**MIRRORING OR MISTING: A CONTINGENT PERSPECTIVE**

At its heart, the mirroring hypothesis seeks to examine 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. In a recent literature review, Colfer & Baldwin (2010) found broad support but notable exceptions[[1]](#footnote-1), leading to calls for a more nuanced view. Some initial work has occurred primarily in the air-conditioning and motor vehicle industries. Furlan, Cabiguso & Camuffo (2014) examine the across-firm mirroring hypothesis in the air-conditioning industry, and find that the ‘mirror’ becomes misted by high rates of component change, and in a study of the motor vehicle industry, Zirpoli, Cabigiuso & Camuffo (2013) suggest that the mirroring hypothesis may become misted as firms seek to integrate external sources of innovation into complex product development.

Most importantly, we recognise that the mirroring hypothesis may be observed at numerous levels e.g. product to firm, component to task boundaries, task to knowledge boundaries and knowledge to firm boundaries. The rate of component change and the degree of complexity as two previously identified conditions under which the mirror may become misted will impact different potential mirroring relationships in different ways. In essence, we show how factors at both the product architecture and the underlying product component level may influence the degree of mirroring and misting, thereby potentially going some of the way to understanding why Colfer and Baldwin (2010) observed inconsistent results.

**TYPOLOGY OF PRODUCT ARCHITECTURES**

**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) so that its interdependence is reduced. 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. Integrated product architectures usually incorporate components that are interdependent, and connect together via closed interfaces. On the other hand, modular product architectures exhibit greater interdependence within product components than across different product components (Ulrich, 1995) so that design changes to one component require little or no modification to other components, so long as there is adherence to a specified interface.

**The open and closed continuum**

Product architectures may also be conceptualised as being either open or closed (Sanchez, 2008; Shibata, Kodama & Yano, 2005). A perfectly closed architecture is one that is proprietary and a firm may protect component technologies and interface specifications (Sanchez, et al,. 2013). Not all closed product architectures are integrated, however. Firms with closed and modular designs may be able to develop modular components and interface specifications via their own firm-specific capabilities, but it is also a decision to forego network externalities (Sanchez, 2008) and the option value of seeking the best quality or lowest cost components (Baldwin and Clark, 2000). In contrast, an open architecture is one whose interface specifications are open and standard, and firms interested in developing components or complementary goods can often ‘plug and play’.

However, many product architectures (at the component level) are often a blend of both modular and integrated components, as well as a blend of both specialised and industry standards. To account for ‘non-perfect’ product architectures, West (2003; 2007) clarified that many architectures can be described as ‘hybrid’ because products, as complex systems, are made up of multiple components, and can often be opened up one product component at a time (Boudreau, 2010).

>>>insert figure 1 about here<<<

We now turn our attention to the idea of mirroring.

**Mirroring or misting**

In terms of integrated product designs, the basic logic is that there is unlikely to be a clear partitioning of component, task and knowledge boundaries and, as such, high-levels of information-sharing are necessarily required to progress its design and development. Whereas, in the case of modular product designs, the basic logic suggests that a clear partition of component, task and knowledge boundaries is possible and, as such, high-levels of information-hiding between product component teams (ie low levels of information-sharing) are possible.

**Nuancing the mirroring hypothesis – product complexity and the rate of product component change**

Modularity is often associated with partitioning knowledge boundaries so that they match component and task boundaries (Sanchez & Mahoney, 1996), however scholars have challenged the assumption that component and task partitioning is a good map for the division of knowledge (for example, Brusoni, Prencipe & Pavitt, 2001; Zirpoli & Camuffo, 2009). The degree to which a product architecture can be classified as ‘complex’ is a key driver in deciding between design modes based upon knowledge integration versus knowledge partitioning. Dynamic component level change, even in modular architectural settings, may also hinder the possibilities for designers to pursue modular innovation as fast technological changes limit the partitioning of components and associated task and knowledge boundaries (Langlois, 2002).

