

Persistent integrality:
Product architecture and inter-firm coordination in the auto industry*

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Abstract

Despite the growing importance attached to modularity in theory and in practice, the automotive industry has shown substantial resistance to the trend towards modularization. This paper explores what this evidence implies for the management of inter-firm coordination and submits that the link between product architecture (modular or not) and inter-firm coordination should be substantially revised. This is demonstrated comparing empirical data gathered at a major first tier supplier on two different co-development projects carried out with two European car makers.

Keywords: innovation management, inter-firm coordination, knowledge integration, product architecture, new product development organization, modularity, auto industry, buyer supplier relationships.

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INTRODUCTION

Recent research has shown that in the automotive industry the diffusion of industry standards (Steinmuller, 2003), industry platforms (Gawer and Cusumano, 2008) and modularity (Sturgeon, 2002) has been quite limited so far. Overall the automotive industry, a prototypical case of inter-firm coordination in the context of product innovation (Womack et al, 1990, Clark and Fujimoto, 1991), has shown substantial resistance to the trend towards modularization (Mac Duffie, 2008).

This paper explores what this evidence implies for the management of inter-firm coordination with a particular focus on *how* the coordination of knowledge production takes place in the automotive industry.

We studied and compared two co-development projects carried out by a Japanese first tier supplier with two European car makers. For each of the two projects we observed the division of design and engineering tasks between the car maker and the supplier and the inter-firm organizational mechanisms at work. By means of a “quasi-experimental design” approach (Romanelli and Tushman, 1986), the goal was to isolate one parameter (the characteristic of the development project and of the system object of co-development) and observe eventual differences in inter-firm coordination between the two car makers.

Our empirical evidence shows that inter-firm coordination depends on (1) buyer’s endowment of resources, (2) the technological capabilities they have developed over time, and (3) the ability to design and operate inter-firm coordination characterized by intense information sharing and cooperation. Moreover, we show that, at least in the automotive industry, the need for ‘thick’ supply relationships persists, no matter how modular components are.

The paper is organized as follows. The next section provides a review of the literature and presents our research questions. Section three describes the method. Section four presents the empirical findings. Section five concludes the paper and offers research and managerial implications.

LITERATURE REVIEW

As predicted by some of the most important studies of the early nineties (e.g. Clark and Fujimoto, 1991, Womack et al, 1990), the last two decades witnessed a steady increase of vehicle development outsourcing. 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 towards a tiered configuration with global mega suppliers (Sturgeon and Florida, 2004).

As this deverticalization process took place, it seemed as if the auto industry would soon mimic the computer industry and converge to a modular configuration, though with an inverse causal sequence. There, modularity in product design had led to modular production, modular organizations and the fragmentation of the industry (Langlois, 2003; Baldwin & Clark, 2006; Jacobides, 2005). Here it was changes in the vertical contracting structure of the industry which was supposed to be driving a differentiated and contrasted transition to modular product design (Fourcade and Midler 2004; Sako and Murray 1999; Sako, 2003). In reality, this did not happen. Despite the efforts of some US and European carmakers, modularization has not been implemented successfully, with rare exceptions.

Ro, Liker and Fixson (2008) show that during the 1990s American automakers dedicated themselves to reengineering their product development systems, benchmarking the Japanese model -regarded as extremely effective in delivering high-quality component systems integrated into the vehicle with short design lead times-, and outsourcing increasing

levels of vehicle content and design responsibility. In a different study (Ro, Liker and Fixson, 2007) they analyze how the auto industry has been attempting to move to modularity, in part, motivated by the desire to emulate the success of Dell Computers in achieving mass customization, build-to-order and a streamlined supply chain. They maintain that this movement towards modularization has led to major changes in supply chain practices based partly on imitation of successful *keiretsu* models in Japan and a move toward modules. They find significant impact of modularity on outsourcing, product development, and supply chain coordination, and observe that modularity has accompanied a major reorganization of the automotive supplier industry.

Both studies, however, show that this reorganization has not been successful because: a) most modularity activities appear to be primarily strategically cost reduction driven, leaving the potential of modularity for mass customization largely untapped; and b) the shift in industry reorganization has not been accompanied by changes in the supply chain infrastructure to encourage long-term partnerships. This contrasts with the more gradual approach used by Toyota and other Japanese automakers, who undertake modularity efforts on a selective basis while moving towards a build-to-order model. Fujimoto and Donsheng (2006) show how Japanese automakers choose strategically transaction patterns for the detailed design drawings of auto parts to achieve the efficiency of inter-firm cooperation in the new product development process. Only within this framework they find that functional modularity of auto parts is positively correlated with the outsourcing of design drawings.

Overall, modularity has been implemented only in the design of selected auto parts, with closed standard interfaces beneficial in strategies based on product variety, quick market response and short product life-cycles (Holweg and Pil, 2004; Pil and Cohen, 2006). Besides, the few empirical studies about the interactions between modularity and outsourcing in the auto industry are controversial and show that the direction of influence between product

architecture and firm boundaries varies across individual processes and over time (Sako, 2003; Camuffo, 2004; Fixson, Ro and Liker, 2005; MacDuffie, 2008).

The empirical evidence is that the product architecture of automobiles has remained integral, with component interfaces that are neither standard, nor open, and with Original Equipment Manufacturers (henceforth OEMs) keeping in house large amounts of design knowledge as concerns both system integration and specific components (Mac Duffie, 2008).

Echoing a growing body of literature that has underlined that “modularity” has left behind many unfulfilled promises (e.g. Chesbrough and Kusunoki, 2001, Sturgeon, 2003), MacDuffie (2008) clarifies what has happened in the auto industry and suggests that inter-firm coordination processes are far from being resolved by loosely coupled organization (Sanchez and Mahoney, 1996). In theory modularization should eliminate interdependencies between assemblers and suppliers -since interfaces between product components are defined and codified *ex-ante*-, but as many studies show in practice organizational interdependencies remain ubiquitous. They continually emerge throughout the product development process, despite efforts to limit them (Staudenmayer, Tripsas and Tucci, 2005). Thus, modularization does not substitute for inter-organizational integration mechanisms, and there may even be decreasing returns to modularity-in-design efforts because of buyer-supplier integration problems (Mikkola, 2003; Brusoni, 2005; MacDuffie, 2008, Zirpoli and Becker, 2008).

