The impact of product attributes and emerging technologies on firms' international configuration

Abstract

International business (IB) literature has largely focused on trade-offs between cost minimisation, knowledge seeking, managing transaction costs, and maintaining control in explaining the international configuration of firms’ activities. By incorporating insights from operations management (OM) we propose a framework that explicitly takes into account product characteristics in understanding the international configuration options available to firms. Specifically, we show how the fundamental architecture of the product and the required physical and knowledge flows within its associated value network determine configuration options. We then utilise this framework to predict how emerging technologies will reshape the international configuration options available to firms.

Introduction

International business (IB) scholars typically define a firm's international configuration as the way it chooses to fine-slice, locate and govern its value chain activities (e.g. Rugman *et al*., 2011; Casson and Wadeson, 2012; Mudambi and Venzin, 2010). These configuration choices have been explained in terms of a variety of factors including on trade-offs between cost arbitrage (Helpman, 1984; Markusen, 1984), knowledge seeking (Doz , Santos and Williamson, 2001; Tallman and Fladmoe-Lindquist, 2002; Mudambi, 2008; Ayse, 2011), the costs of moving knowledge over distance (Buckley and Hashai, 2005), internal organisational considerations (Bartlett and Goshal, 1989; Alcacer & Delgado, 2015), path dependency and strategic inertia (Collis, 1991), diminishing returns from the dispersion of activities (Narula, 2014; Fratocchi, *et.al*., 2014) and power and micro-politics (Bouquet and Birkinshaw, 2008). Few of these studies, however, explicitly take into account constraints on the choices of international configuration of activities available to firms that potentially arise from the physical characteristics of their products and their implications for the flows of materials, components and knowledge that underpin the value-creation process. Even exceptions that do acknowledge the relevance of technical and engineering considerations, such as research into how the modularisation of products might influence the architecture of multinationals, still tend to emphasise strategic considerations as the key driver of modularity and the architecture of multinational firms (McDermott, *et. al.*, 2013).

In the operations management (OM) literature, by contrast, product characteristics are cast as the primary drivers of the configuration of value-chain activities because of the way they influence how its constituent parts and value-adding activities can be decoupled and dispersed (Ulrich, 1995; Cooper *et al*., 1997; Baldwin and Clark, 2000).

In this paper we bring together IB and OM perspectives to develop a framework to show how the physical and technological characteristics of a product and its associated value chain might constrain the viable decoupling (and therefore dispersion) options available to the firm when deciding on the international configuration of its activities. By explicitly distinguishing these constraints from firm choices we seek to enhance existing IB explanations and provide a more general framework to understand the current dispersion of activities and tasks (Baldwin and Evenett, 2015) that haves hitherto been investigated in industry studies (e.g. MacDuffie, 2013; Alcacer and Delgado, 2015; and Gray, *et. al*., 2015).We then show how this framework can be used to better predict the likely impact of advances in information and communications technologies (ICT) and new manufacturing technologies on firms' international configurations..

Horizontal and Vertical Decoupling of Product Value Networks

We adopt Dunning and Lundan's (2008) characterisation of the value chain which we extend to encompass the full "value network" (Stabell and Fjeldstad, 1998) comprising both a vertical value chain of activity stages, including possible outsourced supply (Lambert *et al*., 1998), and a horizontal set of technologies, processes and components that may comprise each activity stage (Choi and Hong, 2002; Carbonara *et al*., 2002). This allows us to explore the fundamental physical and knowledge characteristics of the product that might determine whether a firm has the *option* to disperse any activity as part of that configuration.

