**MISTING THE MIRROR: THE VALUE CHARACTERISTICS OF PRODUCT COMPONENTS - A PERSPECTIVE ON ORGANISING FOR INNOVATION**

**Introduction**

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 (Baldwin & Clark, 2000; Colfer, 2007; Henderson & Clark, 1990). At its heart, the so-called mirroring hypothesis seeks to examine two important and pervasive relationships: (1) the extent of an architectural mapping between firms’ strategic choices of product architecture and firm architecture – within-firm mirroring - and (2) between firms’ architectural choices and industry structures – across-firm mirroring.

More specifically, different types of mirroring may be examined at different hierarchal levels. For example, a ‘weaker’ test of mirroring may be characterised as the correspondence between product component, task and firm boundaries, whereas a ‘stronger’ test may seek to also establish a correspondence of knowledge boundaries (ie, Burton, 2015). Weaker tests of mirroring that examine whether product modularity is associated with task partitioning and outsourcing (ie, mirroring between product component, task and firm boundaries) have received strong levels of support in the extant literature such as Colfer & Baldwin (2010) who found support for the mirroring hypothesis in 68% of ‘within-firm’ cases and 47% of ‘across-firm’ cases.

In supporting the theoretical logic for the strong test of the mirroring hypothesis (ie that the mirroring extends to the knowledge boundaries), advocates of modularity argue that its design principles permit an easier partitioning of knowledge and hence productive capabilities. For example, Sanchez (2003:382) writes that *“the standardising of component interfaces based upon the firms current architectural knowledge largely decouples architectural knowledge-based processes from the component-level knowledge used to develop specific component design during product development”* such that manufacturers/assemblers of modular products can specialise in architectural knowledge and outsource product component design and development across firm boundaries. However, despite the intuition that knowledge boundaries can be successfully partitioned, its enactment appears less prevalent in practice, causing a ‘misting of the mirror’ in respect to the strong form of the mirroring hypothesis.

Unsurprisingly then, the largest body of work on ‘misting’ comes from scholars who have challenged the assumption that product component, task and firm boundaries are a good map for the division of knowledge and hence productive capabilities (ie, Brusoni, Prencipe & Pavitt, 2001; Furlan, Cabigiosu and Camuffo, 2014; MacDuffie, 2013; Sosa, Eppinger & Rowles, 2004; Zirpoli & Becker, 2007; Zirpoli & Camuffo, 2009). To date, the misting of the mirror has been linked to high levels of product complexity (e.g. MacDuffie, 2013; Zirpoli and Becker, 2007) and the rate of component change (Furlan, Cabigiosu and Camuffo, 2014).

To extend this work on understanding when the mirror may become misting, this paper investigates the whether the strong test of mirroring in respect of the UK pension industry between 2000 and 2015 holds. We add to the existing contingent variables of complexity and rate of change in terms of misting the mirror the notion of value and how it would seem to determine whether knowledge boundaries are partitioned or integrated and, hence, whether mirroring is present or absent. In other words, the value characteristics of a product component determine how a firm organises for innovation. High value components within a product architecture provide opportunities for firms to differentiate and may underpin a firm’s competitive position. For this reason, firms seek to control this knowledge and may limit outsourcing or simply take on the role of a systems integrator. By considering how both task and knowledge boundaries vary in respect of different product architectures as part of examining the mirroring hypothesis, and by incorporating the role of value into the analysis, this paper further develops our understanding of the contingencies that may see a ‘misting of the mirror’ and it also makes clear that mirroring and misting may occur *at the same time,* depending on whether a weak or strong test of the mirroring hypothesis is explored.

The paper is structured as follows: (1) the extant literature is examined, focusing on recent contingent perspectives to the mirroring hypotheses, (2) the research method is explored, (3) findings from a retrospective study of the UK personal pensions product market between 2000 and 2015 are presented, (4) the findings are discussed and further contingencies are highlighted that may ‘mist the mirror’, and (5) some concluding remarks and directions for future research are identified.

