

---

## Modularisation and outsourcing: who drives whom? A study of generational sequences in the US automotive cockpit industry<sup>1</sup>

---

Sebastian K. Fixson\*

University of Michigan, Industrial and Operations Engineering,  
1205 Beal Avenue, Ann Arbor, MI 48109, USA  
E-mail: fixson@umich.edu  
\*Corresponding author

Young Ro

University of Michigan-Dearborn,  
Department of Management Studies,  
4901 Evergreen Road, Dearborn, MI 48128, USA  
E-mail: yro@umich.edu

Jeffrey K. Liker

University of Michigan, Industrial and Operations Engineering,  
1205 Beal Avenue, Ann Arbor, MI 48109, USA  
E-mail: liker@umich.edu

**Abstract:** In this paper, we study the interactions between modularity and outsourcing in the auto industry. Focusing on vehicle cockpit projects in North America, we collect data over three product architecture generations and the associated shifts in firm boundaries for multiple processes covering product development and production. We find that the direction of influence between product architecture and firm boundary varies across individual processes and over time, resulting in a zig-zag path towards higher levels of modularity and outsourcing over the observed timeframe. The relative strength of the factors that drive these changes appears to be dependent on (a) idiosyncrasies of the logic of individual processes, i.e., their cost structure, their perceived strategic value, and the capabilities available in the supply chain for their completion, and on (b) the relevance and relative weight of external factors such as labour costs, capital cost, and external development of technologies.

**Keywords:** automotive suppliers; firm boundaries; modularity; outsourcing; product architecture; technological/organisational change.

**Reference** to this paper should be made as follows: Fixson, S.K., Ro, Y. and Liker, J.K. (2005) 'Modularisation and outsourcing: who drives whom? A study of generational sequences in the US automotive cockpit industry', *Int. J. of Automotive Technology and Management*, Vol. 5, No. 2, pp.166–183.

**Biographical notes:** Sebastian Fixson is Assistant Professor of Industrial and Operations Engineering, University of Michigan, Ann Arbor. His current research interests include modularity/product architecture, cost evaluation techniques and product development processes.

Young Ro is an Assistant Professor in the Department of Management Studies at the University of Michigan-Dearborn. His current research interests are in the areas of supply chain management, product development and the management of technology.

Jeffrey Liker is Professor of Industrial and Operations Engineering, University of Michigan, Ann Arbor. He studies lean manufacturing, lean product development, and manufacturer-supplier relations in product development. He is the author of *The Toyota Way*, McGraw-Hill, 2004.

## 1 Introduction

Two major recent trends in the global auto industry have been the related movements toward new approaches in supply chain management, in part influenced by the Japanese model, and an engineering move toward the use of modular product architectures. While the extent to which modularity has occurred in the auto industry is still debated, it appears that the versions of modularity that did occur have affected both automakers and suppliers. Modularity has affected the firms' organisational structures, both internal and external, and has helped shape the relationships between automakers and suppliers. At the same time, there is an argument that it is the supply chain structure, and in particular the location of the firm boundary, that contributes to the modularisation of the automobile. This paper aims at disentangling what is the cause and what is the effect between the product architecture and the supply chain structure in the auto industry.

In the past, 'modularity' and 'outsourcing' were investigated predominantly in separate research communities. Modularity has been promoted as a design principle in the engineering community (Kusiak, 1999; Pahl and Beitz, 1996) and outsourcing has been discussed in economics, management, and strategy communities ever since Coase asked more than 60 years ago: why do firms exist? (Coase, 1937).<sup>2</sup>

More recently, however, a research stream has emerged that links these two topics together. For the computer industry, it has been shown that IBM's modularisation of the computer architecture in the 1960s has been a precondition for the emergence and subsequent dramatic expansion of the personal computer industry (Baldwin and Clark, 2000), and the success of the business model of computer maker Dell has been declared all but impossible without taking advantage of the modular computer architecture and novel forms of just-in-time supply chain management (Kraemer and Dedrick, 2001). Similarly, it has been argued that firms can only produce products that exhibit structures that are similar to their own organisational structure, and most firms fail when confronted with the demand to change their own products' architecture in response to competition (Henderson and Clark, 1990). Expanding the organisational aspect beyond the firm to include the whole supply chain, it has been argued that a product's architecture oscillates between modular and integral while simultaneously firms contract and expand their boundaries, i.e. outsource and insource work (Fine, 1998).

While there is ample evidence that product architectures and firm boundaries affect each other in the auto industry, the precise mechanisms remain underexplored. In more general terms, do products design organisations, or do organisations design products? Some argue that only real data can answer this question: 'It is then an empirical question to gauge which causal direction has been stronger over a particular period of time.' (Sako, 2004) With the study on the product development and manufacturing of automotive cockpits in North America, this paper attempts to shed some light on this question.<sup>3</sup>

The paper is organised as follows. In the next section we present the state of the discussion in the literature on the causal link between product architecture and firm boundary. The literature is presented in three camps: one that emphasises the causal link

running from product architecture to organisational architecture, another that stresses the reverse orientation of the link, and a third that promotes a view of simultaneous interactions. Next follows the description of our multiple case studies on automotive cockpits in North America. We find that the reality is much messier than most simple models suggest. Not only do we find interactions of various degrees for different sub-processes, it also seems that there are powerful external forces that drive both variables. Finally, our observations indicate that the entire automotive industry is in a massive transition phase, and despite observing cases over a period of almost a decade, we must be cautious and interpret our findings more as a snapshot than a true longitudinal study. We conclude with implications for future research and management practice.

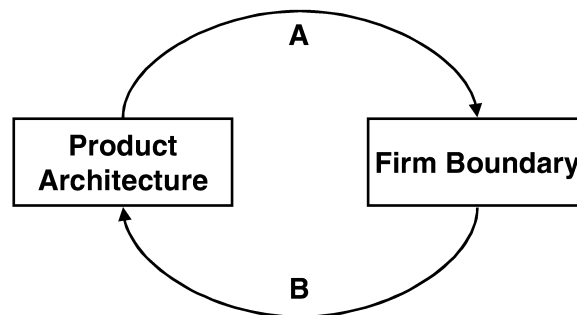
## 2 Background and literature

The topics ‘modularity’ and ‘outsourcing’ have been individually discussed extensively in their various disciplines. With respect to products, modularity represents a characteristic of a product’s architecture. Choosing a product’s architecture is a central task in the conceptual design phase during product development. Consequently, a number of design engineering and product development textbooks discuss how to choose a product architecture, including the relevant issues surrounding modularity (Kamrani and Salhieh, 2002; Ulrich and Eppinger, 2000).