MacDuffie (2008) concludes that the automotive industry is a typical example of an industry where modularity shows its technical and organizational limits and, hence, remains characterized by *persistent integrality*. But if the auto industry is characterized by persistent integrality and, at the same time, by high levels of product development outsourcing, two challenges stand out: (1) how can firms effectively organize the involvement of suppliers in their new product development process, and (2) what are the variable that firms have to consider in making decisions concerning supplier involvement.

Early literature on these questions offered many heuristics, based on ideas such as segmenting suppliers according to the product that is purchased, the timing of involvement, the type of interface, the nature of the relationship, etc. (Lamming, 1993, Clark and Fujimoto, 1991, Liker et al., 1996, Dyer, Cho and Chu, 1998). The dominant approach on how to discern about the nature of the relationship, however, was considered to be rooted in the assessment of the typology of the component purchased. Dyer (1996), for example, argues that buyer-supplier relations should be at arm's length relationships in the case of commodities or standardized parts with no significant side effects on other components and supplier relations. Instead, collaborative partnerships should be preferable with suppliers offering complex, high value, non-standard inputs, characterized by multiple interaction effects with other inputs.

More recent literature has brought into the picture other sources of heuristics. Following management research focus on knowledge as the most important asset in today's business world (Grant, 1996, Spender, 1996), studies on new product development have also emphasized the role of knowledge and framed "make or buy" decisions as decisions on how the knowledge required to carry out design tasks is allocated between buyers and suppliers (knowledge partitioning) (Takeishi, 2002; Lee and Veloso, 2008). The decision on how to allocate design and production tasks along the supply chain in such a way that coordination cost (including transaction cost) is minimized (Dyer, 1996) needs to be complemented with the decision on what knowledge buyers and suppliers need to develop and maintain (Takeishi, 2002, Fujimoto and Takeishi, 2003). Indeed, the outsourcing rationale and the "coordination toolkit" to manage the problem of coordination induced by outsourcing, should be different contingent on the innovativeness of the purchased component: more innovative components

are more complex to handle when the knowledge dimension is taken into account¹ (Takeishi, 2002). Wolter and Veloso (2008) develop this point linking the evolution of product architecture through innovations to the vertical scope of an industry, with transaction costs and capabilities as moderators. In their view, modular innovations should be associated with vertical disintegration, while architectural and radical innovations should call for vertical integration.

From this overview of the literature it emerges that when firms design and adopt inter-firm coordination mechanisms, in the case of complex products development, they have to consider a complex bundle of variables, spanning from the type of component they buy, the type of interfaces between components and the impact of the allocation of design activities on knowledge development. These variables, moreover, tend to change over time and across projects, even when the same supplier is involved, thus complicating the picture. It is possible, however, to distill some synthetic remarks on the link between product architecture, the division of labor and knowledge and inter-firm coordination that seem to be supported convincingly by empirical evidence in the auto industry:

1. product architecture alone cannot determine either the nature of buyer-supplier relationships or the level of product development outsourcing (Sako, 2003; Ro, Fixson and Liker, 2005; Mac Duffie, 2008);
2. “thick” buyer-supplier relationships aimed at learning and problem solving are key for achieving coordination in complex product development (Helper, MacDuffie and Sabel, 2000; Sabel and Zeitlin, 2004; MacDuffie and Helper, 2006);
3. the integrating firm’s knowledge and the impact of product development outsourcing on the allocation of learning opportunities along the value chain is a

¹ More innovative components development, in fact, entails potential knowledge spillovers to competitors, potential hold-up, uncertainty about development and manufacturing cost, perspective impact on other models sharing the same platform or architecture.

key variable in deciding on inter-firm coordination modes (Brusoni, Prencipe and Pavitt, 2001; Takeishi, 2001, Fujimoto and Takeishi, 2003; Lee and Veloso, 2008).

DATA AND METHOD

With these assumptions in mind, we designed and carried out a *case study* in order to observe how buyer and supplier coordinate their engineering and design efforts. We decided to build our sample using the principles of experimentation. More specifically we applied to our qualitative approach a “quasi-experimental design” (Romanelli and Tushman, 1986). The basic idea was to isolate one parameter (the characteristic of the development project and of the system object of co-development) and then see whether and how coordination mechanisms changed. To do so, we followed a two-step process. First, we decided what component/system would be the object of analysis. Then, we set the conditions to make the two cases comparable.

Case study selection

The choice of the component/system object of the analysis was key to make the comparison fruitful. Following Takeishi and Fujimoto’s (2003) observation that a vehicle can be decomposed using different levels of granularity (from a single component such as brake caliper to a front module made of many heterogeneous components), we chose to select a system at relatively aggregate level of analysis, i.e. a system made of a significant number of sub-components involving heterogeneous technologies. In fact, in the development of such systems, car makers usually involves many suppliers facing challenging coordination processes. Among the main systems that make up a vehicle - occupant safety system, brake system, power train, heat, ventilation and air conditioning, doors, cockpit, front end, etc. - we

selected the Air Conditioning System because, relative to the others, it is more “modular”. In fact, its interfaces are typically clearly defined and codified by the OEM both in terms of performance requirements and technical specifications, including the definition of physical interfaces. We deliberately opted for a system characterized by a relatively high level of functional and physical “isolability”, because we wanted to study if the presence of a self-contained component with clearly defined and codified interfaces could influence inter-firm coordination. We made this choice assuming that clearly defined and codified interfaces:

- *either* work as an *ex-ante*, embedded, partial substitute for high-power inter-firm integration mechanisms (i.e., mechanisms enabling intense cooperation and information sharing). In this case, loose coupling in component designs would work as a functional equivalent of inter-organizational coordination mechanisms – which is what standard modularity theory maintains. The need for ‘thick’ collaborative supply relationships should be reduced because knowledge encapsulation within modules would allow for economizing on inter-organizational coordination and control.
- *or* work as a *complement* to high-power inter-organizational coordination mechanisms. In this interpretation, ‘thick’ and collaborative supply relationships based on high-powered inter-organizational coordination mechanisms remain even in the case of a relatively highly modular component (as the A/C system), because modularization is not the logical antecedent but a consequence of inter-firm integration. In fact, modularity would require long time and comprehensive efforts by both assemblers and suppliers to be achieved and, hence, buyers and suppliers would tend to remain engaged in ‘hand-in-glove’ relationships.