**Prior work on mirroring**

Despite being criticised as being technologically-deterministic (Sako, 2003), the general idea of the mirroring hypothesis is that the architecture of a firm corresponds to the product architecture it designs to the extent that an integrated firm is necessary for developing an integrated product architecture, whereas a modular firm is necessary for developing a modular product architecture (Colfer, 2007; Colfer & Baldwin, 2010; Fine, Golany, & Naseraldin, 2005). In other words, ‘products design organisations’ (Sanchez & Mahoney, 1996).

While the mirroring hypothesis examines the correspondence between one structural layer of a product market and another, there are different targets for mirroring. Colfer (2007:5-6) identifies four types of architectural structure that are amenable: (1) the product; (2) the product development firm; (3) the division of labour and, (4) the division of knowledge. For example, (1) in the case of the product architecture, the target for modularisation is the interdependencies between product components, (2) in the case of the firm, the target is the communication patterns and relationships between the organisational actors who develop the product (such as individuals, teams, firms), (3) in the case of the division of labour, the target is the technical product interdependencies among the product development tasks of different firms, and, (4) in the case of the division of knowledge, the target is the technical interdependencies among the skill sets required to perform the development tasks (Colfer, 2007:6). In sum, Colfer (2007) suggests that we can talk of a ‘within-firm’ mirroring – the extent of architectural correspondence between the product and the product development firm – and an ‘across-firm’ mirroring – the extent of architectural correspondence between the product and the division of labour and/or division of knowledge across firms, as shown in Figure 1.

*[insert Figure 1 about here]*

In order to examine the mirror between product component, task, knowledge and firm boundaries, many scholars have used a proxy measure. Colfer and Baldwin (2010:6) argue that an ‘ideal test’ for mirroring is one that analyses how product architectures may relate to other layers and would seek to examine organisational ties such as (1) firm co-membership, (2) geographical co-location, or (3) communication and information-sharing patterns, suggesting that it is then possible to see whether “*a technical dependency was correlated with the presence (or absence) of a given type of organisational tie*”. Despite the range of organisational ties that are feasible, the amount of information-sharing between architectural layers is often foregrounded in many empirical studies.

In terms of *integrated product designs*, the usual logic is that there is *unlikely* to be a clear partitioning of product component, task and knowledge boundaries and, as such, high-levels of information-sharing would be required to progress its design and development. Whereas, in the case of *modular product designs*, the usual logic suggests that it is *likely* a clear partitioning of product component, task, and knowledge boundaries is possible and, as such, low-levels of information-sharing between product component teams would be observed. However, it is important to distinguish between *ex-ante* and *ex-post* information-sharing across the layers (Cabigiosu & Camuffo, 2012). For example, ex-ante information-sharing is often required to partition modular product component boundaries and negotiate interface standards which then permits low-levels of ex-post information-sharing, as product development proceeds according to the agreed interface standards. In Sanchez and Mahoney’s (1996) terms, ex-ante information-sharing to agree standards acts as an ‘embedded coordination’ mechanism ex-post.

In contrast, misting occurs where high-levels of ex-post information-sharing remain necessary to co-ordinate co-development or to resolve unexpected design issues. In other words, high levels of ex-post information-sharing may persist for a number of reasons, despite the presence of modular product components and interface standards. For instance, (1) firms often need to keep access to product component knowledge even where product component design is outsourced (Brusoni, *et al,* 2001; Zirpoli & Camuffo, 2009), or (2) firms may wish to engage in information-sharing and knowledge integration in order to develop or maintain systems integration capabilities (Brusoni, *et al.,* 2001).