The question that underlies the issue of outsourcing, whether a firm chooses to do work in-house or to give it to a supplier has also been discussed widely in multiple disciplines under the heading of firm boundaries. A firm’s boundaries determine the content of work the firm does on the inside relative to what remains outside as well as the number and type of interactions the firm has with its environment. Consequently, researchers in fields ranging from management to economics have focused on this issue (Fine and Whitney, 1996; Holmstrom and Roberts, 1998; Pisano, 1990; Williamson, 1985).<sup>4</sup>

Our intention with this paper is to focus on the *interactions* between product architecture and firm boundary. The existing constructs for these interactions in the literature can be clustered into three categories (Figure 1). In the first category, the causality runs from product architecture to firm boundary (A). In other words, a product’s architecture affects the type and location of the firm’s boundary. The second category represents the reverse argument: the attributes of the firm’s boundary impacts on the product’s architectural characteristics (B). Finally, the third category presupposes that both issues influence each other simultaneously (A+B).

**Figure 1** Three effect combinations between product architecture and firm boundary: A, B, and A+B



### *2.1 Product architecture affects firm boundary*

The general idea that a firm's organisational structure over time mimics the structure of the products it produces has been extensively investigated. With respect to a firm's internal organisational structure this phenomenon has been identified as representing an advantage in stable environments (Sanchez and Mahoney, 1996), and being a disadvantage if competitors introduce products with a different product architecture (Henderson and Clark, 1990).

In either case, the underlying rationale is that a product's architecture determines the processes required to develop and produce the product, and in turn, contributes to the definition of the firm's organisational structure, including its boundaries. The classic example is IBM's decision to introduce the System/360 with a modular structure (Baldwin and Clark, 2000). Once IBM had designed the system with a modular product architecture, it became possible for independent manufacturers to provide individual components to customers. Market forces led to driving down prices for individual components, such as hard drives, which could be mixed and matched and eventually became commodities. Leaving aside for a moment the question as to what extent this outcome was intentional by IBM, the causality runs from, firstly, defining a product's architecture to, secondly, establishing firm boundaries of certain types and at certain locations. The conclusion in general terms is that a modularisation of the product architecture results in the outsourcing of components and processes.

In a recent paper, Baldwin and Clark provide the underlying reason for this interpretation. They understand every production system as a network of tasks and transfers. Transfers are necessary in every system that is beyond the cognitive limitation of a single individual. Only a subset of the transfers, however, falls into the category of what economists call 'transactions'. Baldwin and Clark argue that for a transfer to become a transaction it needs to be standardised, countable and evaluated. The actions that make it possible to agree upon the content of the transfer (standardised), that make it possible to count whatever is to be transferred (countable), and that make it possible to measure the quality of what is transferred (evaluable) are design decisions. Thus, design decisions translate into tasks that can either be encapsulated, i.e. they become independent of each other, or they are interdependent with other tasks. Baldwin and Clark understand the firm itself as an encapsulated system defined by design decisions: 'Firms are a form of encapsulated local system, thus the location of transactions and contracts perforce defines the boundaries of firms.' (Baldwin and Clark, 2003)

There is some empirical evidence for this interpretation, albeit not across the board. In his empirical study of the computer notebook industry from 1992 to 1998, Hoetker investigates whether the level of dependence of a subsystem on the rest of the product (he defines the increase in size of a flat panel display as a non-modular innovation, and the increase in resolution as a modular innovation) affects the supplier selection of the buyer. While he finds that product modularity allows quicker reconfiguration of the supply chain, his findings do not support that this kind of product modularity drives outsourcing (Hoetker, 2003). On an industry level, some argue that a defacto standardisation of the bicycle into a modular product architecture has resulted in the fragmentation of the industry with the consequence that no one firm is sufficiently powerful to change the prevalent product architecture. Galvin argues that this situation has caused the product architecture to remain constant as a modular architecture (Galvin, 1999).

170 *S.K. Fixson, Y. Ro and J.K. Liker*

## *2.2 Firm boundary affects product architecture*

The central line of argument in this case focuses on the influence that the firm boundary exercises on the product architecture. It has been proposed that systems try to adapt to external forces to increase their level of fitness with respect to demands from their context. For example, Schilling suggests that systems migrate toward or away from increasing levels of product modularity as a reaction to factors such as heterogeneity in inputs and demands, in addition to inherent system characteristics (Schilling, 2000).

As external forces Schilling defines the degree of heterogeneity of input and demand. If a multitude of suppliers exists and offers a wide variety of technologies, the product architecture will migrate to higher levels of modularity to take advantage of the situation. To the extent to which the firm boundary choice represents the available capabilities – and this is precisely the situation in a supply chain – it is the location (and type) of firm boundary that translates into a force that drives the product architecture toward or away from higher levels of modularity.

Similarly, higher levels of demand heterogeneity often require a variety of sales channels, customer relations, etc., which, in turn, exercise pressure to modularise the product. One phenomenon that has been suggested as a mechanism that can cause these shifts in demand is the ratio of product performance provided by the firm relative to the product performance demanded by the market. If the performance provided is significantly better than that which the mainstream market can absorb, the favoured product architecture switches from non-modular to modular one (Christensen and Raynor, 2003).

## *2.3 Product architecture and firm boundary affect each other*

The third category of interactions assumes that both product architecture and firm boundary affect each other simultaneously. For cases studied in the automotive industry, researchers have argued that there is a reciprocal relationship between product architectures and organisational structures.<sup>5</sup> At the supply chain level, a model has been suggested that describes product architectures and firm boundaries complementing each other. The model incorporates a feedback mechanism that ensures that the entire system oscillates between modular products in horizontally stratified supply chains and integral products in vertically integrated supply chains (Fine, 1998).

In his model, labelled ‘the Double-Helix of Business’, Fine explains that this joint oscillation between integral and modular stages is driven by three forces from each side. According to this model, relentless entry of niche competitors, the challenge of keeping ahead of the competition across many dimensions of technology and markets required by an integral system and the bureaucratic and organisational rigidities that often settle upon large, established companies, all drive an industry to a horizontal stage with modular products. On the other hand, if technical advances in one subsystem make that subsystem the scarce commodity in the chain, if market power in one subsystem encourages bundling with other subsystems, or if market power in one subsystem encourages engineering integration with other subsystems to develop proprietary integral solutions, then the system moves to products with integral architectures in a vertically integrated industry structure. All forces exhibit first increasing and then decreasing strength the closer they come to achieving their goal. As a result, neither the state of product architecture nor the associated industry structure is permanently sustainable. This effect keeps the oscillation alive.