Vertical decoupling is the opportunity to decouple and disperse any process stage of a product value network from the stage adjacent to it either upstream or downstream. Horizontal decoupling is the opportunity to decouple the components or technologies being worked on in parallel at any given stage (what Baldwin and Evenett, 2015, describe as the fragmentation of tasks). In order to focus on the options to disperse activities and tasks, we adopt the definition of spatial complexity suggested by Choi and Hong (2002), that calibrates the option to decouple and disperse any two value-creating activities along a spectrum going from “necessarily co-located on the same site” to “possible to locate on different sites in the same country”, or to “locate in different sites at any distance from each other” (i.e., to disperse internationally). These options are summarised in Figure 1. They depend on both the physical product architecture and the knowledge attributes of its associated value network.

<< Insert Figure 1 About Here >>

Physical product architecture

Where the product *architecture* is integral the opportunities for horizontal decoupling will be reduced compared with modular product architectures where each “functional element” acts as a specialised module that operates independently (Ulrich, 1995; Baldwin and Clark, 2000). The scope for vertical decoupling, instead, depends on the architecture of the processes needed to develop, design, manufacture and deliver the product. Where this is dominated by continuous processing, there are fewer opportunities for decoupling and dispersing the vertical stages of the value network compared with products where processing involves many potentially separate transformation steps (Srai, 2013).

The value density (the ratio of the value over the weight) associated with the product architecture will also influence the scope for decoupling. Low value density products, tend to have high transport cost relative to their value, compelling firms to operate a vertically integrated supply chain close to a foreign market (Voordijk, 1999). The impact of these costs can be expected to vary between the horizontal and vertical dimensions of the network depending on the value density of both intermediates and finished products.

Knowledge attributes

Configuration options will also be influenced by the *nature of the knowledge flows* across the value network because this impacts the extent to which distance acts as a barrier to horizontally or vertically decoupling. IB scholars have investigated these barriers in the context of studying how networks of subsidiaries interact (Birkinshaw, 2002; Kogut and Zander 1993, 1995) pinpointing the key role of knowledge tacitness (e.g. Kogut and Zander, 1993) and embeddedness (Birkinshaw *et al.*, 2002) between distant locations. Product characteristics that necessitate significant flows of tacit and/or embedded knowledge between activities or tasks will militate against decoupling and dispersion (Birkinshaw, 2002; Narula and Santangelo, 2012).

Depending on the impact of a product's characteristics on the scope for horizontal and vertical decoupling, Figure 1 sets out the different configuration options available to the firm. Specificallya firm supplying it will choose among the different configuration options shown in Figure 1. Specifically:

Local co-location will be the only viable configuration option available to firms which supply products where some combination of the following characteristics predominate: integral (rather than modular) architecture, relatively low value density, continuous/or limited processing technologies, and a value network that depends on highly tacit and embedded knowledge in both horizontal and vertical dimensions.

Firms supplying products with a combination of integral architecture and dependence on flows of highly tacit and embedded knowledge in the horizontal dimension of the value network (such as R&D that requires the fusion of multiple technologies), will need to co-locate the tasks required for each stage in the chain. But they will have the option of choosing a *decoupled value chain* configuration if the chain can divided into discrete vertical stages that can be located in favourable geographies and brought together economically (because of higher value density) and coordinated using flows of codified knowledge.

Firms supplying products that face high barriers to the coordination of dispersed vertical stages because of low value density and/or the need for flows of tacit and embedded knowledge between vertical transformation stages will be constrained to replicating the complete vertical chain in each location in which they operate. But if the product architecture and knowledge network allows some of the technology development, design activities or component production required for each stage to be decoupled and dispersed, they will have the option of *multi-domestic replication*. In this case, each stage of this chain may be “thin” (with few horizontal activities) in some locations and “thick” in others (high horizontal fragmentation but low vertical fragmentation). For example, all locations may need some local R&D and design for adaptation to market conditions, but the bulk of basic R&D and design might be undertaken centrally.[1]

Finally, firms which supply products characterised by a combination of modular product architecture, discrete/batch processing, relatively high value density that reduces~~d~~ the costs of dispersion relative to the value of components and products and only limited flows of tacit and embedded knowledge will have the option of choosing a *globalised network* configuration. Here ~~where~~ activities are decoupled and widely dispersed i.e. ~~(~~high horizontal and vertical fragmentation~~)~~.

