Long title: Product architecture and product market internationalisation: A conceptualisation and extension

Short title: Product architecture and product market internationalisation

Summary sentence: Designing a modular product architecture and corresponding organization design may enable firms to more effectively and efficiently internationalize

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Key points

We explore how open and closed, integrated and modular product architectures may be associated with increasing product market and firm internationalisation

We postulate that the more open and modular the product architecture, the easier product market internationalisation becomes

We hypothesised that an open and modular product architecture may permit international product markets to become “components” within a “modular internationalisation” strategy

Introduction

Over the past five decades, a great deal of international business research has focused on the process, scope, motivations, determinants, extent, methods, and speed of firm international expansion (Casillas & Acedo, 2013; Leonidou & Katsikeas, 1996; Mathews & Zander, 2007). Aligned to this line of research is economic geography scholarship that focuses on the role of location in the multinational firm's international activities (Alcacer, 2006; Narula & Santangelo, 2009; 2012). Literature in these research areas emphasise that a firm expands internationally in order to exploit its specific ownership advantages, with the success of the international expansion dependent on the ability of the firm to overcome the generic challenges of going abroad (Dunning, 1980; Hymer, 1976). Multinational enterprises (MNEs) are suggested to be the main drivers of internationalisation and globalisation (Welch & Luostarinen, 1988). Internationalisation is considered as a series of events through which a firm increases its level of involvement in foreign markets over time (Johanson & Vahlne, 1990; Leonidou & Katsideas, 1996). Accordingly, the internationalisation of a firm can be assessed by reference to the number of countries to which the firm exports its products or has subsidiaries, the diversification of its foreign markets, and the cultural and/or physical distance between countries it operates in (Casillas & Acedo, 2013).

An emerging body of work has also begun to examine the 'architectural fit' between home and host country, for example the role of industry architecture in shaping firm international expansion success (Jacobides & Kudina, 2013). Industry architecture refers to the rules and mechanisms that determine how labour and surplus is divided among firms within a value chain (Fitzgerald & Veliyath, 1995; Jacobides et al., 2006). Accordingly, firms' capabilities and competitive environment are shaped by the industry architecture - which may be similar or different from those in other countries. The pioneering work of Jacobides and Kudina (2013, p.150) revealed that "separability and similarity of industry architectures across countries are robust and important predictors of success in international expansion". Specifically, they found that the 'fit' between

home and host countries' industry architectures in terms of similarity and comparability, as well as institutional separability facilitates successful internationalisation. Institutional separability refers to the separability of the parts of an industry value chain" (Jacobibes & Kudina, 2013, p.151). It is therefore suggested that industry architectures should be factored into examining internationalisation success.

Arguably, the literature on internationalisation, international entrepreneurship, and economic geography all hint that firms' internationalising behaviour encompasses a wide range of aspects (Welch & Luostarinen, 1988; Casillas & Acedo, 2013). However, the dominant theoretical lenses in these research streams tend to anchor and facilitate discussions along the lines that internationalisation is a function of factors among which product architecture is not rarely mentioned or identified (Vernon, 1966; Buckley & Casson, 1981; Dunning, 1980; Johanson & Vahlne, 1990). Yet, arguably, the internationalisation process is not limited to firms' sequential international involvement over time, but actually begins with the nature of the firm's product in terms of its adaptability for local market needs, and how that influences product market development in foreign markets over time. The nature of the firm's product in terms of its architectural parameters –integrated versus modular (eg, Burton & Galvin, 2018a; Ulrich, 1995) - as well as its adaptability for local market needs, precedes and influences all other international involvement decisions. Khurana and Talbot (1998) note that the internationalisation and international entrepreneurship scholarship have failed to adequately account for the role of product architecture in the internationalisation process, but the inclusion of which could provide a richer understanding of current global manufacturing and management practices. Furthermore, Sanchez and Mahoney (1996) argued that the nature of product architecture influences the strategic activities of organizations, implying that product architecture precedes and influences firm and industry internationalisation decisions.