Fine argues that entire industries cycle through this double helix. To the extent that most industry participants' ability to shape their industry is limited, they are required to 'swim with the stream'. Not adjusting to this ever changing environment, a firm may find itself in a trap represented by a misfit between product structure and industry structure (Chesbrough and Kusunoki, 1999).

The frameworks and models in all three categories produce powerful insights into the intertwined nature of product and industry structures. To extend our understanding of the detailed mechanics of the processes that link these two areas, we studied them in detail across 18 projects in the US automotive interior supplier industry.

### **3 The case of automotive cockpits in North America**

#### *3.1 Research setting*

In order to address the question of causality between changes in product architecture on one hand, and shifts of firm boundaries on the other, one would want to study data for both constructs over time. In the ideal case sequences of events would demonstrate directions of causality; or, at the minimum, it would lead to excluding one direction of causality.

We focus with this study on a large, complex component to allow for sufficient change in product architecture. Automotive cockpits are currently a prime candidate for such a study because they have experienced various degrees of 'modularity' over the past decade. We call a cockpit the sum of components that include the instrument panel, instrument cluster, HVAC (Heating, Ventilating, Air Conditioning), Audio, AC electronic controls, wiring harness, steering wheel/column, airbags, cross-car beam, and some smaller components such as ducts, glove box and bezels/trim components.

Our unit of analysis is the individual cockpit development project because it is the level at which firm boundaries are determined anew for every project. Our research design is based on multiple case studies with data collected retrospectively at a point in time. We collected data on 18 development projects from six different companies.<sup>6</sup> In each company, we studied cockpit development across three different product architecture generations. Given the sample size, our sample is not representative in a statistical sense. However, we believe it does provide some insights into the mechanics at work between product architecture and firm boundary in this industry for several reasons. Firstly, on the firm level, our data set covers all major companies active in the automotive cockpit industry in North America. Secondly, on the project level, while our sample is not random – data accessibility issues made this impossible – we asked the participants to provide us with data on a project 'typical' for each of the three generations. In addition, the sample covers both SUV and car programmes, as well as large and small volume productions. The data were collected through a questionnaire and multiple face-to-face interviews in each company. In all cases we clarified data with follow-up phone interviews. To allow for meaningful cross-case comparisons, we constructed measures that approximate the two constructs 'product architecture' and 'firm boundary' as well as a number of control measures.

172 S.K. Fixson, Y. Ro and J.K. Liker

## 3.2 Measures

### 3.2.1 Product architecture

The precise determination of various degrees of modularity has proved very difficult, mostly due to the fact that multiple product characteristics are often subsumed under the heading modularity and the weight of these individual characteristics is strongly context dependent (Fixson, 2003). To overcome this obstacle, we defined three generations of product architectures. The three generations stand for three different levels of modularity, albeit specific to the product under investigation. The first generation (termed generation 0) represents the rather integral product architecture that has been used for decades in which the automaker (customer) engineers the product, buys components, and then installs the components individually and sequentially while the automobile travels down the assembly line. In contrast, cockpits of generation 1 are designed to be pre-assembled off the main assembly line. After assembly and test completion, they are attached to the automobile essentially in one piece. The main difference between generation 0 and generation 1 is a change in the design of the interface *between* the cockpit and the rest of the vehicle that allows the separate cockpit assembly. Internally, the cockpits are fairly similar in architecture. In contrast, it is primarily the *internal* structure of the cockpit that is affected by changes between generation 1 and generation 2, while the external relationships between cockpit and vehicle are comparable for these two generations.

While these three generations of product architectures appear to be coarse measure of modularity, we found that this three generation framework closely resembles how industry experts view the development of automotive cockpits. This helped to increase the comparability of our data across firms.

### 3.2.2 Firm boundary

Previous research has treated the location of the firm boundary often as an integer decision. For example, the decision to acquire or to license a technology can be interpreted as a decision to locate the firm boundary (Schilling and Steensma, 2002). To add a higher level of precision we decided to measure the distribution of the total work. We asked the participants for the percentage of work content delivered by the different supply chain participants. We collected these data individually for four different phases of product development (concept, design, engineering and testing/validation), as well as for parts fabrication, assembly and supply chain management. While the exact percentage values represent less precision than the data seems to provide, it is the trends reflected in the changes across product architecture generations that we are interested in.

### 3.2.3 Controls

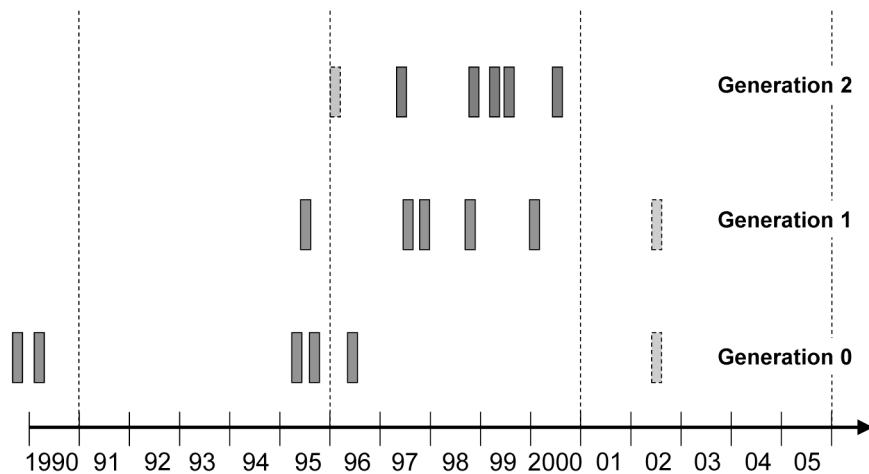
To ensure comparability across development projects we collected data on a number of control variables. These are not controls in a statistical sense as the sample size is too small for any such statistical adjustment. But they do allow us to consider alternative explanations for the patterns we observe. We asked for the *duration* of the total development project as well as the individual development phases. Further, in order to control for differences in work content we asked for the fraction of *new components*, as compared to so-called carry-over components from other vehicle programmes. We also asked to identify the *vehicle type*, i.e. car or SUV, in order to allow us to compare size of the vehicles (and consequently their cockpits) as well as to account for fundamental

differences in overall vehicle architecture (Trucks and SUVs historically exhibit fewer integrated body structures). Finally, we asked how *responsibilities*, such as compensation for R&D efforts and warranty, are distributed among supply chain partners.