**PROPOSITIONS**

**Degree of mirroring in closed and integrated architectures**

Sanchez & Mahoney (1996:65) were one of the first scholars to formalise within-firm mirroring and asserted that “…processes for developing tightly-coupled component designs require intensive managerial co-ordination, since the change in the design of one component is likely to require extensive compensating changes in the designs of many inter-related components. Thus, product designs composed of tightly-coupled components will generally require development processes carried out in a tightly-coupled organisation structure coordinated by a managerial authority hierarchy, an organisation design typically achieved within a single firm”. As such, the usual logic is that closed and integrated product architectures are associated with vertical integration. The presence of highly interdependent components is likely to severely limit the partitioning of task and knowledge boundaries and, as such, firms are likely to rely on face-to-face information-sharing, close geographical proximity or co-location and formal managerial authority to coordinate highly interdependent product development activities. Thus:

*P1: Closed and integrated product architectures are positively associated with component, task and knowledge integration and with high levels of information-sharing between product developers within firm boundaries*

**Degree of mirroring in closed and modular architectures**

The specification of modular components and specialised interfaces within a significantly closed architecture may over time begin to supplant existing interdependencies, taking seed where increased component mixing and matching or speed to market may offer a firm competitive advantage. Considering now the architectural relationships, where the closed and modular product architecture can be characterised as *simple*, a firm will often possess a broad scope of architectural and component level knowledge in order to scope ex-ante component boundaries and specialised interfaces leading to ex-post information-sharing being minimised. However, if the product architecture is *complex*, there is often a need for actors to maintain high levels of ex-post information-sharing, even where the components are stable. As product complexity affects how a component interacts with other components, increasing complexity raises the potential for unforeseen design and system integration problems across the architecture limiting the potential for knowledge partitioning.

The architectural mirror may often be influenced by the rate of underlying component change[[2]](#footnote-2) (Fulan, et al., 2014). Where the modular components within a simple product architecture are stable ex-post, the need for rich ex-post information-sharing between component development teams within firm boundaries is often reduced. As a consequence, a firm is often likely to begin to redesign itself into quasi-independent structures under one corporate umbrella (Baldwin & Clark, 2003). However, where the components are fast-changing, either as part of a complex or simple product architecture, ex-ante investments will often be required to understand how the technological changes affect other components. Therefore, where a component is subject to technological change, frequent ex ante and ex-post information-sharing may often be required in order to coordinate integration. Thus:

*P2a: Closed and modular product architectures are positively associated with component and task partitioning between product developers within firm boundaries*

*P2b: Closed and modular product architectures are positively associated with task and knowledge partitioning and with low-levels of information-sharing between component developers only when product architectures are simple and component technologies are stable*

**Degree of mirroring in hybrid modular architectures**

The re-architecting of the focal firm into quasi-independent units that function based on internal shadow prices may propel a firm to consider market exchange. Assuming an intermediate market exists, it makes sense for these firms to seek gains from trade in those components that are not central to the product’s competitive positioning in the market. This splitting of a product into sets of components (or sub-sets of the product architecture) where some are open and modular, others are closed (or at least restricted to limited collaborators) but modular and others that are closed and integrated was observed in the second generation mobile phones of select manufacturers (Galvin & Rice, 2008). Where a firm decides to open up (parts of) its product architecture, the usual logic then is that contracting firms in a value chain will often recognise the benefits of making ex-ante investments in modularisation. Product complexity and a fast rate of underlying product component change is likely to, however, affect the basis of contracting relationships with external firms and “require more complex inter-firm devices (and hence more information-sharing)” (Furlan, et al., 2014: 791). Therefore, as we have noted before, where a product architecture is *complex* frequent ex-post information-sharing may often be required in order to coordinate the integration of both insourced and outsourced product components into the overall architecture (see for example, Lau & Yam, 2005; Furlan, et al., 2014).

Brusoni, et al., (2001) were one of the first to examine the relationship between modularity and technology. They argue that when components are stable, firms often outsource components. However, when components technologically evolve at uneven rates, there is the potential for technical imbalances which often requires a cognitive overlap (Furlan, et al., 2014) in order to control or exploit them. A cognitive overlap can either be achieved through either keeping some components within firm boundaries or through remaining engaged in thick collaborative relationships with external firms. Where fast-changing components are outsourced, firms need to develop collaborative relationships with external firms in order to absorb component-specific knowledge, even when the component is modular. In sum, in intermediate or hybrid product architectures, modularity does not mitigate the need for high levels of ex-post information-sharing, as such architectures often tend to be either complex or subject to fast rates of product component change. Thus,

*P3a: Hybrid product architectures are positively associated with component and task partitioning between product developers within and across-firm boundaries*

*P3b: Hybrid product architectures are negatively associated with task and knowledge partitioning and with low-levels of information-sharing between product developers within and across firm boundaries*