When we approached the designated A/C supplier, DNTS, a major global supplier of thermal systems for the automotive industry, we found confirmation of our approach. As predicted by the literature (MacDuffie, 2008), the R&D chief explained to us that the

components designed and produced by DNTS could not be easily functionally isolated. However, the R&D Chief confirmed that among the various main systems of a car the A/C system could be considered among the most modular or loosely coupled with the rest of the vehicle.

Object of comparison

The second step was to set the context to conduct our comparative analysis. We selected two distinct development projects, started approximately in the same period, in which DNTS was developing respectively the A/C system for two car models developed by two competing OEMs. Both A/C systems should have targeted the same market segment, and should have been characterized by similar technology and degree of novelty. The two projects should have been typical, i.e. a good proxy for the usual way DNTS and its customers co-develop an A/C system. With these criteria in mind, we selected the following projects:

- Project-A, i.e. the development of the A/C system for a new ALPHA light commercial vehicle with a passengers use variant. The project was launched in 2003 and was derived from an existing A/C platform;

- Project-B, i.e. the development of the A/C system for a new BETA light commercial vehicle with a passengers use variant and a direct competitor of the Alpha model we analyzed. Also this project was launched in 2003 and was derived from an existing A/C platform.

As regards data sources and gathering, we analyzed company documents and conducted several rounds of structured and semi-structured interviews between November 2007 and April 2008. Table 1 lists the managers we interviewed and the duration of the interviews². We decided to interview both the projects ‘account managers’ (responsible for the commercial

² We also conducted Design Structure Matrix and Task Structure Matrix analysis for both projects. The details and the result of this analysis are reported in another study.

relationship with the OEM from the pre-offer phase until the end of the project) and the ‘project managers’ (responsible for component or system development)³.

TABLE 1 HERE

FINDINGS

This section is structured as follows. First we frame the relationship between DNTS and BETA and ALPHA in the broader context of DNTS business in Europe. We then describe the specific inter-firm organizational settings characterizing the projects under observation. After having reported in details on the relationship between DNTS, ALPHA and BETA we will provide a comparison between the two dyads.

The genesis of DNTS relationships with ALPHA and BETA

DNTS was established in 1987 as Magneti Marelli Climatizzazione at a time when the Fiat Group and Magneti Marelli decided to enter the growing car air-conditioning industry. In 1990 a joint venture was set up with the Japanese Denso Corporation (Nippondenso, at the time), world leader in the industry, leading the company into a phase of rapid growth of investments in R&D structures, new production facilities, technologies and competencies, and a stronger presence in the European Market. In 2001 Denso acquired full ownership of the company that adopted the name Denso Thermal Systems S.p.A. (DNTS). This allowed the company to become a fully fledged part of the Denso group, world leader in the field of automotive thermal systems. Nowadays, DNTS designs, develops, manufactures and sells air-conditioning systems, engine cooling systems, heat exchangers, radiators and compressors for

³ As Table 1 shows we did not interview managers at the car makers. In fact, as we were interested in triangulating data on two projects, only DNTS’ managers could provide us the comparative perspective we needed.

cars, commercial and industrial vehicles and also for tractors, earth moving machinery, busses etc. It is also active in designing and assembling integrated cockpit and front-end modules for cars. DNTS supplies all the major automotive manufacturers in Europe and South America.

DNTS started its relationship with ALPHA and BETA, two major european automotive companies, by targeting the commercial vehicle segment in the early 1990s. DNTS intuition was that there was a possibility to attack this niche because it was characterized by (1) a below average quality of the systems offered by the existing competitors and (2) a relative minor importance that the local suppliers gave to the light commercial vehicle segment at that time. These two aspects combined helped DNTS to enter a quite protected local market where most suppliers were local.

Project-A

The Project-A project was developed by DNTS for ALPHA. The project concerns the development of the A/C system for new ALPHA light commercial vehicle with a passengers use variant. The Project-A was derived from an existing product platform. DNTS was the only supplier for both projects. Currently, the previous project and Project-A represent about 40% of the DNTS's volumes with ALPHA, about 13% of the DNTS's revenue with ALPHA, and about 2% of the total DNTS's revenues.

The genesis of the Project-A project dates back in 2002 when ALPHA asked to its usual suppliers to suggest a new concept for the A/C system of the a new ALPHA compact car. More specifically, ALPHA asked to its suppliers to develop a conditioning system with a semi-centred architecture and with an air mixture system based on the one employed by Mercedes (an air mixture system based on air). This concept was novel for ALPHA though not for the industry where other OEMs had already employed this A/C solution (e.g. Mercedes). After an initial evaluation of the supplier proposals, ALPHA selected the Behr

project. The DNTS sales & marketing manager reported to us, “Behr got the contract because it was the main ALPHA supplier and because they were the main expert of the mixture air system required by ALPHA. Behr supplied this kind of A/C systems to Mercedes”. ALPHA paid all the development activities and acquired the property of the designs. Behr developed the project for one year. When the process reached the industrialization phase, ALPHA defined the project requirements and asked for a quotation not only from Behr but also from Valeo and DNTS.