Empirical Analysis

We now adopt this framework to describe fragmentation of different industries. Specifically, we first asked product/industry experts to assess the scope for decoupling and dispersing different activities and tasks; second, we estimated the relationships between these perceptual options and measures of the product characteristics mentioned in the previous section.

[1] This category captures the case where the firm has the option to choose what the IB literature, coming from a strategy perspective, has frequently referred to as the “multi-domestic firm” (Prahalad and Doz, 1987; Bartlett and Ghoshal, 1989).

Questionnaire development and sample selection

In order to collect the data on the configuration options independent from the choices made by particular firms we focused the subsequent interviews on product designers, engineers, industry experts and researchers rather than company employees[2]. Respondents were randomly chosen from different engineering institutes and design centres in Europe, USA and emerging countries (China, Brazil, Mexico and Egypt). Over one hundred and sixty respondents were contacted over twelve months (follow- up emails were sent to all respondents to ensure that the data remained accurate and valid). Of a total of 106 responses, 96 were useable. These covered sixty-seven product (United Nations Central Product Classification) categories across eighteen industries, listed in Supplementary data A.

Product attribute measures

We collected survey responses for 17 indicators of product architecture and knowledge characteristics detailed in Table 1 along with their sources and measurement scales, and notes on the reliability of the scale. We then applied factor analysis to these data resulting in five factors corresponding to our explanatory indicators of product attributes: knowledge tacitness, knowledge embeddedness, value density, modularity and tier structure (Table 1). Application of Harman's one-factor test for possibility of common method variance bias confirmed the presence of these five distinct factors with an eigenvalue greater than 1.0 (See Supplementary data C).

[2] We refined and validated the questionnaire through three rounds of exploratory interviews with 15 product designers/engineers over a period of two months.

Measures of the scope decoupling

Our questions on the scope for horizontal and vertical decoupling and dispersion delivered perceptual measures of the scope for geographically separating different activities and tasks (Choi and Hong, 2002) as described in supplementary data B. Thus the indicator of the scope for horizontal decoupling and dispersion within the R&D activity, for example, measures the maximum geographic distance between different technology development centres that is viable. An indicator of the scope for vertical decoupling and dispersion between production and distribution was the viable geographic distance between these stages. Scores for each stage of activity chain and task were averaged to calculate a single measure of the scope for horizontal and vertical decoupling respectively that was used in an OLS regression against the factors measuring the attributes of each product.

Results for decoupling and configuration

Our regression results are reported in Table 2[3]. As expected, high product modularity was positive and significantly related to increased scope for horizontal decoupling, while knowledge tacitness and knowledge embeddedness both significantly reduced it. Value density also appeared to significantly reduce the scope for horizontal decoupling, possibly because the fragmentation of tasks associated with high value density products imposes other transaction costs which we do not measure directly.

The scope for vertical decoupling increased along the~~a~~ spectrum of continuous to discrete (batch) transformation processes (positive and significant coefficient on tier

[3] The reason for the relatively low adjusted R^2, especially in the equation for vertical decoupling, is worth noting. An examination of the residuals revealed that some of our sample products exhibited outlier values for certain indicators, especially value density. But we decided not to exclude these products in order to avoid losing valuable observations on the other indicators that were within the normal range.

structure). The nature of the knowledge flows required between stages of the chain showed up as an important factor in determining scope for vertical decoupling. The knowledge embeddedness had a negative and strongly significant impact; knowledge tacitness also had a negative coefficient (although not statistically significant). Modularity showed a positive (although insignificant impact). Value density was also insignificant (although separate analysis of the data separating upstream and downstream stages suggests it constrains decoupling of physical stages of the value chain, such as manufacturing, while having no effect on decoupling of R&D and design stages).

