**IS THE MIRRORING HYPOTHESIS DYNAMIC?**

**EXTENDING THE MIRRORING HYPOTHESIS VIA TRANSACTION COST ECONOMICS AND REAL OPTIONS PERSPECTIVES**

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There is a growing management literature examining the possible benefits of modularity and the presence of a ‘mirroring hypothesis’ between product architecture and organisational architecture.

Despite some criticisms and limitations, such a relationship has been examined in the literature, with many empirical studies supporting the hypothesis both within and, to a lesser extent, across firms. However, surprisingly few empirical studies have explicitly examined the possibility of a triadic mirroring relationship encompassing the boundaries of the firm, or examined how the mirroring hypothesis may evolve over time in response to changes in the product or market environment. This raises the central questions of ‘Is the mirroring hypothesis dynamic and evolutionary in response to changes in the product or market environment?’; ‘Is the mirroring hypothesis supported encompassing firm boundaries?’ and, ‘Is the evolutionary path bi-directional in response to architectural innovation?’

In response, this developmental paper sets out two evolutionary possibilities concerning how firm and product architectures may align over time on the basis of transaction cost economics (TCE) and real options theory, and establishes some initial propositions.

**UNDERPINNING LOGIC OF EVOLUTION AND BI-DIRECTIONALITY**

Technological innovation has been conceptualised as an evolutionary process. The life cycle and dominant design logic lie at the heart of the process; that the nature of innovation around a product changes over time predicated upon product diffusion and the economies of innovation (Abermathy & Utterback, 1978). The basic premise has been largely unchallenged in the literature, namely that innovation evolves throughout the life cycle from focusing on product architecture and its functionality to process improvements that reduce costs and/or improve service. The dominant design logic, however, has been argued to be bi-directional (Fine, 1998); a new ‘architectural innovation’ will disrupt the dominant design, opening up the industry structure again to new entrants. Clark (1985, p235) succinctly sums up that “as that the technology of product and process evolves, so too do associated systems of organisation and managerial practice”.

Product architectures are either integral or modular as ideal types (Ulrich, 1995), although, in practice, product architectures are rarely at one extreme or the other. Shibata et al (2005) classify product architectures as integral, modular or open architecture, and argue that there is a relationship between the emergence of modular product architectures and the emergence of a dominant design. Putting it another way, modularity requires the emergence of a dominant design in order that inter-firm standardisation can be accomplished. Importantly, like Fine (1998), they argued that this change is not always one-directional; when a new ‘architectural innovation’ is adopted, the direction of change may be reversed, going from a modular to integral structure.

**THE MIRRORING HYPOTHESIS: PRODUCT-ORGANISATION**

Modularisation is increasing in many industries. Sanchez and Mahoney (1996) cite studies that examined examples of modularisation in aircraft, automobiles, consumer electronics, household appliances, personal computers, software, and power tools. Products vary from integrated to modular (Schilling, 2000). While the literature has defined modularity in a number of ways, the underpinning concept of product modularity is as a system whose architecture supports the substitutability of modules (Sanchez and Mahoney, 1996).

Much of the literature on product and organisation modularity has stressed the possible benefits of modularity (Sanchez and Mahoney 1996) who argue that modularity is not only a characteristic of product design, but is also a characteristic of organisation design; the so-called ‘*mirroring hypothesis’*. They argue that a modular product makes possible the adoption of a modular pattern of organisation. Although contested in some studies, the mirroring hypothesis has been supported in many industries (Baldwin & Clark, 1997; Galvin & Morkel, 2001), both within and across firms (Colfer & Baldwin, 2010).

**EXTENSION OF THE MIRRORING HYPOTHESIS: PRODUCT-ORGANISATION-INDUSTRY**

*TCE lens*

TCE has been the dominant paradigm used to explain vertical scope decisions across contexts. Internalisation is preferred where transaction costs are excessive; conversely, the market will be selected where transaction costs are low (Williamson, 1975, 1985). Therefore, according to TCE, firms opt to perform production activities in house when the combined costs of production and internal coordination are less than the suppliers’ costs of production plus the corresponding transaction costs (Williamson, 1975). Due to the bounded rationality of managers and the risk of opportunism, TCE favours vertical integration with high levels of uncertainty and asset specificity.

When comparing the internal production with market contracting, historical discussions assume a static setting (Langlois & Robertson, 1995). TCE does not specifically address co-evolutionary perspectives [that] highlight the importance of endogenous changes in transaction costs (Jacobides & Winter, 2005). Therefore, the vertical scope inferences founded on static settings may not necessarily hold true in dynamic environments over time. However, there is a growing literature that supports logic in respect of the dynamic boundaries of firms. Scholars have shown this dynamism and evolution in a number of contexts (Stigler, 1951; Teece, 1996). Representative of the literature, Afuah (2001) argues that as a technology evolves, so to do the efficient boundaries of the organisation, with firms that are vertically integrated early in the life of the technology being better off than those that are not, and firms that are specialised before the arrival of the next capability-destroying technological change better off following the change. Putting it another way, as a technology evolves, so too does the efficient boundaries of the firm and its vertical scope.