When the Request for Quotation (RFQ) was launched in 2003, Behr, Valeo, and DNTS had 3-4 months to reply. DNTS despite the early success of Behr managed to acquire the business. The sales & marketing manager that worked on the project said that DNTS won for three main reasons. First, ALPHA did not specify the kind of mixture air system in its offer: DNTS’s intuition was that ALPHA was not fully satisfied by the new mixture system developed by Behr; DNTS, hence, decided to develop a concept with a “standard” mixture air system instead of the new one. The reason was mainly that the Mercedes system was working well only under specific conditions that did not seem to apply to the architecture of ALPHA cars. Second, the prototype developed by DNTS had the highest performance levels. Third, DNTS was the only one that had decided to open a new production site co-located to ALPHA (Vigo, Spain). In this phase ALPHA did not fix a target price and DNTS suggested its own price. In defining this price DNTS had an advantage over its competitors, also due to the decision of locating the production of the component close to the ALPHA assembly plant. DNTS won the RFQ in 2003, and was involved by ALPHA 48 months before the expected ramp-up.

In the next three sections we report respectively on the role of interfaces and component architecture in DNTS-ALPHA inter-organizational coordination, the role of high-powered inter-organizational coordination mechanisms, the nature of the DNTS-ALPHA relationship.

The role of interfaces and component architecture in DNTS-ALPHA inter-organizational coordination

Our interviewees were unanimous in stating that ALPHA fixed the product's architecture and the interfaces in great detail. Overall, ALPHA did not leave space to its suppliers for what concerns the architecture definition. Moreover, as seen above, while during the concept development, DNTS had the opportunity to ask changes about the interfaces, during the product development phase the interfaces were stable.

All the managers we interviewed stressed the ALPHA's ability in well defining the specifics (interfaces, functions, performance levels, etc.) claiming that these were one of the main coordination tools used by ALPHA. "In ALPHA the specifics remain stable after the *avant* phase" (48 months before the ramp up). The R&D chief of the project explained to us that ALPHA had a main set of specifics for the A/C system that was articulated in dossiers, one for each component. The main set of specifics contains the general requirements and standards for the system. The interfaces, defined inside the main set of specifics, were usually well specified also because ALPHA previously designed the other components of the car and then the A/C system. "ALPHA is seen as 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's projects are very stable for all the suppliers")⁴.

Interface standardization was not coupled with functional isolation though. The R&D chief of the project explained that "the A/C system shares several functions with other components, and the integration issues are all managed by ALPHA that defines the A/C system performances and interfaces knowing the interdependencies with the other

⁴ In a companion study, using TSM and DSM analysis, we measured analytically the stability of interfaces and the level of modularity in the project finding confirmation of this qualitative description.

components of the car. [...] When ALPHA defines the specifics for the compressor, it knows that the compressor interacts with the A/C system, therefore sets the right specifications for both the A/C system and the compressor”.

The R&D chief of the project reported to us that “ALPHA on the same platform has several groups made by different suppliers that are interchangeable even if the systems are not the same. This is because ALPHA well defines all the specifics that are available to all the suppliers”. These manager said, “ALPHA is very modular”⁵. We then asked to the R&D ALPHA Engineering Manager what was his perception about modularity. The manger told us that “modular designs would greatly reduce the necessity to interact with the clients [ALPHA]” because in case of modular designs “the car-maker would define the specifics, and the suppliers might interpret these trough their modalities”. “Now there is a certain transparency, with the systems of different suppliers that are pretty similar”. But the manager also specified that product modularity required a high level of system and component knowledge to well and precisely define both the specifications and the interfaces. ALPHA, in fact, had a strong knowledge both about the A/C system and its integration inside the car. ALPHA translated this knowledge not only in good specifics but also in the detailed specifications of the components inside the A/C system. The R&D managers went on saying “the car maker should define the A/C system functions and the performances leaving us the possibility to find the best technical solution. Nobody [in the car industry] has this approach. I believe that modularity is mainly diffused in the electronic industry but in our industry we have not already found the right level to have true black boxes because OEMs need more

⁵ More generally in our interviews it emerged that when Alpha develops a platform, the A/C system has the same architecture for models. Even when there is a carry-over, the A/C system’s architecture does not change, while other carmakers, as Beta, allow changes in the interfaces. The engineering manager said: “Alpha is excellent about standardization. Thanks to this ability, they realize several car models, as the model X, model Y, and model Z, with the same air conditioning system”.

experience. ALPHA is near the modularity approach but they are intrusive, they should make a step back.... An OEM needs several competences to modularize a system”.

Therefore, ALPHA that had a high vertical integration level was considered by DNTS to be close to define a modular A/C system. The key for achieving modularization in component design was ALPHA’s knowledge about the design of the architecture and the sub-components of the A/C system. This knowledge was at the heart of ALPHA’s ability to define both the interfaces between the A/C system and the rest of the vehicle and the interfaces between sub-components *ex ante*. We also observed that the interfaces were stable because ALPHA got involved in the design of the A/C system sub-components. The R&D manager acknowledged the paradox “product modularity might allow employing a pure black-box approach but product modularization requires a high knowledge about the components to modularize and when you can combine modularity and a black-box approach you risk losing the product competences needed to control the system architecture”.

Therefore, we asked whether DNTS preferred an OEM that defined the architecture and the specifics leaving the supplier the freedom to develop the component in a black-box fashion, or if it preferred an approach such as that of ALPHA. “Definitively the first”, the R&D chief said, because a black-box approach leaves more space to the supplier. The manager specified that ALPHA by providing the specifics for inner A/C components, limited DNTS’s contribution to innovation. On the other hand, the same managers admitted that ALPHA supported DNTS’s design and engineering. Overall, DNTS managers acknowledged that during the project they had many opportunities for learning from ALPHA.

From the interviews, hence, it emerged that ALPHA had high technical competences about the A/C system and its sub-components. Following the sales & marketing manager, ALPHA deepened and maintained its technical knowledge directly cooperating with some second tier suppliers, especially to develop new components: “ALPHA is integrating internal

competences till being able to develop the components inside the A/C system”. “They are increasing their integration level to be more competent and competitive, and they have the resources to do it.” It was due to its technical knowledge that ALPHA was able to define all the A/C system interfaces and, often, it defined the characteristics of the border components. The engineering manager reported to us that when they tested together with ALPHA the performance of the Project-A, results were totally positive. DNTS managers also said that they were highly confident that the test results would have been good as “their [ALPHA’s] specifics were clear and did not change so much. Moreover, we strictly followed their specifics”.