### 3.3 The data

The data of project start dates show that the industry as a whole has been progressing from cockpits with product architectures of generation 0 to those of generation 1 and towards those of generation 2. However, this progression is partially uneven across firms with respect to its timing. To some extent this unevenness is a consequence of our anchoring the three generations in technical descriptions of the product architecture rather than in particular time periods. In each generation we identified one vehicle programme as an outlier with respect to its start date. In generations 0 and 1, these are vehicle programmes with significantly later start dates. The vehicles of these programmes are mid-size sedans with large production volumes. These relatively generic but high-volume vehicle programmes are typically the programmes that change last. In generation 2, the outlier is a programme that starts significantly earlier than the other five programmes of this generation. The explanation for this effect is that this vehicle programme was a test case for the company, and to some extent for the industry as a whole. Treating these three projects as outliers makes the progression across the three product architecture generations visible (Figure 2).

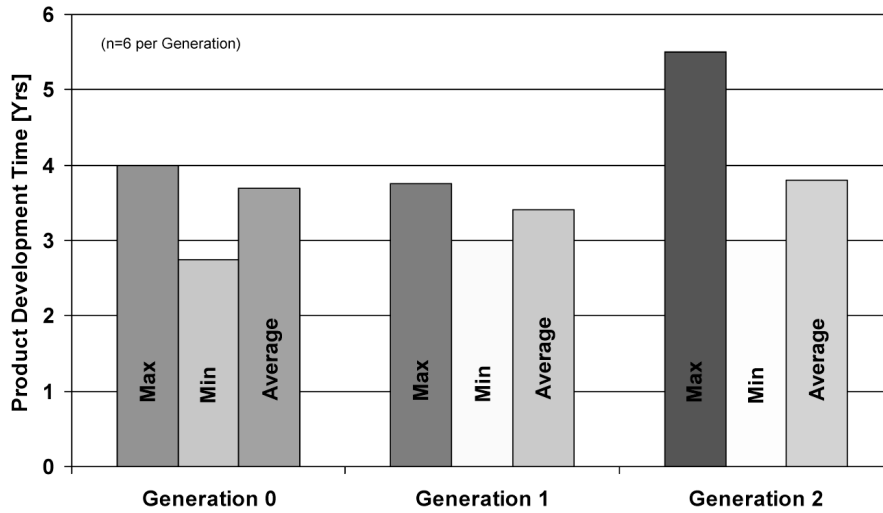
**Figure 2** Project start dates (n=6 for each generation)



With respect to the length of the total development time, all projects show similar numbers. The length of generation 0 development projects averaged 3.7 years, of generation 1 projects 3.4 years, and of generation 2 projects 3.8 years (Figure 3). The slightly longer duration of the longest project of generation 2 (as compared to the longest of generations 0 and 1) is explained by the fact that that project was the company's first project. It is the same project that was started significantly earlier than all other generation 2 projects.

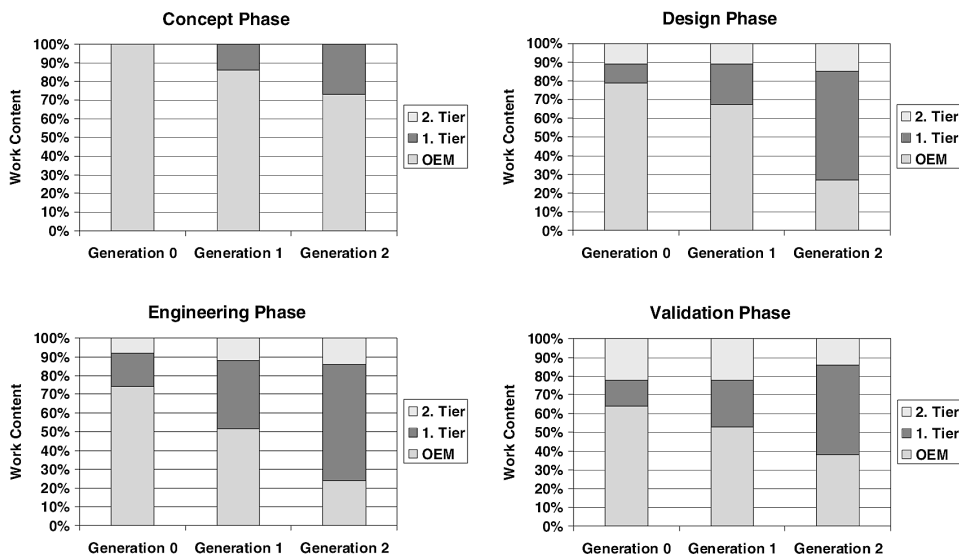


Figure 3 Project durations (n=6 for each generation)



If distribution of work content is a proxy for the location of firm boundaries in a supply chain, Figure 4 shows how the firm boundary shifts in product development across the three different product architecture generations.<sup>7</sup> We show the percentage of work in each phase by tier level from the automaker (OEM), to its direct suppliers (1st Tier), to their suppliers (2nd Tier). While – from the OEM’s perspective – the overall trend is towards greater outsourcing, this trend is uneven across product architecture generations, i.e. across different levels of modularity, and is uneven across different sub-processes in product development.