*Contingent perspectives*

Much of the conceptual and empirical research concerning the mirroring hypothesis has focused upon whether the mirroring hypothesis holds, and only recently has it turned its focus to the contingent conditions under which it may hold (ie, Cabigiosu & Camuffo, 2012, Furlan, *et al.,* 2014). This is important, however, because as Sako (2003:230) highlights, *“there is no simple deterministic link between the type of product architecture and organisation architecture”.* Some initial empirical work that examines the conditions under which mirroring may hold have primarily focused on how product complexity (ie, Brusoni, *et al,* 2001; Cabigiosu, Zirpoli & Camuffo, 2013; MacDuffie, 2013; Zirpoli & Camoffo, 2009) and the rate of product component change (Cabigiosu & Camuffo, 2012; Furlan, *et al.,* 2014) may lead to a misting of knowledge boundaries, and hence, high-levels of ex-post information-sharing.

Zirpoli and Camoffo (2009), for instance, studied air-conditioning systems in the motor vehicle industry and noted that product component and task boundaries mirror. However, they also noted a knowledge-task boundary overlap in both manufacturer/assembler firms and suppliers, and that a firm’s strategy, knowledge and productive capabilities determined task allocation more so than product component boundaries. Zirpoli and Becker (2007) also argue that product component boundaries are often an inadequate map for task and knowledge partitioning, and highlight a number of reasons why this thesis may have limits, (1) product architectures are rarely fully decomposable and, as such, product component knowledge needs to retained and assimilated by a manufacturer/assembler firm in order to minimise any remaining product component interdependencies, (2) dynamic product market environments often necessitate new partitioning schemes which may also require a manufacturer/assembler firm to retain product component level knowledge, and (3) technological newness raises uncertainty which also may necessitate a manufacturer/assembler firm to keep product component knowledge within firm boundaries. Cabigiosu, Zirpoli and Camuffo (2013) offer a slightly different perspective. In their study of air-conditioning systems they found that where a manufacturer/assembler firm held high-levels of product component knowledge, it was able to successfully partition product component and task boundaries. However, where the manufacturer/assembler firm had insufficient product component know-how, it nurtured co-development practices with external suppliers and engaged in high-levels of ex-ante and ex-post information-sharing to acquire product component knowledge.

Brusoni and Prencipe (2001) and Brusoni *et al.,* (2001) studied the aircraft engine and chemical engineering industries and found that it can be difficult for a group of firms to develop a modular product architecture without a ‘systems integrator’ or ‘lead firm’ who can orchestrate the involvement and activities of others. Accordingly, modular product design is associated with the mirroring of product component, task and firm boundaries, but not with knowledge boundaries as *“systems integrators know more than they do”* (Brusoni & Prencipe, 2001:202). In other words, the *“decisions to outsource technological knowledge differ from decisions to outsource component production….”* (Brusoni, *et al.,* 2001:608). The misting of knowledge and task boundaries, according to the authors, arises from the fact that underlying product components evolve and change at different and uneven speeds which creates ‘imbalances’ in the technical architecture that necessitates keeping product component knowledge in-house, even when the product component design and/or production is outsourced.

Many of these contingent studies are situated in industries characterised by a high degree of product complexity (ie, motor vehicles, aircraft engines) and complexity may hinder the degree to which a successful product component, task, and knowledge partitioning can be accomplished. However, even when the product architecture is characterised as ‘simple’, knowledge partitioning may also be difficult to sustain. For instance, when underlying product components are subject to fast rates of technological change or product markets are characterised as ‘dynamic’. Furlan, *et al.,* (2014) examined the air-conditioning industry and noted that misting can occur in the presence of fast rates of product component change. The authors suggest that product component change increases information asymmetry and asset specificity and this leads to more frequent ex-post information-sharing, regardless of the degree of product component modularity. In addition, manufacturer/assembler firms retained access to product component knowledge in order to keep up with fast rates of technological change.