There are also evolutionary drivers towards industry re-integration. Jacobides & Winter (2005) argue that the trend towards specialisation gets reversed when new and superior capabilities are misaligned with existing vertical structures in the industry. This may eventually make vertical re-integration possible, endogenously re-increasing transaction costs along the way.

*Uncertainty and real options lens*

TCE has been largely supportive of the relationship between asset specificity and vertical scope. However, uncertainty remains an under-developed and contested concept in the TCE literature, and there is an absence of consensus on uncertainty constructs such as market or technological uncertainty (Stanko & Calantone, 2011; Carter and Hodgson, 2006).

The empirical studies that have examined these uncertainty constructs have revealed mixed results. On the one hand, technological uncertainty may promote external market contracting through the flexibility afforded. Balakrishnan & Wernerfelt (1986) argued that as the likelihood of obsolescence goes up, the value of the investment goes down and with it the incentive to bargain, and hence the gains from vertical integration. On the other hand, technological uncertainty may complicate the process of contracting. Namely, where technical requirements cannot be foreseen, it is difficult to write and enforce contracts. As a result of these costs, this may promote internal governance.

Representative of the wider field, and quoted in Carter & Hodgson (2006), studies such as Walker & Webber 1984, find a positive relationship between market (volume) uncertainty and internal production but a statistically insignificant negative relationship between technological uncertainty and internal production; and, Balakrishnan & Wernerfelt (1986) find that technological uncertainty is negatively related to vertical integration.

*Real options* analysis has emerged as a compelling approach for evaluating investment opportunities in uncertain or ‘risky’ environments. As such real options theory emphasises the value of investments that allow firms to manage risk proactively by confronting uncertainty over time in a flexible fashion. Proposed by Myers (1977), real option theory argues that some investment opportunities confer the right, but not the obligation, to take specific action in the future. In the management literature, attention has focused on flexibility options, as it recognises that there is opportunity costs associated with irreversible investments under uncertainty. As a result, the ability to defer committing resources under uncertainty is valuable.

These insights suggest that certain initial investments allow management to capitalise on favourable opportunities and mitigate uncertainty by confronting it in a flexible fashion. This flexibility allows managers to exploit opportunities when the firm receives new information regarding, for example, market demand, competitive conditions or the viability of new technologies. These insights have important implications for organisational governance as it suggests that firms may choose governance structures in a dynamic fashion in anticipation of future, uncertain, opportunities.

When investments are irreversible, the future value of the investments is uncertain, real options theory indicates that committing early may impose considerable risks. In such situations, there is economic value is waiting for new information, and the ability to defer or wait can be an important source of flexibility. For instance, if vertical integration entails greater sunk costs than market contracting, integration will expose the firm to the risk of owning assets that may turn out to have little value due to changes in the underlying product or technology demand. Market contracting, contrarily, may incur greater short-term marginal production costs but provide the firm with the flexibility to pursue alternative technologies in the future. Real option theory recognises the value of this flexibility and indicates that, under uncertainty, it may be optimal to utilise market contracting. The value of the option to defer is greatest when uncertainty is high and immediate cash flows lost due to postponing investment are relatively small.

Sanchez (2003) argues that in a dynamic market environment with high levels of demand uncertainty for specific products, the options value of greater speed to market, reduced financial risk of incurring sunk costs, and the flexibility to switch asset use may be significant. In other words, in a dynamic market context, subject to conditions of uncertainty, such as in the emerging stage of an industry life cycle model, the options value is high, and this leads to market contracting as the preferred options for strategizing managers. As the market environment grows and stabilises, with low levels of market and technological uncertainty, such as a period just prior to or following the emergence of a dominant design and modularisation, low demand uncertainty lowers the value of avoiding large sunk costs. Under these conditions, the additional value to be derived by using low sunk cost, flexible assets may not be significant compared with the economic cost reductions and potential quality improvements that may be obtainable from internalising technological assets. In other words, when market uncertainty is low, the value of options is low, and this favours a vertically integrated scope.

**INITIAL PROPOSITIONS – EXTENDED MIRRORING HYPOTHESIS**

P1: There is a triadic mirroring hypothesis between product, organisation and industry architectures

P2: The extended mirroring hypothesis evolves over time in response to product-market environment changes

P3: The process of evolution of the product-organisation-industry architecture is bi-directional

Transaction cost economics predicts that:

P4a: In the emergent stages of a new technology, with high levels of market and technological uncertainty, the product-organisation-industry architectures will be integrated

P4b: Once a dominant design is established, with reducing levels of market and technological uncertainty, the product-organisation-industry architectures will disintegrate and modularise

Real options theory predicts that:

P5a: In the emergent stages of a new technology, with high levels of market and technological uncertainty, the product-organisation-industry architectures will be disintegrated and modular

P5b: Once a dominant design is established, with reducing levels of market and technological uncertainty, the product-organisation-industry architectures will integrate

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