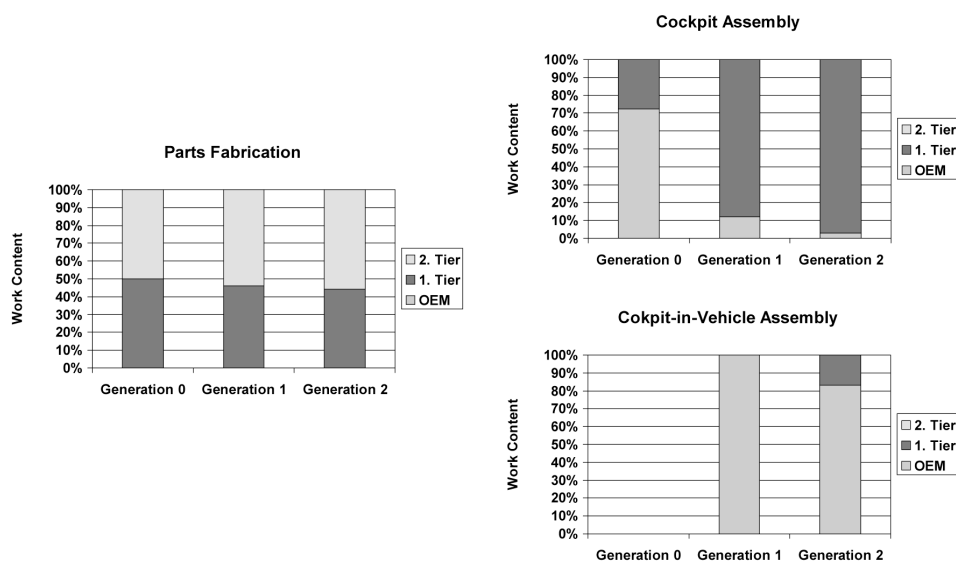
Figure 4 Firm boundary shifts in product development across three product architecture generations



Despite the changes in product architecture, the OEMs seem reluctant to outsource much of the concept work. On a generation 2 project, the OEM still conducts, on average, 73% of the concept work. In contrast, the work conducted during the design and engineering phases has been shifted to a much larger degree up the supply chain. For generation 2 projects, the 1st tier supplier conducts on average 58% of the design work and 62% of the engineering work, while the OEM's contributions have shrunk to 27 and 24%, respectively. The remaining work is provided by 2nd tier suppliers. Concerning the fourth phase of product development, testing and validation, the OEMs are more cautious with respect to outsourcing the work of this phase, compared to the design and engineering phase. Nevertheless, the validation phase also illustrates a clear trend towards shifting the work from OEMs up the chain to the suppliers. The shifting is being done principally to the first tier suppliers with relatively little change from the perspective of the second tier.

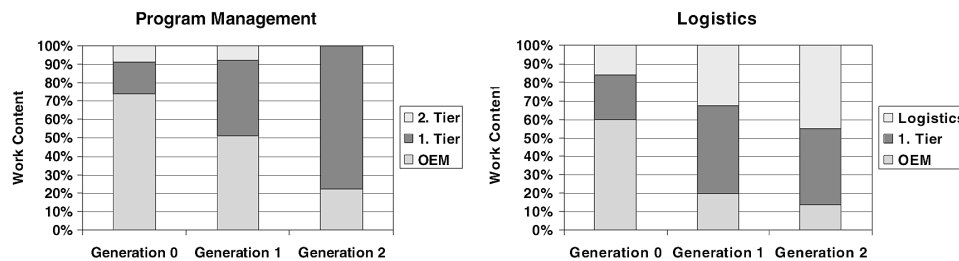
We also collected work distribution data for two sub-processes of manufacturing: parts fabrication and assembly (Figure 5). The data show that parts fabrication had been outsourced before the product architecture change was first observed. In generation 0, on average, 1st tier and 2nd tier suppliers conducted about 50% of the work each. In generation 1 and generation 2 projects, this balance slightly shifts towards the 2nd tier suppliers. The view on assembly presents a split picture. We asked for work content distributions for two different assembly processes: the separate assembly of the cockpit and the assembly of the cockpit into the vehicle. With respect to the cockpit assembly, the majority of the assembly work was outsourced, i.e. moved from the OEM to the 1st tier supplier, between generation 0 (28% work content provided by 1st tier supplier) and generation 1 (88% work content provided by 1st tier supplier). In generation 2 projects, this number climbs, on average, to 97%. For cockpits of generations 1 and 2, there is an additional assembly process: to insert the pre-assembled cockpit into the vehicle. In generation 1 projects this work is exclusively conducted by the OEMs. In generation 2 projects, 1st tier suppliers provide, on average, 17% of the work.

Figure 5 Firm boundary shifts in manufacturing across three product architecture generations



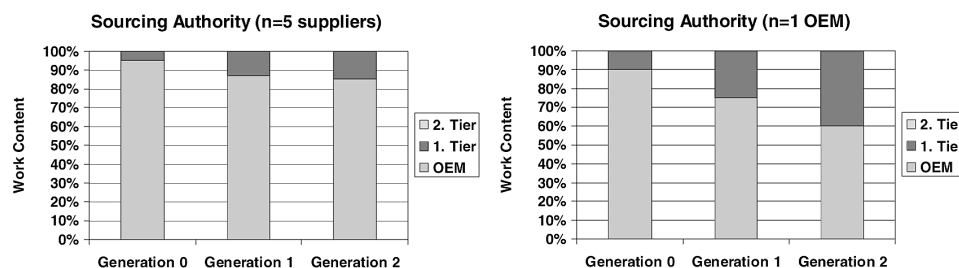
The third set of data we collected is concerned with the distribution of work content, i.e. the location of firm boundaries, for supply chain management. We asked for data on two sub-processes: programme management and logistics (Figure 6). Across the three product architecture generations, programme management was handed over almost completely from the OEMs to the 1st tier suppliers. First tier suppliers increased their share of programme management work, on average, from 17 to 41 to 78%. Logistics, the work concerned with shipping the material was handed up the supply chain even further. An increasing share of this work is provided by specialist logistics companies. They increased their work content share across the three product architecture generations from 16 to 33 to 45%, respectively, while 1st tier suppliers share first increased from 24 to 48% but then levelled off at 41%.

**Figure 6** Firm boundary shifts in supply chain management across three product architecture generations



Whereas the first three data sets were concerned with the distribution of responsibilities (work content), a fourth data set was collected concerning the distribution of decision authority. In early test interviews it became apparent that the issue of sourcing authority, i.e. the power to decide who among other suppliers (1st and 2nd tier) will supply components and subassemblies, is extremely important to the cockpit suppliers. The data we collected allow two insights (Figure 7). Firstly, across all three product architecture generations there is only a limited shift of sourcing authority from the OEMs to the suppliers. Secondly, the perception of the extent of delegated sourcing authority differs significantly between OEM and suppliers.<sup>8</sup> While the OEM sees almost 40% of the sourcing authority delegated to suppliers in generation 2 projects, the suppliers, on average, report being given the sourcing authority for only 15% of the components.

