**Product architecture, modularity**

**and product market internationalisation**

**Abstract**

The product modularity literature has burgeoned in recent years. However, there has been limited focus on how product modularity may potentially facilitate product market internationalisation strategies. The focus of this conceptual paper is in exploring whether open and modular product architectures may be associated with increasing product market internationalisation, and whether therefore the relationship between product architecture and product market internationalisation can be hypothesised as an extension of the so-called mirroring hypothesis – that there exists an architectural mapping between product, firm and industry architectures. Our propositions may provide the basis for future empirical research.

**Product architecture, modularity and product market internationalisation**

The coordination of complex product development has a long tradition (ie, Galbraith, 1977; Williamson, 1971) and more recently theorists within the modularity tradition have hinted at the potential benefits of a “mirror” between the structure of a product development firm and the technical product it designs (Henderson and Clark, 1990; Sanchez and Mahoney, 1996, Baldwin and Clark, 2000). Put plainly, the mirroring hypothesis seeks to examine two important and pervasive relationships: the extent of an architectural mapping between firms’ strategic choices of product architecture and firm architecture – within-firm mirroring - and between firms’ architectural choices and industry structures – across-firm mirroring.

We develop and extend similar ideas pertaining to the role of product market internationalisation - the potential relationship between the degree of modularity in product architectures and the ease of product market internationalisation In developing these ideas, we present two stylised product architecture types, and postulate that the more open and modular the product architecture, the easier product market internationalisation becomes, to the extent that the product markets themselves may be hypothesised as “market components” within a “modular internationalisation” strategy. To the contrary, firms who decide to compete based on the strategic choice of a closed and integrated product architecture may find it harder to internationalise into product markets across national boundaries. We highlight the need for managers to understand the role of industry standards and how product market internationalisation may be mediated by the presence of international standards.

**product architecture TYPES**

In any given product market, it is possible that a number of different architectures might be strategically feasible, each with different combinations of performance, quality or cost. A more complete understanding of how different product architectures emerge and then establish themselves, as well as how such architectures may be subject to internationalisation is therefore a critical issue for academic research. In defining product architecture, many theorists adopt a definition that encompasses the relationship between a product’s functions, its components and its interfaces; Sanchez and Mahoney (1996: 64) suggest that a product architecture is “ *a way in which the total functions that a design is intended to achieve have been decomposed into specific functional components, and secondly, it defines the way in which the functional components that make up the design will interact when the components function together as a system – known as the interfaces*”. Ulrich (1995) classified product architectures into two ‘ideal types’ – integral or modular. At one end of a continuum, an integral architecture is where the components, interfaces and their relationship is complex, interdependent and non-standardised. At the other end of the continuum, a modular architecture has relationships between components and interfaces that are simple, independent and standardised.

***The integrated - modular continuum***

Modularity theory is based upon the notion of the decomposability of a system into subsystems or components (Simon, 1962, Alexander, 1964) and information-hiding and parallelism (Parnas, 1972). The characteristics of product architectures, therefore, often differ fundamentally in the degree to which components and interfaces are independent or interdependent (Ulrich, 1995). The degree of independence/interdependence depends upon the extent to which a change in the design of one component requires design changes in other components.

Product architectures with significant integrated characteristics often cannot be easily adapted without redesigning the entire architecture or many other interdependent components (Ulrich, 1995). Often an integrated product architecture is one that has been designed for strategic optimisation, such as maximum performance or lowest cost (Sanchez, 2008). In comparison, modular product architectures occur where components are loosely-coupled – interdependencies exist within components but not across or between components (Simon, 1962; Baldwin and Clark, 2000) - and such architectures can either emerge or be purposely developed through a process of specifying design rules (Baldwin and Clark, 2000, Sanchez, 2008). Modularisation often therefore creates ‘thin crossing points’ in the product architecture; breaking up interdependencies that may generate the potential to use market-based transactions without the need for extensive managerial control (Baldwin, 2008). Modular product architectures, therefore, can often provide a form of “embedded coordination” (Sanchez and Mahoney, 1996; Galvin and Morkel, 2001) that supports in-parallel component development by loosely-coupled teams or even loosely-coupled organisations.

***The open and closed continuum***

Product architectures may also be conceptualised along a continuum of being either open or closed (Sanchez, 2008). A perfectly closed architecture is one that is not able to be used by other firms; it is proprietary and a firm may hide, encrypt, patent or copyright components and interface specifications or engage in other types of ‘secrecy’. Interface specifications between components are unlikely to have emerged or the knowledge underpinning them in tacitly held within the focal firm. In contrast, a perfectly open architecture is one whose interface specifications are open and standard, dispersed across firms in an industry in order to support widespread interoperability, unencumbered by intellectual property rights and other means of secrecy, and firms interested in developing components or complementary goods can often ‘plug and play’.