Beyond the contingencies of product complexity and the rate of component change, we suggest that the value characteristics of a product may also mist up the mirror. The role of value in determining how an organisation may structure the amount of information-sharing that is associated with component, task and knowledge boundaries can be traced back to the ideas of Parnas (1972) who stressed the potential benefits of ‘information-hiding’. While his view is grounded in the notion that that high levels of information-sharing can overwhelm a product development project, and it would be more efficient to hide or encapsulate information within a component boundary so that it cannot affect other parts of the system, the basic principle of information hiding may have relevance across different scenarios. Under Parnas’ (1972:1056) approach, every product component “is characterised by its knowledge of a design decision which it hides from all others. Its interfaces or definition was chosen to reveal as little as possible about its inner-workings”. Certainly Galvin and Rice (2008) identified that there were hybrid modular structures in the second generation mobile phone handset industry where some dimensions of the product architecture were entirely open and others that were closed as these represented the basis for the firm’s competitive advantage. It is this desire to ensure control over a firm’s competitive position that leads firms to limit the degree to which the knowledge boundaries are modularised to allow for the effective outsourcing of these components. At a minimum, firms are likely to adopt a systems integrator role of high value components such that they maintain their centrality in the value creation process and exercise a degree of control concerning the direction taken concerning innovation and development of relevant components.

Overall, the extent to which product component, task and knowledge boundaries are partitioned would appear to be a strategic choice; mirroring may be beneficial in stable and/or modular product market settings (Sanchez & Mahoney, 1996) or detrimental in more complex or dynamic settings (Chesborough & Kusunoki, 2001) and where the perceived value is high. In sum, in the case of simple product architectures with stable product component technologies, the extant literature suggests that ex-ante partitioning of product component, task, knowledge and firm boundaries in order to benefit from lower-levels of ex-post information-sharing may be an appropriate governance mode for innovative activities. However, on the other hand, when product architectures are complex, are subject to fast rates of product component change, or utilise high value components, firms maintain a broader knowledge than task boundary and maintain high-levels of information-sharing both ex-ante and ex-post. Given that high value components will feature somewhere in most products wider architecture and that many product markets are often today characterised as ‘dynamic’ or ‘complex’, the strong support for mirroring, therefore, seems rather puzzling.

Despite these contingent contributions, few studies have inductively examined mirroring or misting across product component, task, knowledge and firm boundaries on a retrospective or longitudinal basis in order to uncover (1) under which contingencies mirroring is present or absent across time, (2) to what extent mirroring or misting can both be present *at the same time*, and (3) to what extent mirroring or misting is sustained across time. The contribution of this paper, then, is to provide a more nuanced view of the mirroring hypothesis, responding to prior calls (ie, Colfer, 2007).

**Method**

The research context is a retrospective qualitative study of the UK personal pensions product market between 2000 and 2014. 2000 is the starting point of ‘retrospective time’ as it is widely-recognised as a period associated with the emergence of modular systems architectures, a so-called architectural innovation (Henderson & Clark, 1990) at the cusp of an evolution from ‘old’ style pensions to ‘modern’ person pensions.

To explore mirroring in the UK personal pensions product market, data needed to be collected at different units of analysis, about the product, the product development firm, and the industry/product market. Semi-structured interviews were used as a basis for data collection. Thirty-one senior managers with board level or senior product development roles agreed to participate, encompassing a range of professional experience profiles and firm membership. Although errors of recall can permeate retrospective accounts, the magnitude of these problems were minimized by drawing upon the advice offered by Glick*,* Huber, Chet Miller, Doty, and Sutcliffe (1990), (1) the interview was explicitly focused on "important" changes that tend to be recalled more reliably; (2) all key informants were senior managers who, by virtue of their positions, tended to be involved with or close observers of the important events and processes about which they reported; (3) respondents were spread across six different organisations; (4) to overcome issues associated with the ‘distant’ past, the sample consisted of respondents with 30 years continuous professional experience so that their accounts could be compared and contrasted against each other to resolve ambiguities A further technique used was to ask respondents to only respond to a question within their own direct professional experience and not to elicit a response if they were uncertain or could not remember, thereby utilising a ‘free report’ method that is associated with higher accuracy (Chet Miller, Cardinal, & Glick, 1997; Koriat & Goldsmith, 1994).