**Figure 7** Firm boundary shifts in sourcing authority across three product architecture generations



#### 4 Discussion: The dynamics between modularity and outsourcing

Our objective with this paper has been to determine how modularity in the product architecture affects the organisational structure with respect to the firm boundary location, and vice versa. More specifically, we were interested in the direction of causality between product architecture change and firm boundary shifts.

While the classic make-or-buy question often reduces the outsourcing decision to a decision affecting a single process, mostly production, i.e. a company needs to determine whether to make a certain product inside or to buy it from suppliers, for the case of the automotive industry it has been argued another important dimension needs to be added: whether to modularise the product (Sako and Murray, 1999). In the Sako and Murray framework, OEMs can follow three different paths from integral products that are produced in-house to modular products that are mostly outsourced. On path 1, the OEM first modularises the product and then outsources its production. Path 2 suggests the reverse order: first outsourcing, then modularisation. Finally, the third path suggests simultaneous outsourcing and modularisation. While conceptually a powerful model, our data show that it masks too much of the idiosyncrasy of the many individual processes that are required to design, produce and deliver a complex product such as an automobile. Consequently, we discuss the sequence of change in product architecture and firm boundary location for each process individually.

For the four phases of the process *product development* a mixed picture emerges. If the product architecture change from generation 0 to generation 1 is understood as creating a weaker interdependence between the cockpit and the rest of the vehicle (one aspect typically subsumed under modularity) and the product architecture change from generation 1 to generation 2 as creating stronger interdependencies *within* the cockpit (another aspect often subsumed under modularity) then it is the first change that needs to happen *before* significant outsourcing can occur in the design and engineering phases. In contrast, neither step of modularisation has a significant effect on shifting the concept phase work from the OEM to the supplier. In the words, of the above named three-paths framework, design and engineering follow more of a path 1 model, while concept work does not follow any of the three paths. On the other hand, one could argue that all phases of product development follow the third path because they all constitute changes in product architecture (modularity) and at least small shifts in work content (outsourcing), albeit to varying degrees. It seems that all phases follow rather a zig-zag path of modularisation and outsourcing, than one of the three cleanly identifiable ones.

Several reasons seem to cause these zig-zag paths, and the deviations among them. During the interviews, we were told that one driver for outsourcing is how the OEMs perceive:

- the strategic value of any particular phase
- the available capability from the suppliers.

Concept and Validation/Integration are perceived by many OEMs as the core competence of the auto companies.<sup>9</sup> Similarly, most OEMs do not trust the suppliers to have the capability to completely develop larger chunks of the automobile, such as the cockpit, by themselves. The suppliers are forced to build up the reputation for having these capabilities one step at a time:

178 S.K. Fixson, Y. Ro and J.K. Liker

“The OEM first trusts us to build parts for them, and then to sequence for them. Then to design and engineer and source and manage suppliers is the biggest jump. Typically you have to build trust.” (1st tier supplier manager)

The wave of mergers and acquisitions among the 1st tier auto suppliers throughout the 1990s to assemble these capabilities can be explained by this view of the OEMs of the suppliers' capabilities (or the lack thereof).

With respect to the processes of *production*, i.e. parts fabrication and assembly, the picture is much clearer. The process parts fabrication had been outsourced to 1st and 2nd tier suppliers long before the advent of modularity (if generation 0 is interpreted as the absence of modularity). In addition, there is very little shift of work content detected across the three different product architecture generations. The processes *cockpit assembly* and *cockpit-in-vehicle assembly* on the other hand show very different paths. Cockpit assembly was almost entirely outsourced once the first step of modularisation was accomplished. In contrast, cockpit-in-vehicle assembly, which only became necessary (and possible) once the cockpit was separately pre-assembled, was only marginally affected by the further modularisation of the cockpit. In the above cited framework, for parts fabrication we observe only the latter part of path 2, whereas cockpit assembly largely follows path 1, and cockpit-in-vehicle assembly really follows neither path. In sum, in production, shifts in firm boundary seem to be ahead of changes in product architecture (with the exception of cockpit-in-vehicle assembly).

There seem to be two, primarily financial, reasons that can explain these findings. For most of the 1990s the US automakers tried to improve their financial measures on Wall Street in order to compete with the dot.com world and more profitable competitors for capital. One of these measures, return on assets (RoA), improves if either the returns increase or the assets are reduced. To increase returns one can either increase revenue or reduce costs. To increase revenue was a difficult proposition in the competitive market in the US, but cost reduction was perceived to be attainable by taking advantage of lower labour costs at the suppliers, relative to the OEMs. The second way to improve RoA is to decrease assets. A shift of expensive assets (tools, machinery) from the OEMs' books to the suppliers' would have this effect. As one former OEM modularity manager put a major motivation for the strategy: ‘We want to reduce our investment and reduce our assets.’

For the process *programme management* a trend towards outsourcing simultaneously to changes in product architecture can be observed. In the Sako and Murray framework, this constitutes a path 3 model. The data for *logistics* show a similar trend, although with a stronger component towards outsourcing, i.e. a slight shift to a path 2 model. The main driver behind these trends appears to be the advantage of lower labour costs that the OEMs perceive to be prevalent at 1st tier suppliers and logistics providers.

Taken together, the sequences of product architecture changes and firm boundary shifts that our study reports demonstrate that there is not a simple unidirectional effect that modularity has on the organisational structures (intrafirm and interfirm) of the supply chain, or the organisational structure has on product modularity. Rather, we find that in most cases there is a two-way relationship between both aspects, and the relative strength of the forces in the two directions can change over time, resulting in a zig-zag path towards higher levels of modularity and more work content being outsourced. The relative strengths of the factors that cause product architecture changes to affect firm boundary locations and vice versa (and, consequently, the direction of their sum) are dependent on:

- idiosyncrasies of the logic of individual processes, i.e. their cost structure, their perceived strategic value, and the capabilities available in the supply chain for their completion.
- the relevance and relative weight of external factors such as labour costs, capital cost, and external development of technologies.

An additional benefit of this study is to shed some light on the forms of modularity that do exist in the auto industry. While the challenges in operationalising 'modularity' in a meaningful way forced us to condense the different levels of modularity to three generations of product architectures, this approach allowed us to demonstrate how product architectures exhibiting different degrees of modularity can be observed, and made it possible to link these generational sequences to outsourcing decisions. In addition, it was this structure of three product architecture generations that enabled us to anchor our data to compare developments across firms. To our knowledge, our data set is the first that investigates the shift in work load distribution, i.e. the location of firm boundaries for individual processes, and reports on simultaneous changes in product architecture.