**Degree of mirroring in open and modular product architectures**

As further components are outsourced to external firms, a product architecture can often be characterised as open and modular. As we have noted, where the product architecture can be characterised as *simple* andwhere underlying product components are *stable,* contracting firms invest ex-ante in high levels of information-sharing in order to define component boundaries and standard interfaces, and then may switch to a low level of ex-post information-sharing. However, in complex architectures, or with fast rates of component change, firms often rely on rich information-sharing – even if simply through a systems integrator – in order to orchestrate a diverse range of component technologies across a number of external firms thus the knowledge is not partitioned to mirror the task and component architecture. Nevertheless, at the task level, as was discussed in respect of closed and modular architectures, the task boundaries may correspond with the product architecture, for as seen in the case of systems integrators, firms may enable “specialisation in the production domain while remaining integrated in the knowledge domain” (Brusoni, et al., 2001: 609).

Stated formally:

*P4a: Open and modular product architectures are positively associated with component and task partitioning between product developers across firm boundaries*

*P4a: Open and modular product architectures are positively associated with task and knowledge partitioning and with low levels of ex-post information-sharing between product developers across firm boundaries, only when product architectures are simple and where component technologies are stable*

**CONCLUDING REMARKS**

We hypothesised that the extent of mirroring or misting across different architectural levels is contingent upon the type of product architecture, its degree of complexity and the rate of component change such that the correspondence between all architectural levels is only likely to be witnessed where the stylised product architecture type can be characterised as simple and where the underlying product components are stable. However, where a stylised product architecture is characterised as complex, we suggest that firms may not resort to knowledge partitioning and low levels of ex-post information-sharing between product developers, either within or across firms as there will be a need to effectively orchestrate the integration of diverse components, access external sources of knowledge and manage unforeseen integrative consequences as they arise. As such, we propose that even where components are modular and stable, high levels of ex-post information-sharing tend to be required to ensure effective integration into complex product architectures. We therefore suggest that our proposed model helps reconcile some of the existing mixed evidence.

**REFERENCES**

Alexander, C. 1964. ***Notes on the synthesis of form.*** Cambridge, MA. Harvard University Press.

Baldwin, C. 2008. Where do transactions come from? modularity, transactions and the boundaries of firms. ***Industrial and Corporate Change*,** 17(1): 155-195

Baldwin, C. & Clark, K. 2000. ***Design rules: the power of modularity.*** Cambridge, MA. MIT Press

Baldwin, C. & Clark, K. 2003. Managing in an age of modularity**.***In*Garud, R, Kumarswamy, A and Langlois, R, ***Managing in the Modular Age: Architectures, Networks, and Organizations*,** 149-171 Oxford, Blackwell Publishing

Boudreau, K. 2010. Open platform strategies and innovation: granting access vs. devolving control. ***Management Science*,** *56*(10): 1849-1872

Brusoni, S. & Prencipe, A. (2001) Managing knowledge in loosely coupled networks: exploring the links between product and knowledge dynamics. ***Journal of Management Studies***, 38(7), 1019-1035

Brusoni, S., Prencipe, A. & Pavitt, K. (2001) Knowledge specialisation, organizational coupling, and the boundaries of the firm: why do firms know more than they make? ***Administrative Science Quarterly***, 46(4): 597-621

Cabigiosu, A. & Camuffo, A. 2012. Beyond the mirroring hypothesis: product modularity and inter-organizational relations in the air conditioning industry. ***Organization Science***, 23(3): 686-703

Cabigioso, A., Zirpoli, F. & Camuffo, A. 2013. Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry. ***Research Policy***, 42, 662-675

Ceci, F., Masini, A., & Prencipe, A. 2014. ***The limits of systems integration: complementarity, contingencies, and solution design choices.*** HEC Paris Research Paper No. MOSI-2014-1069.

Chesbrough, H, & Teece, D. 1996. When is virtual virtuous**. *Harvard Business Review***, *74*(1): 65-73

Clark, K. 1985. The interaction of design hierarchies and market concepts in  
technological evolution. ***Research Policy***, 14: 235–251

Colfer, L. 2007. ***The mirroring hypothesis: theory and evidence on the correspondence between the structure of products and organizations.*** Unpublished manuscript, Harvard Business School, Boston, MA

Colfer, L & Baldwin, C. 2010. ***The mirroring hypothesis: theory, evidence and exceptions***. Working Paper, 10-058, Harvard Business School, Boston, MA

Ethiraj, S., Levinthal, D. & Roy, R. 2008. The dual role of modularity: innovation and imitation, ***Management Science***, 54(5): 939-955