The role of high-powered inter-organizational coordination mechanisms

Despite the detailed and stable definition of specifics and interfaces, the project required intense information sharing. The formal information exchange consisted of a monthly meeting to plan the activities, plus other two meetings a month to resolve technical issues. Moreover, the DNTS’s project and area chief engineers were in contact via e-mail or telephone calls with the ALPHA corresponding chiefs. These interactions were more frequent (daily interactions) and intense during the concept development and the preliminary design, while they were less frequent after these phases⁶.

The daily contacts usually aimed at resolving problems that might stop the project. In fact, ALPHA defined the interfaces and the specifics but these could not resolve all the interdependencies between the A/C system and the car ex-ante. In this respect, the engineering manager said: “We contact ALPHA to verify to have correctly understood their requirements or if we needed help. The goal is to not stop the project development till the next meeting”.

⁶ We were told that, while the frequency of the e-mails and telephone calls usually depended on the complexity, newness, and phase of the project, the number of meetings was standard.

In any case, DNTS co-located the design and engineering team close to the main ALPHA location in France. For the occasion DNTS rented a space and permanently staffed two engineers. In fact, despite the scheduled monthly meetings, frequent phone calls, detailed interfaces definition and contractual agreements, DNTS managers highlighted the fact that face to face communication was indispensable: “when the project was launched, we rented a space near ALPHA to be able to meet the client on a daily basis. The “human interfaces” consisted of two engineers coordinated by the area-chief”.

The nature of the DNTS-ALPHA relationship

DNTS managers univocally described the relationship with ALPHA as a cooperative one. However, they acknowledged that they were accepting some potentially harmful behaviors by ALPHA. For example, DNTS knew that it could be substituted during the life of the project by a supplier offering better conditions and despite the fact that DNTS had invested in development activities. However, despite this possibility existed DNTS affirmed: “We are not afraid, ALPHA has never changed a supplier with another”. DNTS managers were aware that DNTS was difficult to substitute having a co-located plant. Moreover, DNTS considered itself a technological leader. This assured protection.

Also ALPHA’s rigidity in the contractual definitions of specifics and interfaces was not considered as an “hostile” practice: “The more an OEM is contractual (i.e. it well defines all the specifics and calls for the respect of the agreement), the less we have to debate, while the less are the specifics the higher is the room for conflicts”. Our interviewees confirmed that: “every time that the specifics are strictly defined by ALPHA, the latter becomes fully responsible for the final result”. On the other hand, “when the specifics are very detailed and strict, every time we believe that they should change, for example because the specifics are incompatible with the performances required, there are conflicts”.

A final note on pricing. Price reductions were established and enforced by the contract (2% every year for four years). The volume to produce (and therefore the production capacity required by ALPHA) was specified in the contract. However, the price was not based and fixed exclusively on these volumes. The DNTS's sales & marketing manager said: "We are not afraid about volumes. Only in one case we did not reach the planned volumes and ALPHA paid us the lost amortization". This is a very fair approach, but also quite rare in the industry.

Project-B

The Project-B project was developed by DNTS for BETA. The project regarded the development of the A/C system for the new BETA light commercial vehicle. DNTS was the only supplier for the analyzed project. Currently, the Project-B has a weight on the DNTS's revenue of about 6% of the total revenues, while this project represents about the 90% of the DNTS's revenue with BETA. The production volumes of the Project-B are about 200000 pieces a year.

In 2003 BETA launched the RFI (Request for Information). During this step BETA provided the competing suppliers with the forecasted A/C system volumes (BETA usually involved five suppliers for the A/C system: DNTS, Valeo, Behr, Delphi, Carlsonic. Valeo was the first with about the 80% of the BETA business). 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 took about two years. The Project-B's production started in 2007.

The sales & marketing manager said that DNTS was able to acquire the above business thanks to its technical knowledge, the cooperative approach toward the carmaker, and for the low price. The DNTS sales and marketing manger explained that price was an important

variable. However, only the suppliers that had previously demonstrated their technical capabilities could participate to the RFQ. BETA, in fact, had employed a complex certification procedure: “to be a BETA’s supplier you need to pass a strict exam every 5-6 years. Therefore BETA supposes that you are able to develop the A/C system required and this is why they push the price competition”.

As for the project DNTS-ALPHA described above, Project-B was developed on the basis of a previous A/C system, the one developed for another BETA model by Valeo. In this project, DNTS introduced some modifications for the OEM. These innovations were mainly related to the internal system’s structure, and had the aim to reduce the system’s noise and volumes. The R&D manager said: “We improved the evaporator dimensions that changed from 90 mm to 38 mm”, “we also improved the performances and noise of the electro-ventilation system”. Moreover the system was able to cool the car more quickly.

The R&D manager said: “To develop this project we took the Model R and inserted our A/C system inside the car. We showed the improvements following the introduction of our A/C system and demonstrated that we were able to fit their specifics and that the changes we suggested were highly performing”. Moreover the DNTS manager said: “To demonstrate the improvements we performed several tests on the A/C system, on car’s prototypes, and on the final model”. “The tests on the system do not allow understanding substantial differences (i.e. among different A/C systems). In fact, only when the system is integrated into the vehicle these differences are evident”. These words highlight how BETA leaves space to its suppliers that can suggest new solutions that can even contradict the BETA specifics. DNTS considers BETA’s cooperative and interactive approach one of its strength. But from our interviews it also emerged that it was difficult for both parties to forecast the A/C system performances until it was assembled in the final product. Our interviewees at DNTS reported once again

that “the tests on the A/C system alone do not always let us understand the true performances of the A/C system”.

As for Project-A, in the next three sections we report respectively on the role of interfaces and component architecture in DNTS-ALPHA inter-organizational coordination, the role of high-powered inter-organizational coordination mechanisms, the nature of the DNTS-BETA relationship.