Thus, we argue that product market internationalization is shaped by the way in which the product is designed or architected. A product architecture is the blueprint for its design, "the scheme by which the function of a product is allocated to physical components" (Ulrich, 1995, p.419), and encompasses the way in which product components are mapped and connect together (Baldwin & Clark, 2000). Ulrich (1995) argued that a product architecture has two ideal types: integral or modular. Modular product designs permit easier product component substitution and variety to meet local market needs which facilitates easier exporting (Cheung et al., 2008; Sanchez, 2008; Yin et al., 2014). Modularity in design also leads to greater modularity in production possibly across firm and national boundaries (Baldwin & Clark, 2003; Cheung et al., 2008; Kumar & Wellbrock, 2009; Yin et al., 2014; Yu & Wong, 2015).

In spite of the growing evidence of the potential clear linkages between product architectures and product or firm internationalisation, much of the existing body of research have developed in isolation. Specifically, both the product architecture (Baldwin & Clark, 2000; Burton & Galvin, 2018a; Sanchez, 2008; Sanchez & Mahoney, 1996; Simon, 1962; Ulrich, 1995) and internationalisation (Buckley & Casson, 1981; Dunning, 1980; Johanson & Vahlne, 1990; Vernon, 1966) scholarships have developed separately and in isolation from each other for decades. Consequently, there remains the lack of an integrated framework to articulate the linkages between the two to facilitate cross-fertilisation. This oversight is puzzling given that product architecture can influence product knowledge diffusion, in foreign market entry and may affect the speed of internationalisation. The aim of this paper is therefore to examine how product architecture influences product market and firm internationalisation pace and scope (see also Figure 1, for the research model).

This paper makes several contributions to strategy and international business research. First, although there is an accumulated body of research on product architectures (Mikkola & Gassmann, 2003; Muffatto & Roveda, 2002; Ulrich, 1995; Wang, 2008) and internationalisation

(Pedersen & Shaver 2011), there remains lack of a unified framework exploring the linkages. Drawing on the 'mirroring hypothesis' (Burton & Galvin, 2018a; Cabigiosu & Camuffo, 2012; Colfer, 2007; Colfer & Baldwin, 2016), we develop a product architecture based view of internationalisation, which emphasises the role of product architecture on product market and firm internationalisation. Specifically, internationalisation is examined in two important ways: product market internationalisation and firm internationalisation. Second, we depart from much of the existing internationalisation literature by going beyond the 'company' and 'country' perspectives to propose a unified framework of how product architecture influences internationalisation. Moreover, our contribution adds to the mirroring hypothesis literature by presenting a stylised view on how the product architecture facilitates, and may 'mirror', product market internationalisation and firm internationalisation.

The rest of the paper is organised as follows. In the next section, we examine the internationalisation and product architecture literatures. We next integrate these perspectives in advancing arguments on how product architecture impact product market internationalisation as well as firm internationalisation. This leads to the development of propositions for future testing. In the final section we set the agenda for future research.

>>>Insert Figure 1 about here>>>

The internationalisation process

The internationalisation literature examines the process through which a firm expands its operations into foreign markets. The international product lifecycle model (Vernon, 1966, 1971, 1974, 1979) and the Uppsala internationalization process model (Johanson & Vahlne, 1977, 1990) were the first dominant theories explaining this internationalization process as incremental and sequential. The location of production activities in a global market is central in these theories within the context of experiential knowledge, scale economies, market presence and cost (Khurana & Talbot, 1998). Accordingly, the process begins with the product launch and production facilities established first in industrialized home country, then production moves into newly industrialized countries, and finally, into developing countries (Vernon, 1966), with the aim to reduce 'psychic' distance, liability of foreignness and market uncertainty (Johanson & Vahlne, 1990).

The OLI eclectic paradigm further underscores that firm internationalisation is a function of ownership (O), locational (L) and internalisation (I) advantages that the firm expects to realise from the international involvement (Dunning, 1980). Accordingly, experiential knowledge, market imperfections, and cost implications are central to a firm's internationalisation in these frameworks. Moreover, these theoretical lenses grounded in economics and international business disciplines view internationalisation as a single firm effort, and that decisions regarding each foreign market entry is made in isolation and based on the product life-cycle (Khurana & Talbot, 1998). These early theoretical lenses focus on the operational and governance processes taking place within a single firm in a single location, and consider each decision afresh about expanding into another country (Kano, 2018). The Transaction Cost Economics (TCE) perspective is usually adopted in underpinning these early theories and in explaining firm internationalisation behaviour (Williamson, 1975). According to TCE, firms will internalise and exploit their ownership advantages in a foreign country if the transaction costs are lower than using market-based strategic solutions such as franchising, outsourcing and licensing (Elia et al., 2017).