However, there are also several limitations in our data set. Our data set covers only one region (North America) and only one, albeit major, subassembly (the cockpit). With respect to the geographic location, it has been suggested that the auto industry in Japan follows a different path in modularisation than that in Europe and the US (Takeishi and Fujimoto, 2001). Also, it is possible that other subassemblies of the automobile show patterns of product architecture changes and firm boundary shifts that are different from the ones we observed for cockpits, although we believe that the forces and mechanisms identified in our study are to some extent component independent.

## **5 Conclusion: implications for research and the auto industry**

It has been argued that there is a difference between task outsourcing and knowledge outsourcing, the former reflecting the making of parts, the latter corresponding to their design. Some suggest that for firms to remain competitive they need to maintain a broader set of knowledge than that which would actually be required to produce the components, and some find that this strategy actually results in higher performance (Brusoni et al., 2001; Takeishi, 2001, 2002).<sup>10</sup> While we were unable to collect performance data, such as product quality or development cost, our data show differences in the level of outsourcing of product development activities compared to production activities. However, there are several reasons why it might be advisable not to rush to a simple conclusion. Fundamentally, the observed differences between knowledge and labour outsourcing (from the OEM perspective) can have two different underlying reasons. The first would be that described above: that in fact these capabilities have different effects on firm performance, and the OEM will do better with lower levels of knowledge outsourcing, compared to task outsourcing. While this explanation sounds plausible, it seems that there is also another issue at work here. This issue concerns the balance between operational efficiency and strategic capability. The question of how much and what kind of knowledge needs to be maintained in-house in order to coordinate efficiently the outsourced processes, without engaging in wasteful so-called shadow engineering, requires managerial attention. Similarly, future research needs to address whether there is an optimal tradeoff between gaining efficiency and maintaining capabilities.

180 *S.K. Fixson, Y. Ro and J.K. Liker*

The second possible reason would be that there is a time lag between outsourcing of production activities and outsourcing of product development activities, and the difference we observe is simply temporary. In that case we cannot be certain of how much of a larger (and longer) process we have observed with our data set (which covers about a decade). This raises the additional issue of overall process direction. In other words, does the process of product architecture change and outsourcing have to lead to higher levels of modularity and greater shares of work content being outsourced? Or can the process take on the reverse direction? The Sako and Murray framework implies that there is a general direction from integral products and in-house production to modular products with larger portions outsourced, at least for the current day auto industry. For the time frame we observe, our data confirm this direction for the US cockpit industry. On the other hand, Fine's framework of the dynamic double helix suggests that the process will reverse itself and head in the opposite direction once further modularisation proves to be disadvantageous.

It seems to us that there are three items crucial to addressing this question. All three deserve both managerial and research attention. The first item is the time constant. If the auto industry is – in Fine's words – a 'slow clockspeed' industry, we might need to collect data over longer time periods to be able to observe a reversal of the process described above. The second item is the level of analysis. If we look closer at the way we defined our three generations of product architecture, both generations 1 and 2 contained elements of what is generally subsumed under modularisation. This is true as long as the vehicle is the unit of our analysis. The vehicle's architecture becomes more modular. At the same time, however, the cockpit's own architecture seems to become more integral, in particular moving from generation 1 to generation 2. Thus, we conjecture that one possible route for the process reversal is the move to another level of analysis. Finally, the third item worth investigating is whether there are factors associated with particular life cycle stages of a technology that impact on the decisions concerning product architecture and firm boundary.<sup>11</sup>

Finally, an additional aspect beyond the simple distribution efficiency of knowledge and tasks across the supply chain is the dissonance between shifted workload, i.e. responsibility, on one hand and delegated decision authority, i.e. sourcing authority, on the other that we observed in our data. Anecdotal evidence collected in the interviews points to the detrimental effects this incongruity has on the combined OEM-supplier performance. OEM Managers need to be aware that maintaining this level of sourcing control is possibly being paid for by foregoing to tap into the supplier's own innovation potential.

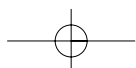
### **Acknowledgements**

The authors wish to thank the International Motor Vehicle Program (IMVP) at MIT and the Japan Technology Management Program (JTMP) at the University of Michigan for research support. We also thank the anonymous reviewers for their helpful comments.



## References

- Afuah, A.N. (2001) 'Dynamic boundaries of the firm: are firms better off being vertically integrated in the face of a technological change?', *Academy of Management Journal*, Vol. 44, No. 6, pp.1211–1228).
- Baldwin, C.Y. and Clark, K.B. (2000) *Design Rules. Volume 1: The Power of Modularity*, Cambridge, MA: MIT Press.
- Baldwin, C.Y. and Clark, K.B. (2003) *Where Do Transactions Come From? A Perspective from Engineering Design*, Paper presented at the Saint-Gobain Centre for Economic Research, Paris, France.
- Brusoni, S., Prencipe, A. and Pavitt, K. (2001) 'Knowledge specialization, organizational coupling, and the boundaries of the firm: Why do firms know more than they make?', *Administrative Science Quarterly*, Vol. 46, No. 4, pp.597–621).
- Chesbrough, H.W. and Kusunoki, K. (1999) 'The modularity trap: innovation, technology phase shifts, and the resulting limits of virtual organizations', in I. Nonaka, and D.J. Teece (Eds) *Managing Industrial Knowledge – Creation, Transfer and Utilization*, London: Sage Publications, pp.202–230.
- Christensen, C.M. and Raynor, M.E. (2003) *The Innovator's Solution – Creating and Sustaining Successful Growth*, Boston, MA: Harvard Business School Press.
- Coase, R.H. (1937) 'The nature of the firm', *Economica*, Vol. 4, No. 16, pp.386–405.
- Fine, C.H. (1998) *Clockspeed – Winning Industry Control in the Age of Temporary Advantage*, Reading, MA: Perseus Books.
- Fine, C.H. and Whitney, D.E. (1996) *Is the Make-Buy Decision Process a Core Competence?*, Cambridge, MA: Sloan School of Management, Massachusetts Institute of Technology, pp.1–32.
- Fixson, S.K. (2003) 'The multiple faces of modularity – a literature analysis of a product concept for assembled hardware products', *Technical Report 03-05*, Ann Arbor, MI: Industrial & Operations Engineering, University of Michigan, pp.1–87.
- Galvin, P. (1999) 'Product modularity, information structures and the diffusion of innovation', *International Journal of Technology Management*, Vol. 17, No. 5, pp.467–479.
- Gulati, R.K. and Eppinger, S.D. (1996) 'The coupling of product architecture and organizational structure decisions', *Working Paper 3906-96*, Cambridge, MA: MIT Sloan School of Management.
- Henderson, R.M. and Clark, K.B. (1990) 'Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms', *Administrative Science Quarterly*, Vol. 35, pp.9–30.
- Hoetker, G. (2003) *Do Modular Products lead to Modular Organizations?*, Champaign, IL: University of Illinois at Urbana-Champaign, pp.1–40.
- Holmstrom, B. and Roberts, J. (1998) 'The boundaries of the firm revisited', *Journal of Economic Perspectives*, Vol. 12, No. 4, pp.73–94.
- Kamrani, A.K. and Salhieh, S.E.M. (2002) *Product Design for Modularity*, 2nd edition, Norwell, MA: Kluwer Academic Publishers.
- Kraemer, K. and Dedrick, J. (2001) 'Dell computer: using e-commerce to support the virtual company', Center for Research on Information Technology and Organizations, University of California at Irvine.
- Kusiak, A. (1999) *Engineering Design: Products, Processes, and Systems*, San Diego, CA: Academic Press.
- Pahl, G. and Beitz, W. (1996) *Engineering Design – A Systematic Approach*, London: Springer.
- Pisano, G.P. (1990) 'The R&D boundaries of the firm: an empirical analysis' *Administrative Science Quarterly*, Vol. 35, No. 1, pp.153–176.