The structure of the interviews was divided into two distinct parts. In part 1, the aim was to invite respondents to create a product architecture timeline, an idea borrowed from the idea of a ‘lifeline’ that is often used in biographical research, where each respondent depicts key phases or events in their life in a chronological sequence (Brannen & Nilsen, 2011).

To facilitate this, a product architecture typology was developed from the extant literature and member-checked with an expert panel. The creation of product timelines are an example of "temporal bracketing" (Langley, 1999) that aims to identify meaningful time units within a stream of retrospective data. As Langley, Smallman, Tsoukas, and Van de Ven (2013:7) highlight “temporal brackets (which generally unfold sequentially over time) are constructed as progressions of events and activities separated by identifiable discontinuities in the temporal flow. They enable researchers to examine the recurrence and accumulation of progressions. This permits replicating theoretical ideas in successive time periods and also to analyzing how the changing context from previous periods impacts subsequent events in current periods”.

In this study, the temporal brackets were not pre-determined, rather identified by respondents based upon their recollection of the evolution of product architecture types from one design style to another. Once the thirty-one respondents had each constructed timelines, the researcher, together with an expert panel, synthesised the timelines into a single timeline that formed the structure of the temporal bracketing used in the data analysis phase. In part 2 of the interview, the respondents product timeline enabled open questions to be directed towards particular transition points from one product architecture type to another, such as ‘what led to this change?’, ‘what was the result of this change?’, and at different units of analysis, such as ‘how were products developed at this point in time?’. In other words, an inductive logic was used to derive any themes related to the firm and industry level units of analysis.

A combination of matrix and template analysis was used to analyse the interview data. Template analysis is a distinct and flexible type of thematic analysis (King, 1998, 2004), however templates were developed within the structuring device of a matrix with the synthesised product timeline (ie, the temporal brackets) represented as columns and the units of analysis (ie product, firm and industry level factors) represented as rows. The matrix served to structure data analysis, which then enabled interview data to be inductively coded to each cell using template analysis. In other words, the matrix helped uncover broad areas of interest, and then followed by a more finer-grained template analysis on elements of rich interest (King, Mirza, & Bates, 2007).

**Findings**

A near-modular product architecture emerged in the mid-90s, where the core systems architecture was maintained within firm boundaries, whereas many peripheral modular product components beyond firm boundaries. This was accompanied by a product development structure coordinated and orchestrated by a systems integration team who held architectural knowledge and individual product component development teams who held product component knowledge. However, architectural and product component knowledge partitioning could not be sustained across time, as unforeseen product component interdependencies often emerged, as one director recalled “*Projects created all sorts of problems. We had all sorts of component teams that were looking at different things, and the trouble was that these teams worked in verticals having agreed a certain standard, the trouble was when you came to the end to join back up again, it didn’t quite join back up again very well. So, you found actually, we didn’t think of that, and that doesn’t now work, and we effectively had to re-work and undo, backwards in those verticals to join back up again”*

Despite a product component, task, knowledge and firm boundary correspondence (strong mirroring) in the mid to late-90s, interviews suggest that system integration teams in incumbent manufacturer/assembler firms began to expand their knowledge boundary to encompass outsourced product component knowledge, and maintain high levels of information-sharing in order to resolve unexpected product design issues. As one senior manager highlighted: *“the proposition team within the firm began to gain knowledge of all the different components on offer, but then of course, you were also dealing with not just the internal component people, you’re dealing with component people outside, we were dealing with fund management people all over London, we were dealing with IT platform suppliers all over the country. It was like a jigsaw puzzle. You had all these pieces that were all over the place, and all had a part to play, but someone needed how to fit them all together to make a coherent proposition to the market”.* At the same time, ex-post information-sharing among the individual product component development teams was low suggesting that modular interfaces acted as an ‘embedded coordination’ mechanism between individual product component development teams, but not the between the product component development teams and the systems integrator.