The role of interfaces and component architecture in DNTS-BETA inter-organizational coordination

BETA usually outsourced the A/C system after having defined the spatial constraints and the main interfaces the A/C system would have to match. However, nearly no interfaces remained stable over the life of the project. An interviewee reported to us that “BETA starts with hypotheses that have to be defined in more details and then selected”. For example “changes in the cockpit style might require changes in the A/C system” or “the options they require might imply changes in the architecture”. Indeed, during new projects the initial architecture defined by BETA evolved, and DNTS was involved in the process of architecture definition⁷. As DNTS engineers reported to us “specifics change even substantially. We always start from hypotheses that need to be refined”. In this respect engineers stressed that “if we develop the system as a black box it is risky. If we open the black box the OEM can understand everything. Only opening the back-box DNTS can help BETA in deciding and evaluating exactly the consequences of the BETA’s requirements: the black-box approach does not allow BETA understanding the impact that some changes required at the system

⁷ Beyond the realm of the specific project, DNTS reported to us that, especially when the project is new, Beta employs a parallel approach in developing the components. The DNTS R&D manager explained that when Beta starts developing the A/C system it builds on simple constraints such as, for example, the definition of the physical interface between the engine and the cockpit.

level might have on the overall A/C performance, while an intense information sharing helps BETA in better defining the final system-configuration”.

As the engineers at DNTS explained, “We give the elements to evaluate different solutions, we do not suggest the best”. Therefore BETA had the competences to decide which solution fit better the requirements of its cars. But the DNTS’s engineer also said: “We have a clear understanding of the technical interdependencies among the A/C system and the other car’s components” while “BETA understands about 50% of these interdependencies”. This was because even if BETA was the final integrator it was not expert of the impact that changes in the A/C system’s architecture had on its overall performance. The DNTS engineers in this respect said that “When BETA requires changes in the A/C system it needs our competencies to evaluate their impact on the A/C system performances. In such cases, DNTS highlights these consequences and eventually suggests other solutions. The final decision is taken by BETA”.

DNTS interviewees reported that BETA had strong competences for what concerns the quality management, the detailed breakdown of overall cost of the A/C system and of its components. DNTS also acknowledged that BETA architectural knowledge was higher than the DNTS’ one but underlined that BETA’s knowledge about the components was definitely low.

How could BETA have such a detailed knowledge about the costs of components and their quality but little knowledge about the sub-components technologies? DNTS managers told us that BETA had developed a very detailed database and asked DNTS to disclose all the information it possessed on the cost of components and even subcomponents. Moreover, BETA had developed a reliable reporting system on eventual problems that the A/C systems reported on the market. The cross comparison of cost details and technical and functional

problems allows BETA to guide DNTS's choices without an in depth technical knowledge about the components themselves.

The DNTS manager stressed the importance of learning from experience. For every project, as for Project-B, that BETA co-develops with its suppliers, it analyses the "warranty costs" in order to understand how and where to improve the A/C system and set the next generation of A/C performance targets. Everything that BETA learns is carefully codified in written procedures. These procedures are helpful for DNTS "because better specifics help avoiding past problems". The rules codified by BETA are both contained in the product specifics and in the validation plans. This systematic approach allowed BETA to acquire an expertise on the overall A/C system's cost and of its sub-components, to control the A/C system performance and its integration. Our interviewee reported to us that BETA's systematic approach helped the car maker to compensate a lack of investment in the development of component specific knowledge.

The role of high-powered inter-organizational coordination mechanisms

DNTS managers confirmed in many occasions BETA's attitude towards the codification of co-development practices into standard procedures: "every day there might be component innovations but every activity in the development process is totally routinized". DNTS managers, in fact, stressed that BETA had a very strict procedure to manage its relationships with suppliers. BETA controlled the project status through a procedure made of five steps and some very detailed milestones and required monthly meetings plus others appointments. Each milestone had a corresponding BETA's specialist. Moreover, BETA had several inspectors that supervised the activities developed by DNTS. DNTS's opinion of this approach was usually that this strict procedure did not always correspond to a robust engineering approach to problem solving. The true value-added of each milestone "often depends on the specific

person that manages the procedure's step". Of course, the strict recourse to procedures also produced the result that "they are good technicians but due to too many procedures some time we risk stopping the project". Intense communication and frequent information sharing in all the available forms were, however, a standard practice.

On a final note, BETA, due to time and cost constraints, was starting externalizing some of the control activities to third parties, like engineering companies. DNTS's people reported to us "that they [third parties] do not have high technical competences and the power to eventually let BETA understand the importance of our suggestions or requirements". This, of course, risked to complicate the picture and required more informal communication between DNTS and BETA people.

The nature of the DNTS-BETA relationship

Also the relationship with BETA was perceived as substantially cooperative: "with the operative teams we have a very good and cooperative relationship".

BETA was known for having strict 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. However, BETA's main concerns were on costs: "they send some analysts that control step by step all the variables we include in the price definition". BETA did not evaluate all sub-components, but it had the knowledge to evaluate the components with the highest impact on the overall product cost.

BETA required producing the A/C systems near its plants. As well as ALPHA, BETA asked for cost cutting of 3% each year for three years. DNTS, in this case, had to develop a

complete cost breakdown and analysis with BETA. BETA paid “cash” the manufacturing tools and equipments.

Finally, despite in the past BETA had changed supplier during the life of the project, DNTS’s sales and marketing manager considered this eventuality not probable because it would have not been economically convenient for a competitor to enter in a project of another supplier and because BETA paid the tools ex-ante.

A comparison of ALPHA’s and BETA’s relational strategies

Our description of the two projects shows a nuanced picture of what drove the division of labor and the coordination mechanisms in the. The same A/C system (same architecture, same complexity, same market segment) was co-developed according to a different conceptual definition of the *interfaces* and employing different *organizational solutions*.

In this section we analyze the main differences between Project-A and Project-B as they emerged from the interviews and the company documents. We present these differences as characterizing, respectively, the ALPHA’s and BETA’s approaches. We solicited the interviewees on the generalizability of the findings and were 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 car makers.