A recent stream of international entrepreneurship scholarship also focuses on the scope, extent and speed of firms' internationalisation (Leonidou & Katsikeas, 1996; Mathews & Zander, 2007). This line of research however highlights the departing insight that not all firms follow a strict sequential 'stages model' of internationalisation. The emergence of the so-called 'born-global' firms is usually cited in support of the international entrepreneurship perspective (Oviatt & McDougall, 1994; Rialp et al., 2005). Another issue discussed in this line of research is that the internationalisation process of some firms are at times interspersed with periods of de-internationalisation when they exit some foreign markets to concentrate on their domestic market operations (Benito & Welch, 1997; Crick & Jones, 2000). This again departs from the traditional internationalisation view of a firm gradually increasing the degree of international markets involvement. Moreover, the increasing emphasis on innovation and fast-paced introductions of new technologies and products around the world has triggered international business scholars' attention on issues such as the role of innovation on internationalisation and value creation in an interconnected world (Autio & Thomas, 2013; Kriz & Welch, 2018).

A recent stream of international entrepreneurship scholarship however rejects the notion that all firms increasing their international involvements follow a strict sequential 'stages model' (Leonidou & Katsikeas, 1996; Mathews & Zander, 2007). This body of scholarship focuses on the speed and time dimension of the internationalisation process (Casillas & Acedo, 2013). Although, the product life cycle and the Uppsala models recognise the role of factory production in the internationalisation process, this is done within a single firm's ownership. Linking international business and operations management literatures in their work, Khurana and Talbot (1998) argue that extant international business theories do not adequately explain current industry manufacturing practices, and how product architecture impact product market internationalisation. Accordingly, in this era of global factory networks, each factory or organisational unit may have a unique mission and role in such networks (Khurana & Talbot, 1998). The different roles reflect the

manufacturing strategy of the business unit (Richardson et al., 1985). Ferdows (1989) further notes that each strategic factory role can be determined in terms of the technical activities it performs and the main strategic reason for establishing that unit. Miller and Roth (1994) identified these different roles to include 'innovators', 'marketers', and 'caretakers'. According to their taxonomy, 'innovators' tend to introduce new products and make design changes, while marketers focus on the broader distribution of the product. Caretakers are associated with the declining stage of the product lifecycle and focus on maintaining some level of competition and low pricing (Miller & Roth, 1994).

This stream of research implies the relevance of product architecture in globally dispersed firms and industries. Few recent studies in manufacturing operations and strategic management have suggested that product architecture has contributed to the emergence of globally dispersed firms and industries (Khurana & Talbot, 1998; Sanchez et al., 2013). Other studies have therefore acknowledged the critical role of networking capabilities in recombining firm specific advantages in multinationals' dispersed cross-border economic activities (Buckley, 2016; Narula & Verbeke, 2015; Verbeke & Kano, 2016). The integration of a network perspective in the internationalisation theories signals the importance of efficient coordination of inter –and –intra organisational network structures in successful cross-border expansion (Iurkov & Benito, 2018). The Transaction Cost Economics perspective is essential in explaining the role of firm architecture and networking in globally dispersed firms. The extent to which firms network, coordinate and collaborate with other firms will depend on whether the market transactions are inefficient or non-feasible. Again, the extent to which a particular product architecture is adopted in firms' internationalisation will be influenced by the transaction cost implications for the firm. Notwithstanding, only limited studies have considered the potential role of the physical products characteristics in the international configuration activities of firms (Rezk *et al*., 2016). Moreover, studies from the operations management, strategic management, and international business literatures have not

systematically examined how product architecture affects product market or firm internationalisation. This study therefore seeks to conceptually explore the role of product architecture on product market and firm internationalisation.

Product architecture types

Product architecture has attracted an extensive body of scholarship over the past decades (Burton & Galvin, 2018a+b; Sanchez, 2008; Ulrich, 1995). In defining product architecture, many theorists adopt a definition that encompasses the relationship between a product's functions, its components and its interfaces. Ulrich (1995, p.419) defined it as "the scheme by which the function of a product is allocated to physical components". By product architecture, we are referring to the bundle of product features which demonstrates the functionality of the product and the interfaces between the components (Fixson, 2005). Ulrich (1995) classified product architectures into two 'ideal types' – integral or modular. At one end of the continuum, an integral architecture is where the components and interfaces are interdependent and non-standardised. At the other end of the continuum, a modular architecture has relationships between components and interfaces that are independent and standardised.