From 2000, a new core systems architecture permeated the product market characteristic of a ‘competence-destroying’ innovation for incumbent manufacturer/assembler firms. The modular innovations throughout the 90s had already largely eroded outsourced product component knowledge, and the architectural systems innovation in 2000 served to erode any remaining architectural systems capabilities, leaving the systems integrators in incumbent manufacturer/assembler firms with ‘old’ and out-dated architectural knowledge. Hence, manufacturer/assembler firms simply did not possess any meaningful productive capabilities and so turned to a strategy of renewing its systems integration capabilities via extensive knowledge integration and information-sharing with upstream and downstream suppliers in order to survive. With few productive capabilities, manufacturer/assembler firms had few options but to license-in the new core systems architecture from external firms, despite the known threats of commoditisation and imitation posed by extreme modularity. As one director suggested: “*we absolutely did not have the expertise to build it ourselves anymore. It was getting to the point where it was just not sustainable. Things were changing so rapidly. Technology was changing and requirements were changing so rapidly, we just didn't have the expertise and it became a massive bottleneck. We didn’t have a core competency around new systems so we didn’t have a new world thinking. The strategy was we knew we wanted to still be in the market, we knew we didn’t have a core competency around it. We knew it would be expensive to do it ourselves. Somebody else needs to do it for us, so let’s pick somebody who’s good at it, despite the risks”* and another remarked that “*there’s been a tendency for a lot of businesses to be very similar, and almost the economics of it created common interfaces, common components, agreements and structures, but that’s all commoditisation, it’s then difficult to have something that looks distinctive”*

With an explosion of complementary product components converging around the new systems architecture, the systems integration teams of incumbent manufacturer/assembler firms maintained product component, task and firm boundaries, but tried to significantly expanded knowledge boundaries and information-sharing in order to acquire knowledge of, and productive capabilities in, the new core systems architecture and high-value complementary product components that offered the potential for differentiation and competitive advantage in order to counteract the threats posed by extreme modularity. For instance, (1) where a product component was perceived as low-value, ex-ante information-sharing was high in order to develop standards, followed by low levels of ex-post information-sharing. In such cases, geographical dispersion was the dominant governance mode for innovative activities. For example, one head of strategy remarked “*it's potentially the sort of simplicity of the components. So, standardised, commodity components, we just outsourced everything. And we probably don't particularly want it to be a differentiator. And so it doesn't get a whole lot of focus. It's almost something we have to have. If you can clearly define something, then who you select to build with is quite straightforward, it’s about capability, at the right price, on time. And, you can collocate or not co-locate for the simple stuff. If it’s a very clearly defined task, go and do it, they can be sitting in Kathmandu as far as I’m concerned, it doesn’t matter”.*

Whereas, where a product component was perceived as high-value (ie, it offered some form of differentiation or potential competitive advantage), high-levels of both ex-ante and ex-post information-sharing were maintained throughout. In such cases, temporary co-location became a dominant governance mode. In other words, the value characteristic of the product component determined the basis of efficient organisation for innovation, misting the ‘knowledge mirror’, reminiscent of Cabigiosu and Camoffo’s (2012) assertion that firms can pursue different information-sharing strategies at the time. One director summed up, “*the team has a more relationship management approach with third-party providers and they are almost like the core team, so it's co-location and it's lots of communication. We have people who go and sit* in *with them and we have people from there come and sit with us, so you can knock down issues, after all, what you find is that when you get clever people together just sitting over a coffee having a chat, they fire off new ideas and create brand new innovation out of nothing. It's more co-creation. If it is complex, it is very difficult to specify. Or you’re creating a differentiated solution, the more you develop things jointly, the more you need to be in the same place and there would be much more oversight, ownership and co-development if the component offered differentiation.* As another respondent summed up, *“I think where we want there to be a differentiating factor, we will work very closely with suppliers, the component that we've outsourced, given that it's probably a) important to us and b) the component knowledge is a separate skill to the core product knowledge. We have then build up a team to specifically look after that component, from our side, in terms of thinking about the innovation of that component, even if it's someone else who actually goes and builds it”.*