Fine, C., Golany, B. & Naseraldin, H. 2005. Modelling trade-offs in three-dimensional concurrent engineering: a goal programming approach. ***Journal of Operations Management***, 23(3): 389-403

Fixson, S., & Park, J. 2008. The power of integrality: linkages between product architecture, innovation, and industry structure. ***Research Policy***, *37*(8): 1296-1316

Fleming, L. & Sorenson, O. 2001. Technology as a complex adaptive system: evidence from patent data, ***Research Policy***, 30(7): 1019-1039

Fujimoto, T. 2007. Architecture-based comparative advantage – a design information view of manufacturing. ***Evolutionary and Institutional Economics Review***, 4(1): 55-112

Furlan, A., Cabigiosu, A. & Camuffo, A. 2014. When the mirror get misted up: modularity and technological change. ***Strategic Management Journal***, 35, 789-807

Galbraith, J. 1973. ***Designing complex organizations***, Boston, MA. Addison-Wesley Longman Publishing Co, Inc

Galbraith, J. 1977. Organisation design: an information-processing view**. *Interfaces***, 4(3): 28-36

Galvin, P. & Morkel, A. 2001. The effect of product modularity on industry structure: the case of the world bicycle industry. ***Industry and Innovation***, 8(1): 31-48

Galvin, P. & Rice, J. 2008. Managing knowledge in the mobile telephone industry: A case study of knowledge protection and diffusion for innovation. ***International* *Journal of Technology Management*,** 42(4): 426-438

Garud, R., & Kumaraswamy, A. 1995. Technological and organizational designs for realizing economies of substitution. ***Strategic Management Journal***, *16*(S1): 93-109

Gawer, A. 2014. Bridging differing perspectives on technological platforms: toward an integrative framework. ***Research Policy***, *43*(7): 1239-1249

Gawer, A & Cusumano, M. 2014. Industry platforms and ecosystem innovation. ***Journal of Product Innovation Management*,** *31*(3): 417-433

Henderson, R. & Clark, K. 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. ***Administrative Science Quarterly***, 35(1), 9-30

Hobday, M., Davies, A., & Prencipe, A. 2005. Systems integration: a core capability of the modern corporation. ***Industrial and corporate change***, *14*(6): 1109-1143

Hoetker, G. 2006. Do modular products lead to modular organizations? ***Strategic Management Journal*,** 27(6): 501-518

Jacobides, M. 2005. Industry change through vertical disintegration: how and why markets emerged in mortgage banking. ***Academy of Management Journal***, *48*(3): 465-498

Langlois, R. 2002. Modularity in technology and organization. ***Journal of economic behavior & organization*,** *49*(1): 19-37

Lau, A. & Yam, R. 2005. A case study of product modularization on supply chain design and coordination in Hong Kong and China. ***Journal of Manufacturing Technology Management*,** 16(4): 432-446

Lawrence, P. & Lorsch, J. 1967. Differentiation and integration in complex organisations, ***Administrative Science Quarterly.*** 12(1): 1-47

MacDuffie, J. 2013. Modularity‐as‐property, modularization‐as‐process, and modularity‐as‐frame: lessons from product architecture initiatives in the global automotive industry, ***Global Strategy Journal*,** 3(1): 8-40

March, J. & Simon, H. 1958. ***Organizations.*** Oxford, England

Mikkola, J. H. 2006. Capturing the degree of modularity embedded in product architectures. ***Journal of Product Innovation Management*,** *23*(2): 128-146

Murmann, J & Frenken, K. 2006. Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. ***Research Policy***, *35*(7): 925-952

Orton, J. & Weick, K. 1990. Loosely coupled systems: a reconceptualization, ***Academy of Management Review***, 15(2): 203-223

Parnas, D. 1971. Information distribution aspects of design methodology. ***Proceedings of IFIP Congress***, Ljubljana, Yugoslavia, Volume 1, 339-344

Parnas, D. 1972. On the criteria to be used in decomposing systems into modules, **Communications of the ACM,** 15(12), 1053-1058

Parmigiani, A. 2007. Why do firms both make and buy? an investigation of concurrent sourcing. ***Strategic Management Journal***, 28(3): 285-311

Porter, M. 1991. Towards a dynamic theory of strategy. ***Strategic Management Journal***, 12(S2): 95-117

Sanchez, R. 2008. [Modularity in the mediation of market and technology change](http://research.cbs.dk/en/publications/uuid(7c463d70-d32d-11dd-8e8d-000ea68e967b).html). ***International Journal of Technology Management***, 42 (4): 331-364