Shibata et al. (2005) and Sanchez (2008) later conceptualised product architecture types along a continuum of open and closed. In closed architectures, the knowledge underpinning the product design is tacitly held within the focal firm as proprietary and is not able to be used by other firms in the industry. In a perfectly open architecture, on the other hand, product component interface specifications are standardised, publicly known, and dispersed across many firms in an industry in order to support widespread interoperability (Burton & Galvin, 2018a+b; Sanchez et al., 2013). Thus, product architectures may be conceptualised as either integrated or modular, or along the dimension of either open or closed. Moreover, product architectures may theoretically exhibit hybrid architectural characteristics (Burton & Galvin, 2018a) – for example, closed and modular,

or open and integrated. For instance, closed and modular product architectures are often conceptualised as 'hybrid' because the design and production of modular components remain within firm boundaries. Similarly, open and integrated product architectures are often associated with complex open source product designs, but are much less likely in typical manufactured products (Colfer & Baldwin, 2016; Shibata et al., 2005).

However, for the purposes of analytical simplicity, we further 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', as shown in Figure 2. A more complete understanding of how these different product architectures emerge and then establish themselves, as well as how such architectures may be subject to product market and firm internationalisation is therefore a critical issue for international business research. We further hope that by illuminating how 'perfect type' product architecture types may be associated with internationalisation, further scholarship may be pursued on how 'non-perfect' or 'hybrid' product architectures are associated with internationalisation.

>>>Insert Figure 2 about here>>>

The integrated - modular continuum

Modularity theory is based upon the notion of the decomposability of a system into subsystems or components (Alexander, 1964; Simon, 1962) Product architectures, therefore, often differ in the degree to which components and interfaces are independent or interdependent (Ulrich, 1995). These differences depend upon the extent to which a change in the design of one product component requires subsequent design changes in other product components. Integrated product architectures often cannot be easily adapted without redesigning significant parts of the architecture as changes in one component have knock-on, and often unforeseen, design changes elsewhere in the product architecture (Ulrich, 1995). Often, an integrated product architecture with

high levels of component interdependence is one that has been designed for optimisation of performance or cost (Sanchez, 2008). Integrated product architectures are then usually difficult to reorientate to new uses or needs without significant re-engineering (Sanchez & Mahoney, 2013), which often means that component level innovation and adaptation is hindered and hard to isolate. In contrast, modular product architectures have greater interdependence within product components than across different product components (Ulrich, 1995), and design changes to one component require little or no modification to other components, so long as there is adherence to a specified interface. Modularisation often therefore creates 'thin crossing points' in the product architecture; breaking up existing 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" (Galvin & Morkel, 2001; Iurkov & Benito, 2018; Sanchez & Mahoney 1996) that supports in-parallel component development by disperse teams or organisations within or across different countries. Baldwin and Clark (2003) argue that product modularity can be strategically important at three different, but interconnected, levels. First, modularity as a design principle enables a product architecture to be partitioned and separated into separate product components that connect together via standard interface specifications. Modularity in design, therefore, may allow a firm to enter international product markets by adapting the home product architecture to heterogeneous needs of local markets more easily and quickly (i.e. via exporting). Second, this is important where international market needs demand a product architecture to have modularity in use, permitting consumers in international markets to plug and play from a range of different product components to create bespoke product choices. Finally, modularity in design permits modularity in production so that discreet product components can be designed and manufactured via a globally-dispersed network of firms within and/or across firm boundaries, and hence providing the blueprint for shifting production across firm and national boundaries. Thus, product modularity and the interface standards that allow plug and play connection greatly reduces the requirement for

explicit managerial authority in coordination, thereby allowing easy adaptability to different international or local market standards, as well as market-based transactions in the design and/or production process. Modularity thus enable the reduction of transaction cost associated with internationalisation (Elia et al., 2017).