2005 is characterised as a further core systems innovation as new upstream entrants entered the product market with a multi-product, multi-component platform systems architecture, with ‘extreme modularity’. The evolution to a multi-product, multi-component platform architecture is accompanied by the evolution of systems integration teams into platform integration teams. In other words, the product architecture moves down a level in the overall systems hierarchy to become, in effect, a component of the platform architecture. Product systems integration teams subsequently become much smaller, and platform integration teams much larger as a result. One director remarked, “*what you saw is the advent of the idea of the platform during this period. So what the platform team was all about was integrating products together, so you retained the product team, typically they got smaller and more specialist in their focus. So the platform team then effectively brought together the components. I suppose what’s happened is this platform team structure emerged and that became the actor in the process that brought it all together. So what happens is the platform team built up its own integration capability, and actually the products were almost quite transactionally handed over to the platform team and they just put them together”*

Whereas from the mid-90s through to 2005, individual product component development teams shared minimal information between them (but high amounts of information-sharing with the system integration team), the emergence of a more technologically-complex platform architecture increases the need for information-sharing across the entire platform system. For example, product component teams needed to share information not only with the platform integration team, but also the product systems integration team, and other product components teams in order to ensure effective integration, despite the presence of standards. Therefore, it is probable that as product complexity increases, the need for information-sharing across the entire system increases. As one director highlighted, information-sharing across the platform architecture is essential such that "we moved to a co-lo*cation partnering model, because we're now in an ambiguous market that .If you’re building new capability that might break new ground in a market, you would look to collocate”. Another suggested that "the team is constructed so it's more relationship management with third-party providers and it's lots of communication, so you can knock down issues”*

**Discussion and conclusion**

Whether mirroring or misting is present at any temporal cross-section seems to depend upon a number of factors at both the product architecture *and* product component level, such as (1) the stylised productive architecture type, (2) the degree of product architecture complexity, (3) whether the product component is integrated or modular, and (4) the degree to which the product component has differentiation or competitive advantage properties. Furthermore, it may also depend upon the empirical target, for instance, any mirroring may occur in respect of the product component boundary, or task activity boundary, or knowledge boundary, or firm boundary. Moreover, how mirroring is measured may also play an important role and different results may be obtained depending upon whether an empirical study examines the information-sharing needs, or the location (including co-location), or the presence or absence of firm co-membership. There is clearly a need for uniformity in further research. A summary of mirroring and misting is shown in Figure 2.

*[Insert figure 2 about here]*

In general terms, the findings show broad support for the proposition that architectural layers may mirror. But the support is not unqualified and a number of contingencies may ‘mist the mirror’. It is possible to assess the mirroring hypothesis through either a ‘weak test’, or via a ‘strong test’. Under a weak test, the findings provide strong support for mirroring. That is, modular product components are associated with task partitioning and outsourcing, whilst integrated product components are associated with task integration and insourcing. Furthermore, modular product components are associated with geographical distance and an absence of firm co-membership, whereas integrated product components are associated with co-location and the presence of firm co-membership. These observations highlight congruence with the simple observation that integrated products are developed by integrated firms, and modular products are developed by specialised firms (ie, Colfer, 2007; Fine, 1998).

In contrast, a strong test of mirroring seeks to further examine the correspondence of knowledge boundaries and the extent of information-sharing between architectural layers. Much of the extant literature assumes that modular product architectures permit knowledge partitioning and hence low-levels of ex-post information-sharing (ie Sanchez & Mahoney, 1996). Here, the evidence is mixed. In the 90s, the ‘simple’ product architecture permitted architectural and product component knowledge to be partitioned providing support for the notion of Sanchez & Mahoney (1996) and Sanchez (2003) that architectural knowledge and product component knowledge can be vertically decoupled.

However, knowledge partitioning could not be sustained across time. The cycles of modular innovation in the mid to late-90s and architectural systems innovation in 2000 eroded the product component knowledge and productive capabilities and necessitated the need for manufacturer/assembler firms to develop systems integration capabilities, resulting in a ‘vertical’ integration of architectural and product component knowledge, and hence high levels of information-sharing with external firms throughout the product development process.