Interface definition and knowledge boundaries

ALPHA demonstrated to possess an in depth system and component specific knowledge that it used to define in detail both the A/C system’s architecture and some of its components. Moreover, according to the people we interviewed at DNTS, ALPHA managed to keep most specifics pretty stable. The main motivation was to leverage the same A/C system in different

models. The main drawback was the limited supplier's freedom in suggesting new and different architectural solutions.

DNTS's engineers also agreed that the interface standardization did not eliminate the information sharing due to the existence of complex functional interdependencies between the A/C system and other components of the car: ALPHA achieved a high interface standardization level but did not manage to achieve functional isolation. ALPHA, hence, in order to control some of the residual functional interactions, had to be involved in the definition of the characteristics of inner components. Even if this approach allowed creating stable interfaces, according to DNTS engineers, this approach was not truly helpful to improve the overall system performance and innovativeness. The reason is, according to DNTS's managers, that ALPHA should have made a step back, in detailing the specifics of inner components.

BETA's approach was in many respects different. BETA co-developed the A/C system with the supplier even for what concerned the system architecture definition and its interdependences with the rest of the vehicle: the system main concept and architecture was set at the beginning but it changed during the project and BETA allowed DNTS suggesting several improvements even at the architectural level. According to DNTS engineers, this approach had some advantages: it increased the possibility to introduce important innovations and improvements and reduced the development time. The main drawback was that the project was less stable, because as DNTS could ask architectural changes, even other suppliers could do so. Moreover, the BETA approach in developing the product often translated into a lower level of architectural standardization of the A/C system, especially for what concerned the interfaces standardization. Therefore, the overall component standardization level of the BETA A/C system was lower than the ALPHA one. In fact, while

ALPHA seemed investing in common platforms and standards, the BETA approach was different.

Figure 1 and 2 represent the ALPHA and BETA approaches in the A/C system development. The main rectangle delimited by the green frame represents the A/C interfaces, the small rectangles represents the inner A/C sub-components, and the oval the overall engineering solutions. ALPHA fully specified all the interfaces (the green zone), some active components (the blue boxes inside the A/C system boundaries), and other characteristics of the A/C (based on previous engineering solutions). The white zones were those fully managed by DNTS.

Insert Figure 1 approximately here

Insert Figure 2 approximately here

Hence, our finding shows that there is a tight link between the way the OEMs define the interfaces and the knowledge partitioning between OEM and suppliers. Moreover, we found that OEM and suppliers integration was eased when interfaces were *either* detailed and stable over the life of the project (DNTS-ALPHA case) *or* general and fluid over the life of the project (DNTS-BETA).

In the former case, we observed that the OEM together with stable and detailed interfaces also gave technical directions on how the suppliers should develop the A/C system and its inner components. 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 low OEM-supplier integration costs (e.g. need of re-design, further info sharing, etc.), intense information sharing and inter-organizational formal procedures are associated to a better and more effective definition of

standard and stable interfaces only if the OEM is vertically integrated (i.e. holds component specific knowledge).

In the second case (DNTS-BETA) the OEM gave indications concerning the interfaces between the system and the rest of the product in a black box sourcing fashion, i.e. without specifying the A/C system architecture and inner components. However, since the OEM knew little about the interdependences and interactions between the components within the system and the rest of the product it must be prepared to face intense information sharing during the project. We infer from this evidence that, in order to increase the chances of optimizing information sharing and coordination costs the OEM which designs fluid interfaces should set up inter-organizational routines that are stable enough to support mutual adjustments in the interfaces design and engineering.

Counter intuitively, we found black box sourcing associated with intense inter-firm coordination and information sharing. The explanation we were provided by DNTS's managers is that what matters for minimizing information sharing is the level of knowledge held by the OEM and its ability to predict the technical interdependences characterizing the design over the life of the project (as the DNTS-ALPHA case shows). In black box sourcing, that we associate with the decision of the OEM to not directly invest in component specific knowledge, the OEM tends to focus on the interface definition. However, the OEM lack of component specific knowledge often leads, when technical interdependences are complex, to re-design or adjust these interfaces during the life of the project (the OEM lack of component specific knowledge prevents the OEM from being able to address all the possible integration problems ex-ante). For this reason, routinized information sharing has to compensate the need of information sharing arising from the OEM lack of technical know-how (as the DNTS-BETA case shows).

Persistent integrality and organizational consistency

Our case study confirms that some of the “rules of thumb” based on the relationship between product architecture, outsourcing decisions and inter-organizational coordination mechanisms are often incorrect. For example, we observed that the reliance on standard and stable interfaces was the consequence and not the cause of vertical integration decisions (on this point our results are consistent with those of Fixson et al., 2005). In both the BETA and ALPHA cases we observed that product architecture was not a major determinant of inter-firm coordination mechanisms and relational setting. The two A/C systems, despite the similarities in terms of characteristics, architecture and performance, were developed by DNTS on the basis of interfaces that were defined by ALPHA and BETA in two substantially different ways. This shows that the decision to rely on stable and detailed interfaces vs. fluid and changing ones was not linked to intrinsic characteristics of the system under development (i.e. its product architecture) but derived from a deliberate choice of the OEM regarding its level of knowledge concerning the components technology and the involvement in its design (i.e. vertical integration).

The “relational style” (Sabel et al, 2008) characterizing the relationship followed as a natural consequence. While BETA, in need of compensating its lack of component knowledge with a more sophisticated and structured inter-organizational procedures, pushed towards a more formalized relationship, ALPHA, being more in control of the technical interdependences, relied more on standard and stable interfaces that were complemented by more informal coordination. Such informal coordination, however, was deliberate and systematic as ALPHA asked for co-located development teams and frequent information sharing. Both relationships were considered by DNTS as cooperative and successful. DNTS’s managers used the term “consistent” to describe BETA and ALPHA behavior.

