth and scope of the knowledge they need to master. This may also facilitate suppliers’ contribution (in terms of suggestions, ideas and innovations) since their effort is not constrained by rigid, standard and stable interfaces at the cost, however, of higher complexity and continuous design changes needed to solve new emerging interdependencies. This obviously asks for more and more sophisticated interorganizational coordination mechanisms.

As far as the generalization of our findings is concerned, our study is subject to all the limitations of industry-specific studies. However, it offers a new grid to analyze the appropriateness of modular strategies in those industries contemporarily characterized by high levels of product complexity (defined as product’s sub-systems connection via numerous interfaces and shared functions), fast technological change and architectural evolution of at least some sub-systems.

Thus, while today the modularity literature has mainly analyzed the strengths and weaknesses of modularity in-design aiming at their generalizability, future studies may focus on the contingent industry settings and firm’s specificities that influence the role of modularity in integrating external sources of innovation.

Finally, while our study questions the role of modularity and its uniqueness in the integration of external sources of innovation, it also represents the first part of the answer to a broader question that is which elements shape the integration of external sources of innovation and how they relate to each other. Future complementary developments of this study may be (a) the analysis of the role of modularity/technology in the integration of external sources of innovation from the OEM’s point of view selecting one module which is sourced from two different suppliers (i.e. test of the hypothesis of the specificity of carmaker organization for a same module developed for two different car projects) and (b) the study of the role of modularity/technology in the integration of external sources of innovation from the OEM’s point of view selecting one OEM, one supplier and two modules as well as the corresponding development projects (test of the hypothesis of the specificity of the organizational dimension (and especially knowledge partition) for two different projects with a same first tier supplier).

Acknowledgments

The authors thank John Paul McDuffie, Carliss Baldwin, Stefano Brusoni, Sendil Ethiraj, Sebastian Fixson, Andrea Furlan, Diego Campagnolo, Anna Grandori, Rob Grant, Richard Langlois, Anne Parmigiani, Andrea Prencipe, Fabrizio Salvadori, Melissa Schilling, Giuseppe Soda, Francisco Veloso, Maurizio Zollo, two reviewers, senior editor Martin Kenney, and participants at seminars at Bocconi and Venice University, the European Academy of Management 2010 Annual Meeting, and at the KITE 2010 workshop for comments and suggestions at various stages of the research on which this paper is based. The usual disclaimers apply. This research was in part funded by CROMA-Bocconi.

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