The open and closed continuum

Product architectures may also be conceptualised along a continuum of being either open or closed (Burton & Galvin, 2018a; Sanchez, 2008). A closed architecture is one that is proprietary and a firm may hide, encrypt, patent or copyright components and interface specifications or engage in other types of 'secrecy' (Sanchez et al., 2013). When a product architecture is both closed and integrated, there is the potential for a firm to extract significant rents in its home market and to sponsor its product architecture as a potential dominant design by investing in the creation of its own 'externalities' through pricing, marketing and branding (Sanchez, 2008; Schilling, 1998, 2002). However, Sanchez, Galvin and Bach (2013) coined the term 'architectural specificity' to describe product architectures that have been partitioned into the kinds of components that are functionally different from those used in other firms' architectures and interface specifications may not be compatible with those embedded in other firms' architectures. As a consequence, firms who choose to sponsor closed product architectures may be unable to plug and play product components from other external firms. In international product markets, such architectural specificity acts as a strong force against product market internationalisation due to the difficulties in adapting the product architecture to international market needs and requirements. Moreover, architectural specifity is associated with high transaction costs of internationalisation and is most efficient under localisation or co-location of the firm's operational activities (Rezk *et al*., 2016). In contrast, an open architecture has interface specifications that are open and standardised, dispersed across many firms in an industry, nationally or internationally, in order to support widespread interoperability, unencumbered by intellectual property rights and/or other means of secrecy.

Mirroring hypothesis

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 (Colfer & Baldwin, 2016). The mirroring hypothesis seeks to examine two important 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 (Burton & Galvin, 2018a; Colfer, 2007). 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 other words, given modular product architectures offer the potential to separate and then recombine the modules within product designs into a wide number of different configurations, it is feasible that the different configurations could be adapted by organizations to meet a wide number of local market needs internationally. Furthermore, modularity accentuates strategic and operational flexibility of business functions, reduces the overall transaction cost of the firms, leading to higher efficiency in resource allocation (Elia et al., 2017). In contrast, given that integrated product architectures are difficult to re-engineer to new uses and needs (eg, Schilling, 2000), the extent to which they can be adapted to meet local market needs is somewhat diminished. Thus, the modularity of the product architecture could be said to mirror the modularity of local market needs. The focus here is not on a single firms' strategic decision to internationalise, but the extent to which the degree of modularity or integrality in product architecture facilitates product market internationalisation.

We postulate that the more modular the product architecture, the easier product market internationalisation becomes, to the extent that the product markets 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 an integrated product architecture may find it

harder to internationalise into product markets across national boundaries. Next, we highlight the need for managers to understand the role of industry standards and how product market internationalisation strategies may be mediated by the presence of international standards.

The role of standards

Modularity is a general systems theory (Schllling, 2000). Similarly, the presence of standards can also be conceptualised as a hierarchy at three nested levels, i.e., firm, industry (national) and international. By standards, we are referring to the explicit and prescribed measures or directives which shape firms behaviour and actions (Ahrne & Brunsson, 2006). For instance, standards can exist either at the level of an individual firm (firm-specific standards) or at the level of an industry within the boundaries of a nation (national industry standards) (Schilling, 2000). Similarly, the presence of international standards can be viewed as a further hierarchal level that encompasses two or more nations. Moreover, standards at one level of the hierarchy often limit opportunity for trade at the higher levels of the hierarchy. For instance, in an industry that has coalesced around a wide range of firm-specific standards, opportunities for trade may be limited by the absence of national or international industry standards. Furthermore, in an industry with widespread adoption of national industry standards, internationalization may be limited by the absence of international standards. Thus, we argue that the presence of international standards – or at least the presence of national standards that span a number of countries - are important for internationalization.

Moenuis (2004, p.5) identified three types of standards that may be present in each of three different nested levels: He noted that "If standards evolve out of the market process, they are generally referred to as de facto standards. Standards imposed by law are called de jure standards. The largest number of standards, however, results from coordination in committees and standardization institutions like the International Organisation for Standardisation (ISO)". Sanchez (1994) also noted a number of stylised standards types, such as how components are connected to

another (the attachment interface), how power is to be transferred between components (the transfer interface), how signals will be exchanged between components (control and communication interfaces), the spatial location and volume a component may occupy (spatial interfaces), and various ways in which the functioning of one component may generate heat, magnetic fields, or other environmental effects that must be accommodated by other components (environmental interfaces). Whichever type of standard is present in a given context, internationalization is much easier when international standards have been adopted by many firms in a global value chain. In such circumstances, a modular product architecture may enable firms to take advantage of internationalization opportunities that such standards-based protocols present.