Taken together, these results are consistent with our proposition that firms supplying products with integral product architecture, and that depend on horizontal flows of highly tacit and embedded knowledge flowing in the horizontal dimension of the value network will need to co-locate the tasks underpinning each stage of the vertical chain. But also that, where this vertical chain can be divided into discrete stages (complex tier structure) and coordinated by codifiable knowledge, these firms will have the option of choosing a *decoupled value chain* configuration where activity stages can be dispersed. Products requiring continuous processing along the vertical chain, but with knowledge flows that do not significantly constrain the ability to disperse some of the technology development, design work or component manufacture, will have the option of *multi-domestic replication.* In this case the vertical chain may be thin in some locations (for example where R&D and design activities are limited to local adaptation) and thick at other locations, where the full range of horizontal activities at each stage is undertaken (as observed by Bartlett and Ghoshal, 1989).

Firms supplying products with some combination of integral product architecture and a value network that depends on flows of highly tacit and embedded knowledge, will be constrained to adopting a *locally co-located* configuration regardless of their preferences concerning ownership, governance, outsourcing or internationalisation of activities. The only firms enjoying the option to disperse their activities in a *globalised network* will be those supplying products with modular architecture, where activities and tasks, can be divided into multiple tiers, and where only limited necessary flows of tacit and embedded knowledge are required.

Mapping firms' configuration options by product

Figure 2 maps the perceptual values for the dispersion options available to firms depending on their product, thus illustrating the viable configurations across product types and industries [4].

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Specifically, firms producing biological products (e.g., biopharmaceuticals and gene therapy) are constrained to *local co-location* where embedded knowledge flowing throughout the value network requires design and manufacturing processes (e.g. cell culture production, isolation and purification of protein) to be tightly integrated and regulated. This is consistent with the findings of recent studies of pharmaceutical industry that colocation of R&D and manufacturing continues to lead to superior outcomes (Gray. *et. al.*, 2015). It also accords with the observation that particular vaccines remain ultimately developed and produced in one largely autonomous facility in a centralised location (e.g. GlaxoSmithKline's biopharma

[4] To test for potential for misperceptions among our respondents, we compared this with a similar mapping using the OLS estimates for our representative product types that share a value network (i.e. the positioning implied by the product attributes using the regression coefficients as weights). The perceptual values and OLS estimates imply decoupling options in the same quadrant for all but two of the product groups mapped (and even here the majority of survey respondents gave values that would have led to consistent positioning using the two methods).

products are manufactured and developed in Belgium, and some AstraZeneca influenza vaccine products are developed and mostly manufactured in the USA).

Firms supplying products with relatively modular architectures where vertical activities can be decoupled into multiple tiers, but that require horizontal tasks associated with technologies, and components comprising each stage to be integrated will be maximally constrained to a *decoupled value chain*. Thus Rolls Royce has an aero-engine manufacturing plant in Singapore, decoupled from R&D and design, but all of the technology, process and component streams required for each stage need to be co-located.

For relatively short-tiered mature product sectors with low value density and integral architecture, such as milk, concrete and household paint, fragmentation will be maximally constrained to *multi-domestic replication*. Only products with modular architectures that be produced in series of discrete transformation steps where standardised interfaces allow knowledge to be codified and free-flowing between tasks and activities, such as smart phones and laptops, will have the option of choosing a *globalised network* configuration.

The impact of emerging technologies on firms' configuration options

By specifying the links between each dimension of the product architecture, its value network, and a firm's configuration options, our framework provides a way to analyse the (often contrasting) impact of new technologies on the potential for fragmentation of tasks and activities

Specifically, ICTs that enable better decontextualisation, codification and communication of knowledge will reduce the opacity of relationships within the value network. Following Andersson *et al*. (2002; 2007) and Yamin and Sinkovics (2010) this should also open up new opportunities for decoupling and dispersion. Indeed, in our framework, greater transparency of knowledge flows provide firms with additional options to move towards a decoupled or globalised network configuration .