Product architectures may theoretically exhibit hybrid architectural characteristics – for example, closed and modular, or open and integrated - however, for the purposes of analytical simplicity, we hypothesise the potential ease of product market internationalisation by examining two stylised product architecture types at each end of the continuum – closed and integrated and open and modular.

**PRODUCT MARKET INTERNATIONISATION**

***Degree of product market internationalisation in closed and integrated architectures***

Product architectures with closed and integrated characteristics are often complex and poorly understood by the people who design them, information exchange patterns are often complicated, and the knowledge underpinning the numerous product component interdependencies is often largely tacit. As firms are often more efficient than markets at resolving conflicts (Williamson, 1991) and facilitating communication flows (Monteverde, 1995), product development tasks are often co-located within the boundaries of a single, focal firm. The usual logic is that firms sponsoring a closed and integrated product architecture tend to internalise production (see for example early works by Stigler, 1951; Chandler, 1977) in the face of perceived opportunities for rent appropriation, as well as to minimise knowledge appropriation through IPR or other secrecy mechanisms. Under these conditions, small numbers bargaining issues (Williamson, 1985) are likely to also impose prohibitive transaction hazards because market, technological uncertainty and asset specificity are high, reducing the perceived benefits of ‘supply-side externalities’ (Sanchez, 2008). In sponsoring its own product architecture, a firm is likely to deny access to potential collaborating external firms that may exist in the intermediate market due to concerns over contracting hazards which, in turn, may also help the firm focus on its own integral capabilities. The firm may also seek to develop its own demand-side externalities (Sanchez, 2008) such as using penetration pricing, marketing or branding to create a significant installed user base and propel it towards the dominant industry standard (Schilling; 1998) thereby increasing its embeddedness in a product market. However, closed and integrated product architectures are often at great risk of becoming legacy assets (Schilling, 1998.1999)

Firms that choose to sponsor a closed and integrated product architecture are likely to engage in ‘thick’ (Baldwin, 2008) information-exchange patterns in order to improve products and processes as changes in one component often have significant and unforeseen changes in other components. High levels of complex information-exchange that is tightly structured around the interdependencies within the product architecture allows firms to more efficiently manage the interaction effects between technical elements and to exchange information freely without worrying about ex-post opportunism in the intermediate market. As a result, product development teams often share the same firm membership and geographically close.

Because changes in one component often have significant and unforeseen design changes in other components, and that product market internationalisation requires design changes to meet the local needs, such internationalisation is often complex and difficult. Thus, our first proposition:

*P1: Closed and integrated product architectures are positively associated with low levels of product market internationalisation*

***Degree of product market internationalisation in open and modular architectures***

In cases where product components are outsourced to external firms and component interfaces are defined, a product architecture can often be characterised as open and modular. As we have noted, contracting firms invest ex ante in high levels of information exchange in order to define product component boundaries and standard interfaces, and then may switch to a low level of ex-post information-exchange as the standardised interfaces become a form of ‘embedded coordination’ of product development activities.

Components can be designed and produced in parallel by globally-dispersed firms and therefore the substitutability of components is high, which may often lead to an increase in product variety that allows a focal firm to offer multiple product variations to a wide number of product market segments both in the home and target country. In addition, where standardised interfaces between product components stretch across national boundaries, the ease of substituting a variety of components to meet local product market needs is enhanced.

Because changes in one component can be made independently and in parallel without affecting other components, and that product market internationalisation requires design changes to meet the local needs, such internationalisation is often easier, especially where industry standards stretch across national boundaries. Thus, our second proposition:

Thus:

*P2: Open and modular product architectures are positively associated with high levels of product market internationalisation, mediated by the role of international product component standards*

**Concluding remarks**

Our propositions postulate that where a product architecture is open and modular, a firm’s product market internationalisation strategy may become more open and modular. We develop the idea that there may exist a potential architectural mapping between the degree of openness and modularity in the product architectures and the degree of product market internationalisation. Such a product architecture may allow a focal firm to adapt and easily substitute product components within an architecture to meet the local needs of international product markets without affecting other components which may lead to product markets themselves being hypothesised as “market components” within a “modular internationalisation” strategy.

We also postulated that where a firm chooses to adopt a closed and integrated product architecture, it may often be very difficult to adapt the product architecture to meet the needs of a range of international product market needs as the interdependencies within the architecture make such internationalisation strategies more difficult. As a consequence, it is likely that such product strategies may often be confined to ‘closed’ competition within national boundaries.

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