The key to understand why both co-development systems are *consistent* lies in the understanding of the very logic on which the two systems hinge. Both ALPHA and BETA seem to be aware of the need of addressing functional interdependences between the A/C system and the rest of the vehicle. ALPHA's high competence on the A/C system technology and its components put the company in the position of designing interfaces between the A/C system and the rest of the vehicle that addressed most of the functional interdependences *ex ante*. BETA, vice versa, knowing that it lacked the necessary component specific knowledge for developing technical specifications and address functional interdependencies *ex ante*, hinged on fluid interfaces and on a higher contribution of DNTS in the definition of the A/C system components. In addition to this, BETA, acknowledging the necessity of structuring communication in more detail, set up very structured inter-firm information sharing processes. In both cases, we observed that neither the nature of the relationship nor the need of frequent and intense communication depended on the type of interfaces used.

ALPHA managed to achieve an efficient and effective coordination by leveraging stable interfaces but not implementing a black box sourcing that notably hinges on the detailed *ex ante* specification of standard interfaces. In fact, ALPHA did design the interfaces but employed an "hands-on" approach on component design, so contrasting with the stereotypical idea of black box sourcing. On the other hand, BETA was also successful by adopting an "hands-off" approach on component technologies without pretending to apply a stereotypical black box sourcing measure, i.e. identifying stable and detailed interfaces. The lack of component specific knowledge, was then compensated by noteworthy investments in developing organizational capabilities.

The level of design and engineering know how as well as the inter-firm organizational routines and capabilities of the car maker seemed to be the main determinants of the

organizational settings used to manage the two projects we observed. Table 2 provides a synthesis.

Insert Table 2 approximately here

DISCUSSION AND CONCLUSIONS

Our study extends research on strategic inter-firm knowledge partitioning as well as on the information-processing view of product development. First, it provides additional, micro-level empirical evidence for the claim that firms' knowledge boundaries extend beyond firms' task boundaries (Brusoni and Prencipe, 2006; Lee and Veloso, 2008). Second, it shows that - *ceteris paribus* - the imperfect overlap between task and knowledge partitioning also differs across firms. We show that the reason why firms make different choices concerning their boundaries does not only lie in differences in the product architecture. Similarly to what happens to the allocation of tasks (Wolter and Veloso, 2007), also the degree of overlap in knowledge domains between an assembler and its suppliers is not technologically determined, as the standard modularity literature would argue (Frigant and Talbot, 2005). Our findings confirm that suppliers dominate component knowledge whereas assemblers lead on architectural knowledge. However, and more importantly, due to persistent integrality and when facing uncertainty we show that firms chose to adjust their knowledge boundary by increasing the knowledge overlap along the supply-chain (Mac Duffie, 2008, Lee and Veloso, 2008). To what extent they do so, however, is a matter of strategy with constraints on options coming from inter-firm routines, existing capabilities and previous choices on firm's boundaries.

Our case study shows that the same conclusion also applies to the choice of the coordination mechanisms. Our findings show that, in fact, the means by which inter-firm coordination is achieved is not determined as a consequence of the nature of product architecture (modular vs. integral). We reached this conclusion “isolating” the effects of product architecture in the management of inter-firm relationships. Our work confirms that persistent integrality leads to the impossibility to cope with complex functional integration, i.e. a complete fit between subsystem performances and the rest of the vehicle performances, and inter firm coordination relying mainly on self contained units, standard and stable interfaces. Collaborative buyer-supplier relationships appears as the logical antecedent and the condition upon which any modularization process is based and/or complement modularization allowing for *ex post* problem solving due to unforeseen design and supply chain management problems. At least in the automotive industry, hence, the need for ‘thick’ and collaborative supply relationships persists, no matter how modular components are.

Moreover, our empirical evidence contributes to the understanding of the rationale according to which firms employ different organizational practices by highlighting the variables that influence the firms’ choice about coordination. Contrary to previous literature that emphasizes the centrality of product architecture in deciding on inter-firm coordination and integration mechanisms, we show that inter-firm coordination actually depends on the level of component specific knowledge that OEMs have maintained in house, the technological capabilities they have developed over time, and the organizational capability to design and operate high-power inter-firm coordination mechanisms. The supplier in our sample considered the consistency of these variables as the key for successfully coordinating inter-firm relationships.

The centrality given to organizational consistency rather than to technology led considerations fosters new research towards the direction of a deeper understanding of how

firms can achieve such internal and external consistency over time and across projects. Both component specific knowledge, organizational competences and inter-firms routine are interdependent and dynamic.

Finally, our results shows the need of further research in order to provide a better understanding of what drives the division of labor between firms and the coordination of knowledge production in industries characterized by persistent integrality.

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TABLES AND FIGURES

Table 1. List and duration of interviews at DNTS

DNTS interviewees	Duration
R&D chief	1h30min
R&D chief for Alpha	2h30min
R&D chief of the project for Alpha	2h30min
R&D chief for Beta	1h45min
Sales & marketing manager for Alpha	1h10min
Sales & marketing manager for Beta	1h

Table 2. A comparative analysis of the Alpha and Beta projects

OEM	Alpha (Project-A)	Beta (Project-B)
A/C system architectural knowledge	High	Low
A/C systems sub components knowledge	High	Low
Interface stability within the A/C systems	High and tightly controlled	Not controlled
Interfaces stability between the A/C System and the rest of the vehicle	High	Low
Information sharing	High	High
Physical co-location of DNTS engineers	Yes	No
Relevance of inter-firm written procedures	Low	High
Emphasis on sub component cost disclosure	Low	High

Figure 1. The ALPHA approach

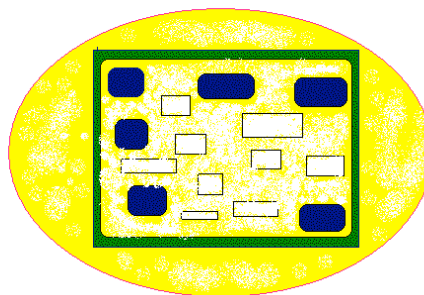


Figure 2. The BETA approach