[Sanchez, R.](http://research.cbs.dk/portal/en/persons/ron-sanchez(7c444a2d-389b-4d9f-a3dd-e81fade41ae0)/publications.html). Galvin, P. & Bach, N. 2013. [***'Closing the Loop' in an Architectural Perspective on Strategic Organizing: Towards a Reverse Mirroring Hypothesis***](http://research.cbs.dk/portal/en/publications/closing-the-loop-in-an-architectural-perspective-on-strategic-organizing(b3f1fb88-6396-45d2-ae81-28aa6abf7f93).html),Frederiksberg: Department of Innovation and Organizational Economics, Copenhagen Business School

Sanchez, R. & Mahoney, J. 1996. Modularity, flexibility and knowledge management in product and organisation design. ***Strategic Management Journal***, 17: 63-76

Sanchez, R. & Mahoney, J. 2013. Modularity and economic organization: concepts, theory, observations, and predictions. In Grandori, A (Ed). ***Handbook of economic organization: integrating economic and organization theory***, 383-399, Cheltenham, England. Edward Elgar Publishing.

Schilling, M. 1998. Technological lockout: an integrative model of the economic and strategic factors driving technology success and failure. ***Academy of Management Review***, 23(2): 267-284

Schilling, M. 2000. Towards a general modular systems theory and its application to inter-firm product modularity. ***Academy of Management Review***, 25(2): 312-334

Schilling, M. 2002. Technology success and failure in winner-take-all markets: the impact of learning orientation, timing, and network externalities. ***Academy of Management Journal*,** 45(2): 387-398.

Shibata, T., Yano, M & Kodama, F. 2005. Empirical analysis of evolution of product architecture: Fanuc numerical controllers from 1962 to 1997. ***Research Policy***, *34*(1): 13-31

Simon, H. 1962. The architecture of complexity. ***Proceedings of the American Philosophical Society,*** 106(6), 468-482

Sosa, M., Eppinger, S. & Rowles, C. 2004. The misalignment of product architecture and organizational structure in complex product development. ***Management Science***, 50(12): 1674-1689

Ulrich, K. 1995. The role of product architecture in the manufacturing firm. ***Research Policy***, 24(3), 419-444

Von Hippel, E. 1990. Task partitioning: an innovation process variable. ***Research Policy***, 19(5): 407-418

Weick, K 1976. Educational organizations as loosely coupled systems. ***Administrative Science Quarterly***, 1-19

West, J. 2003. How open is open enough?: melding proprietary and open source platform strategies, ***Research Policy***, 32(7): 1259-1285

West, J. 2007. The economic realities of open standards: black, white and many shades of grey, ***Standards and Public Policy***, 87-122

Zirpoli, F., & Becker, M. C. 2007. ***Beyond product architecture: division of labour and competence accumulation in complex product development***. SSRN Working Paper Series.

Zirpoli, F., & Becker, M. C. 2011. The limits of design and engineering outsourcing: performance integration and the unfulfilled promises of modularity. ***R&D Management*,** *41*(1): 21-43.

Zirpoli, F., & Camuffo, A. 2009. Product architecture, inter‐firm vertical coordination and knowledge partitioning in the auto industry. ***European Management Review***, *6*(4): 250-264

FIGURE 1

Product architecture typology

|  |  |  |  |
| --- | --- | --- | --- |
| Closed and integrated | Closed and modular | Hybrid | Open and modular |
| A proprietary architecture with a high number of integrated components and low number of specified interfaces  Example: Performance-enhanced engines | A proprietary architecture with many independent components and high number of specialised interfaces  Example: Power tools | A proprietary architecture with a blend of component types and a mix of specialised and industry standard interfaces  Example: Motor vehicles | A non-proprietary architecture with a high number of independent components and a high number of industry standard interfaces  Example: Hi-fi systems |

1. Colfer and Baldwin (2010) found uniform support for the within-firm mirroring hypothesis in 68% of studies, but 77% supportive when partial or mixed results were incorporated. Similarly, the across-firm mirroring hypothesis found uniform support in 47% of studies, but 74% when partial or mixed results were incorporated. [↑](#footnote-ref-1)
2. Furlan, Cabigiosu and Camuffo (2014) suggest that the rate of product component change may influence the architectural mapping between product and firm in the case of buyer-supplier relationships. We see no reason to extend this reasoning to closed and modular product architectures developed within the boundaries of a single firm. [↑](#footnote-ref-2)