Emerging technologies, such as additive and continuous manufacturing, may also alter the process architecture and the nature of knowledge flows in the value network. Additive manufacturing (AM), which uses layer-by-layer manufacturing in order to build a component/product using a three dimensional computer-aided design (CAD) model. This requires the design information, and hence the interface to production, to be codified in software (Petrovic *et al*., 2011) giving firms the option to decouple their downstream manufacturing activities from their upstream design, (Hague *et al*., 2003). This opens the way for firms to move vertically in Figure 2. Greater use of CAD and numerical processing power can also allow firms to design products and systems with higher modularity than was possible in the past (Mustakerov and Borissova, 2013) opening up new options to choose multi-domestic replication or globalised network configurations.

The replacement of batch processing by continuous manufacturing (CM also requires the codification of knowledge, thus opening up new options for firms to decouple and disperse these activities and hence move from local co-location to a decoupled value chain or even global dispersion (Hague *et al*., 2003).

On the other hand, AM and CM lead to fewer production stages and a more integral product architecture. This will require production activities and tasks to be closely coupled and integrated (Hague *et al*., 2003, Cooney and Konstantinov, 2014), transforming products formerly delivered through complex, multi-tier value chains to a relatively short-tiered, integrated chains. This may constrain firms to adopting multi-domestic replication and local co-location configurations (depending on the associated knowledge attributes). Decoupled product development may also become unnecessary, as in the case of pharmaceuticals, where

CM has smoothed the path from the laboratory to full production, allowing the elimination of tests in parallel with clinical trials (Plumb, 2005).

Products designed to utilise these new transformation technologies also tend to be more integral compared with traditional, subtractive or batch manufacturing reducing the options for fragmentation and international dispersion. This shift has been observed in customised health products where researchers and scientists have integrated several stages of the value network to minimise cost and delivery time (Petrovic *et al*., 2011) and in the production of new lightweight, highly integrated systems such as air ducts used in aircraft (Lyons, 2012).

Conclusion

In this paper we integrated the traditional IB determinants of firms' international value-network configurations within a framework borrowed from the OM literature, where the product architecture (value density, degree of modularity and tier structure) plays a key role in orienting firms' decisions

First, we highlight the need to go beyond "industry-level" generalisations (such as that based on "smile curve" of value). The constituent tasks and activities that make up a product and its associated value network need to be examined to understand variations in the viable international configurations open to firms and industries.

Second, we suggest a typology of four viable configuration options, based on the constraints firms face when they consider international fragmentation. Our results confirm and extend previous single industry studies (e.g., MacDuffie, 2013 for the automotive industry; Alcacer and Delgado, 2015 for biopharmaceuticals; and Gray, *et. al*., 2015 for pharmaceuticals) demonstrating that in an increasing globalised world some activities and tasks may still need to remain collocated while others can be decoupled and dispersed (Pisano and Shih 2012). We also confirm and add to previous work on the role of technical and engineering influences on international configuration (Sanchez and Mahoney (1996), Schilling (2000), Baldwin and Clark (2000), Brusoni and Prencipe (2001), McDermott, *et. al.*, 2013) and firms' location choices (e.g. Ketokivi and Ali-Yrkko, 2009; Alcacer and Delgado, 2015).

Third, our framework provides some hints about the impact of emerging technologies and ICT advances on the configuration options available to firms. While we have not been able to test these predictions directly, this certainly promises to be fruitful area for future research.

Our findings may also help in guiding national strategies. Products where R&D, design or sales and distribution benefit by close coupling and co-location with manufacturing will be good candidates for emerging economies, such as China, seeking to exploit their strengths manufacturing to upgrade their value added. Conversely, products where the R&D and design tasks need to be co-located because they rely on tacit and embedded knowledge, and where high value density and short tier structures favour new technologies such as additive and continuous manufacturing, will be good candidates for advanced economies wishing to expand high value manufacturing. In this respect, both developed and emerging countries' policy makers may benefit from going beyond industry-level characteristics to consider product value network differences as they shape industry and investment promotion policies.