Propositions

Degree of product market internationalisation in closed and integrated product architectures

Product architectures with closed and integrated characteristics are often complex, information exchange patterns are often complicated, and the knowledge underpinning the numerous product component interdependencies is often largely tacit. Closed and integrated product architectures are often developed in the emergent stages of a product market as firms experiment with unique product designs (Sanchez, 2008). The prevailing logic is that in many product markets, firms often develop *"product architectures that are idiosyncratic to the firm and that feature customised and highly interdependent components"* (Argyres & Bigelow, 2010, p853).

As firms are often more efficient than markets at resolving conflicts (Williamson, 1991), product development tasks are often located within the boundaries of a single firm. The usual logic is that firms sponsoring a closed and integrated product architecture tend to internalise production (see for example early works by Chandler, 1977; Stigler, 1951) as changes in one component often have significant and unforeseen design 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 are often co-located and share firm co-membership. 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, internationalisation is often complex and difficult.

In the context of internationalization, in-house product design and development also serves as an ownership advantage that is central to firm internationalisation decisions (Dunning, 1980). Notwithstanding, the cost and effort of coordinating integrated product design and development across international markets tends to be both high and onerous, thus limiting the speed and extent of product market internationalisation. We therefore contend that closed and integrated product designs are more likely to be designed and produced in the home country due to the intensive coordination needs and adaptation challenges. Moreover, due to the difficulty in adapting such products designs to international market needs without redesigning the entire product architecture, closed and integrated product architectures are not easily internationalised across different international markets. This is particularly more so because of the possible different characteristics of standards across different countries or regions. In other words, firms who chose to sponsor an integrated product architecture are faced with two critical problems. First, the non-separability of the product architecture makes product component level innovation much more difficult, and results in the necessity of more time-consuming and expensive architectural innovation to adapt the product architecture to local market needs. This is compounded by high transaction costs associated with internationalisation and is, therefore, a less desirable approach of entering foreign markets. Second, the closed and integrated design of the product architecture makes it much more difficult to meet any prevailing national and international standards. 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 product 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. Product components can be designed and produced in parallel by globally-dispersed teams or 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 quicker and easier, especially where industry standards stretch across national boundaries. Modularity also enables the reduction of transaction costs associated with internationalisation, and enhances inter-organisational networking and learning (Elia et al., 2017). Thus, our second proposition:

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

Conclusion

By emphasising the role of product architecture on product market internationalisation, this paper sheds light on an unexplored driver of successful internationalisation. Our propositions emphasise

the importance of the technological characteristics of a product in constraining or facilitating product market and firm internationalisation. We depart from much of the existing internationalisation literature by going beyond the 'company' and 'country' perspectives to propose a unified framework of how product architecture influences internationalisation. Moreover, we add to the mirroring hypothesis literature by presenting a stylised view on how the product architecture facilitates, and may 'mirror' with, product market internationalisation and firm internationalisation. This approach also enriches emerging international business scholarship that examines the global value chain of multinational firms, as well as the dispersion and coordination of the firm international operations (Baldwin & Evenett, 2015; Elia et al., 2017).

Our propositions postulate that where a product architecture is open and modular, a firm's product market internationalisation strategy may also 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 markets 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.

Pathways for future research might include examining how product architecture changes influences the pace and scope of internationalisation activities. Another avenue for future research might be exploring product architecture influences on international market entry modes.

Furthermore, where an international market has a mix of firm-specific, national and international standards present, an open and modular product architecture may require some architectural or product component level innovation to be able to meet international markets' needs. This may, in effect, require part of the product architecture to become less modular in order to meet performance or cost standards for different local markets, an interesting form of 'hybridity' that offers further opportunities for scholarship in this domain. For instance, the adaptation required for left-hand drive motor vehicles to right-hand drive, not only requires product component level innovation, but has knock-on consequences for other product components within the overall architecture.

The above discussion also have practical implications. Firms seeking successful international expansion need to evaluate the nature of the product or service architecture in addition to the other traditional drivers in the extant international business literature in order to identify the optimum and most efficient internationalisation strategy.

Our paper has some limitations. First, this is a conceptual paper and future studies could collect empirical data to quantitatively examine and confirm or reject the propositions developed in this study. Future studies could adapt a variety of scales across different disciplines including operations management, strategy and international business literature to develop appropriate instrument of effective quantitative testing of the propositions and the proposed model.

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