1. Introduction

It is commonly accepted that decentralized supply chains require modular product architectures, while integral products can be better designed in integrated organizations. Several reasons are suggested. First, there may be technical coordination difficulties across firm boundaries (Fine and Whitney 1996, Ulrich and Eppinger 2004). Second, it may be preferable to design interacting components in-house due to costs of economic coordination (Baldwin and Clark 2000; Sanchez and Mahoney 1996). Third, a modular architecture can make better use of generic supplier components than an integral one (Grahovac and Parker 2003). Finally, outsourcing can lead to loss of integration skills in the long run (Anderson and Parker 2002). Since modular products require little integration, they may be more suitable for decentralized supply chains.

In this paper, we seek to understand the inter-relationship between product architecture (i.e., its degree of modularity) and supply chain configuration (i.e., whether the firm outsources the product design). We take both the product’s degree of modularity and whether to outsource the design as decision variable and address the following questions: How does the optimal product architecture depend on product, firm and market characteristics? When should component development be outsourced? Is there a link between product architecture and supply chain structure; does an integral product architecture imply an integrated supply chain?

First, we show how architecture depends on the identity of the architect (design costs, bargaining power, technical coordination costs); market characteristics (scale of the market, customer’s taste for performance); and the nature of the underlying technology. Next, we demonstrate that a more integral product may be developed in a decentralized supply chain, rather than
an integrated OEM – this is the case when the supplier capabilities are high and the technical collaboration penalty is not excessive. We also show that a more integral architecture may be desirable even when a high performance generic component exists, and derive insights about the evolution of product architecture over the life of a product category.

2. Model

We define parameter \( m \) to model the level of modularity in product architecture. A captures the

\[ H = \text{inseparability, } H \in [0,1] \]
\[ m = \text{modularity, } m \in [0,1] \]
\[ A \in [0,1] \]

Figure 1: Product and market models

We consider a product composed of two components (e.g. hardware and software). The product’s performance is measured in two dimensions (e.g. speed and battery life). While each attribute \( q_j, j \in \{1, 2\} \) is primarily driven by one of the components \( \alpha_i, i \in \{1, 2\} \), depending on product architecture, the second component may also contribute towards better performance. A modular architecture leads to some loss of performance, since some interdependencies among design parameters are not exploited. The modularization penalty is lower if the product is separable by nature, and the natural decomposition is known. Otherwise, performance can be improved by an integral architecture, as design can be optimized with fewer interface constraints.

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relative importance of the second component, $H$ captures whether the product is separable or not. The finished product is sold to a homogenous market of size $D$. The customer willingness to pay in this market is increasing in product performance.

We assume that total design cost consists of three elements; design costs for components one and two, plus a cost of technical collaboration: $c^i_1 \alpha^2_1 + c^i_2 \alpha^2_2 + c^i_c (1 - m)^2$. The cost of component design is lower if the firm has significant expertise in the domain ($c^i_\alpha$) and it is convex increasing in the level of performance.

Integral designs might typically require more frequent communication between design teams; a larger number of engineering changes; and more extensive integration effort at the end. We refer to the collection of these costs as the technical collaboration cost. With a fully modular product, the collaboration cost is minimal as components can be designed independently and can easily be linked together as a final step. This is captured by $c^i_c$.

We consider two alternative supply chain scenarios: In the integrated supply chain, all design activities are performed by a single OEM who sets both the product architecture ($m$) and the quality of components ($\alpha_i$, $i \in \{1, 2\}$). When design is outsourced, the OEM receives a share $\mu_o$ of profits based on its exogenously specified bargaining power. In this case, the OEM sets $m$, while supplier $i$ sets $\alpha_i$, $i \in \{1, 2\}$. Outsourcing potentially improves component quality and design costs ($c_i^M < c_i^I$). However, technical collaboration cost is higher due to geographical distance, differences in technical language and information system standards ($c^I_c \geq c^M_c$).

3. Insights

We find that firm capabilities play an important role in determining product architecture. Firms with superior structural insight are expected to come up with more modular products, since they
can modularize the product with little performance sacrifice. On the other hand, component design expertise and coordination capability lead to more integral products. Similarly, when component design is outsourced, supplier selection has an impact on product architecture: if the suppliers have superior design capabilities and compatible IT systems we would expect to see more integral architectures.

The use of collaborative design technologies is expected to lead to more integral and higher performance products. In addition to their direct effect on component quality (these technologies allow fast engineering changes and facilitate communication between teams), there is an indirect effect: component performance is higher since lower coordination costs lead to a more integral design which in turn increases the value of designing higher quality components.

Figure 2: Comparison of architecture and profits under in-house design and outsourcing

Figure 2 depicts the product architecture and organizational structure chosen as a function of technical coordination penalty and relative firm capabilities. While Regions I and II confirm the literature, Region III is in disagreement: A more integral product is specified by the OEM when component design is outsourced, rather than performed in-house. In this region, suppliers have
significantly superior capabilities compared to the OEM; therefore they can design much better components, and help increase revenues in the end-market. Since the technical coordination cost is also sufficiently low, the OEM chooses a more integral architecture in order to leverage the supplier capabilities and their components to the fullest extent. A more integral design not only improves the overall product performance directly, but also leads to better component designs due to performance spillovers.

Next, we examine the evolution of architecture through the life-time of a product category. An increase in demand for variety, and improved understanding of interdependencies are expected to lead to higher modularity over time. On the other hand, lower technical coordination costs and improvements in design capability push for a more integral architecture.

Figure 3 illustrates a sample trajectory for product architecture. Initially, the supplier’s design capability is not sufficiently high. Hence, the OEM keeps product design in-house. As the capability gap between the OEM and the supplier grows, and the technical collaboration penalty decreases, product architecture first becomes more modular. Modularization allows outsourcing, with little need for coordination across firm boundaries. As collaboration becomes cheaper and the capability gap deeper, architecture becomes gradually more integral. We conclude that outsourcing with modular designs may be a transient phase.

Finally, does the existence of off-the-shelf components lead to modular architectures? We find that, contrary to intuition, a more integral architecture may be appropriate. When the generic component’s performance is high, and its functionality is valued by customers, the rest of the product is designed around this component. While high integration effort may be required to ensure close fit, the result is better customer experience, therefore higher revenues. This argument is valid for both externally and internally available components.
Figure 3: Equilibrium architecture

References


*Working Paper*, MIT.