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Figure 1: Options for product value chain decoupling

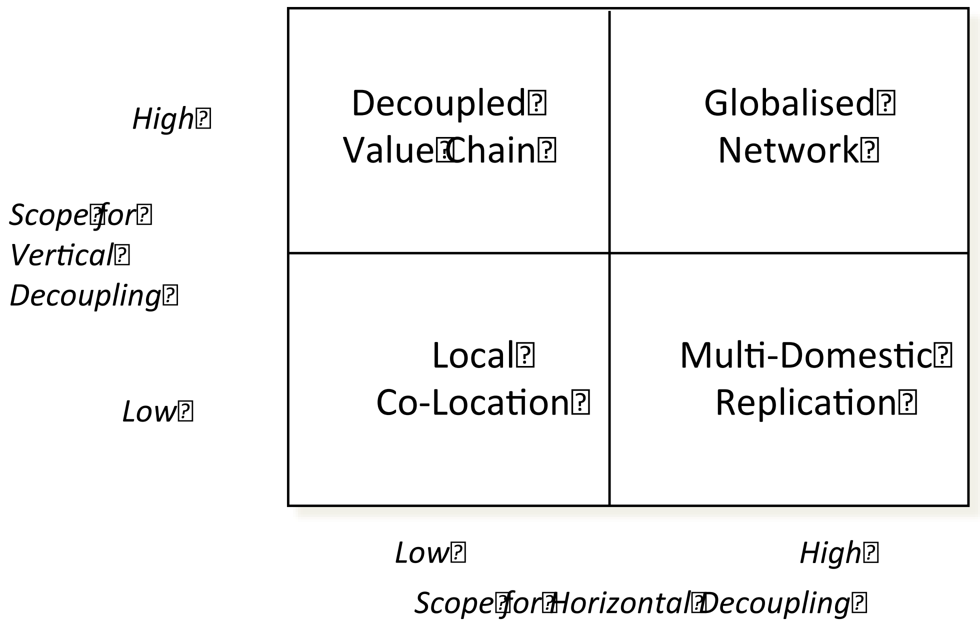

Figure 2: Product value chain decoupling

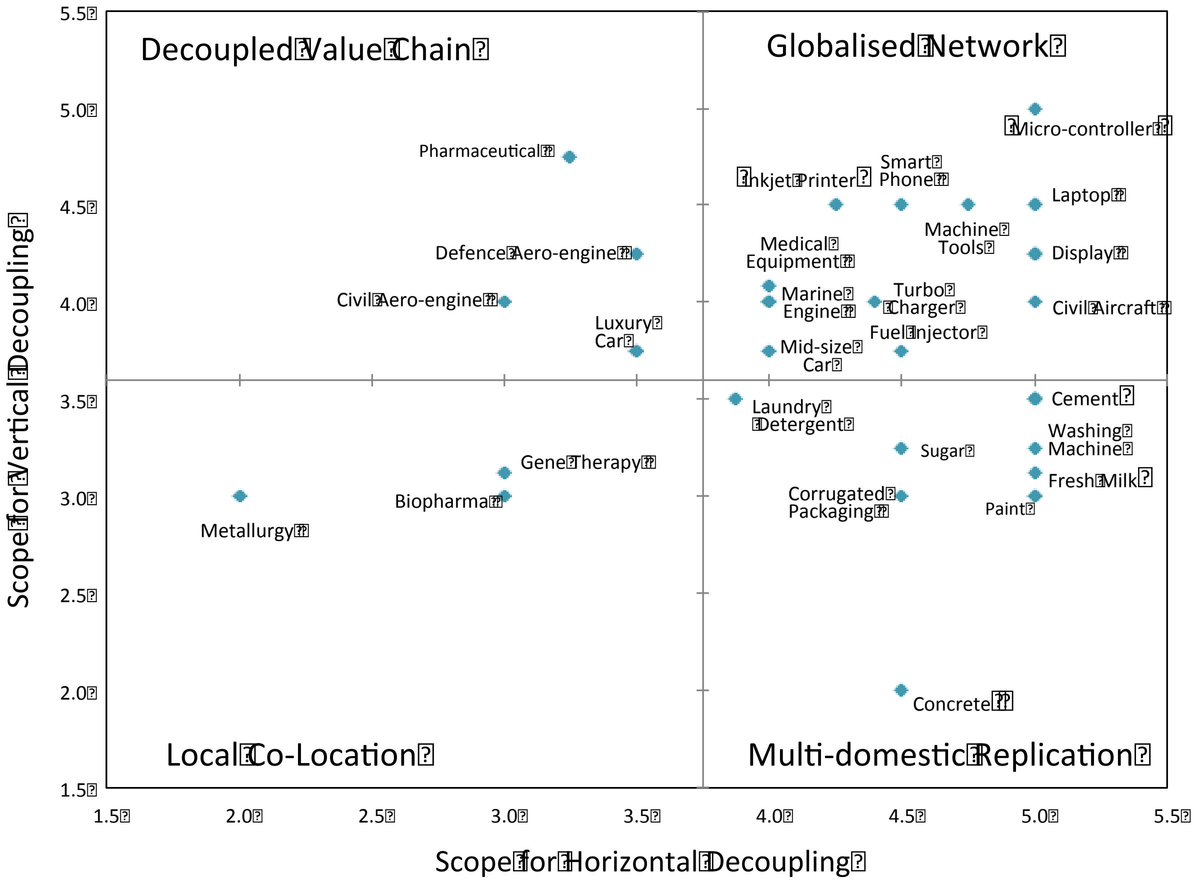

Table 1: Factor analysis to estimate indicators of product attributes

Attribute	Measure	Loading	Alpha	Source of Scale
Tier Structure	R&D tiers	0.84	0.92	Carbonara et al. (2002)
	Design tiers	0.87		and Srai (2013)
	Production Steps	0.83		
	Bill of material levels	0.78		
Value density	Finished product VD	0.92	0.97	Lovell et al. (2005)
	Tier 1 value density	0.94		
	Tier 2 value density	0.93		
Knowledge	Design codifiability	0.81	0.84	Zander and Kogut (1995)
Tacitness	Production codifiability	0.77		and
	Production teachability	0.63		Birkinshaw et al. (2002)
	Re/Design Complexity	0.65		
Product	Concept modularity	0.74	0.69	Ulrich (1995); Baldwin
Modularity	Component/module interface	0.77		and Clark (2000)
	Function-component allocatio	0.80		
Knowledge	Technologies embeddedness s	0.70	0.63	Zander and Kogut (1995)
Embeddedness	Design embeddedness	0.69		and
	Production- distribution embeddedness	0.79		Birkinshaw et al. (2002)

Table 2: Predictors horizontal and vertical decoupling and dispersion

	Horizontal Decoupling	Vertical Decoupling
Architecture		
- Product Modularity	0.284***	0.127
	(3.68)	(1.67)
- Tier Structure	0.045	0.180**
	(0.57)	(0.04)
- Value Density	-2.06**	0.034
	(-2.59)	(0.44)
Nature of Knowledge Flows		
- Knowledge Tacitness	-0.156*	-0.018
	(-1.98)	(-0.23)
- Knowledge Embeddedness	-0.393***	-0.226***
	(-5.00)	(-2.91)
Constant	4.271***	3.887***
	(53.82)	(49.59)
N	67	67
F	9.017 ***	3.125 **
Adjusted R^2 value	0.425	0.204

* p<0.1, ** p<0.05, *** p<0.01 t statistic()