182 S.K. Fixson, Y. Ro and J.K. Liker

- Sako, M. (2004) 'Modularity and outsourcing: the nature of co-evolution of product architecture and organisation architecture in the global auto industry', in A. Prencipe, A. Davies, and M. Hobday (Eds) *The Business of Systems Integration*, Oxford, UK: Oxford University Press.
- Sako, M. and Murray, F. (1999) 'Modules in design, production and use: implications for the global auto industry', *IMVP Annual Sponsors Meeting*, Cambridge, MA, pp.1–32.
- Sanchez, R. and Mahoney, J.T. (1996) 'Modularity, flexibility, and knowledge management in product and organization design', *Strategic Management Journal*, Vol. 17, Winter Special Issue, pp.63–76.
- Schilling, M.A. (2000) 'Towards a general modular systems theory and its application to interfirm product modularity', *Academy of Management Review*, Vol. 25, No. 2, pp.312–334.
- Schilling, M.A. and Steensma, H.K. (2002) 'Disentangling the theories of firm boundaries: a path model and empirical test', *Organization Science*, Vol. 13, No. 4, pp.387–401.
- Takeishi, A. (2001) 'Bridging inter- and intra-firm boundaries: management of supplier involvement in automobile product development', *Strategic Management Journal*, Vol. 22, pp.403–433.
- Takeishi, A. (2002) 'Knowledge partitioning in the interfirm division of labour: the case of automotive product development', *Organization Science*, Vol. 13, No. 3, pp.321–338.
- Takeishi, A. and Fujimoto, T. (2001) 'Modularisation in the auto industry: interlinked multiple hierarchies of product, production, and supplier systems', *International Journal of Automotive Technology and Management*, Vol. 1, No. 4, pp.379–396.
- Ulrich, K.T. and Eppinger, S.D. (2000) *Product Design and Development*, 2nd edition, Boston, MA: McGraw-Hill.
- Williamson, O.E. (1985) *The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting*, New York: Free Press.

## Notes

- <sup>1</sup> Parts of this paper have been presented at the Annual INFORMS meeting in Atlanta, GA, USA, October 19–22, 2003, and the Annual Academy of Management meeting in New Orleans, LA, USA, August 3–6, 2004.
- <sup>2</sup> In his essay on the nature of the firm Coase writes: 'Outside the firm, price movements direct production, which is coordinated through a series of exchange transactions on the market. Within a firm, these market transactions are eliminated and in place of the complicated market structure with exchange transactions is substituted the entrepreneur-coordinator who directs production. It is clear that these are alternative methods of organising production. Yet, having regard to the fact that if production is regulated by price movements, production could be carried on without any organisation at all, well might we ask, why is there any organization?' (Coase, 1937, p.388).
- <sup>3</sup> The paper is based on a study we conducted in Summer/Fall 2003.
- <sup>4</sup> Economics and management literature streams diverge slightly in the perspective from which they study this issue. Economists typically view the locus of the firm boundary as an abstract decision for the firm, whereas management scholars often use the term 'make-or-buy' to signal the individual firm's decision problem that occurs for each actual product and component. For the economists' viewpoint, see, for example, Williamson (1985) or Holmstrom and Roberts (1998); for the management perspective see for example, Pisano (1990) or Fine and Whitney (1996).
- <sup>5</sup> While Gulati and Eppinger (1996) make this argument with respect to intrafirm structures, Takeishi and Fujimoto (2001) make a similar argument for the interim case.
- <sup>6</sup> Five of the companies in our data set are suppliers, one is an OEM. Confidentiality concerns made it impossible to collect data from supply chain partners on the *same* project. However, the data we collected show – using some of the controls – fairly consistent results. This included the data set from the OEM, with the small deviation of portraying the OEM as shouldering a slightly higher work load than that which the suppliers would agree on.



*Modularisation and outsourcing: who drives whom?*

183

- <sup>7</sup> We report the average values across firms for each product architecture generation for data confidentiality reasons. However, since the variation in the data is fairly small across firms we believe that the average values allow some conclusions across product architectures.
- <sup>8</sup> Since this is the only item where the responses of suppliers and the OEM differ significantly we report them separately.
- <sup>9</sup> One reviewer commented on the assertion that OEMs view their concept and testing as core competencies with the remark that the OEM might lose these competencies over time once sufficient content of design and manufacturing work has been outsourced. While this development is entirely possible (and represents an interesting area for future work), our data set is too limited to detect such a long-term development.
- <sup>10</sup> Brusoni et al. (2001) make this argument for aircraft engine control systems and Takeishi (2001, 2002) finds similar effects in the auto industry.
- <sup>11</sup> For one of the variables that we investigated in our study, firm boundary, it has been shown that selecting the appropriate governance mechanism is a dynamic problem impacted by the stage of the technology (Afuah, 2001).