Furthermore, under conditions of an architectural innovation in 2000, manufacturer/assembler firms varied how they organised for innovative activities, depending upon the value characteristics of the product component. With higher levels of product modularity emerging, incumbent manufacturer/assembler recognised the threats posed by commoditisation and imitation (ie Pil & Cohen, 2006) and expanded boundaries in an attempt to create opportunities for differentiation and competitive advantage in an increasingly standardised product market. As a consequence, knowledge integration, high-levels of information-sharing and co-location are associated with high value outsourced modular product components and knowledge partitioning, low-levels of ex-post information-sharing and geographical distance are associated with low value outsourced components. Moreover, the findings indicate that a strong test of mirroring is supported, but only to the extent that the product component is low-value.

Misting occurs to the extent that manufacturer/assembler firms develop and maintain knowledge in high value outsourced product component technologies. The findings further develop the idea of ‘misted’ knowledge boundaries arising from technological newness (Zirpoli and Becker, 2007), fast rates of product component change (Furlan, *et al.,* 2014), and uneven rates of product component change (Brusoni, *et al.,* 2001). In other words, contingencies that ‘mist the mirror’ can be extended to the value characteristics of the product component. In turn, it seems probable that a firm’s strategy, its knowledge endowment, and threats to differentiation and competitive advantage arising from extreme modularity is more likely to determine knowledge boundaries than product component boundaries.

The findings also show how mirroring and misting may both be present *at the same time*. For example, following the architectural innovation in 2000, a weak test of mirroring - product component, task and firm boundaries – is supported. In contrast, a strong test of mirroring – encompassing knowledge boundaries – is unsupported, at least where the product component has high value characteristics. The empirical evidence on the mirroring hypothesis is mixed, and how mirroring is measured may be a possible explanation of the inconsistent results.

Many scholars have also highlighted the role of product complexity in determining the degree of mirroring or misting, as complexity is often associated with unforeseen product component interdependencies (ie, Pil & Cohen, 2006; Zirpoli and Becker, 2007). The findings suggest the degree of product complexity may reach a ‘tipping point’ that necessitates the emergence of systems integration capabilities and hence knowledge integration and high-levels of ex-post information-sharing. For example, in the early to mid-90s the product architecture can be characterised as relatively ‘simple’ and manufacturer/assembler firms relied upon a vertical and horizontal division of architectural and product component knowledge, supporting mirroring. However, the architectural innovations in 2000 and 2005 are associated with a step-change increase in product complexity, owing to the multi-technology explosion of complementary product components that could plug and play into the architecture, and then a widening-out of the product layer to a multi-product platform architecture. As such, increasing product complexity is associated with increasing levels of information-sharing across the entire system, regardless of the degree of system modularity.

**Concluding remarks**

This study has examined the mirroring hypothesis in the context of the UK personal pensions product market highlighting the extent to which mirroring is sustained across time. By charting the correspondence across a 14 year period, the product market appears to have evolved through periods of mirroring and misting at different focal layers. As a consequence, to avoid future inconsistent results, it is evident that there is need for a consistent approach to mirroring in respect of future empirical work, and that further retrospective or longitudinal analysis would be beneficial in order to illuminate the co-evolution and mirroring or misting of architectures across time. Static, cross-sectional studies may run the risk of ignoring temporal delays in aligning task, knowledge and firm boundaries in response to product component change and hence yield results that may be misleading.

The main contribution of this paper has been to add to the contingent perspectives that may ‘mist the mirror’. The paper has shown how mirroring and misting can occur at the same time depending upon whether just the task and firm boundaries are considered as part of the ‘weak test’ of the mirroring hypothesis, or whether the architectural alignment extends to knowledge boundaries as per the ‘strong test’. Furthermore, the paper moved our understanding that misting of the mirroring hypothesis occurs where the product component has high value characteristics. Together, these contributions help provide a more nuanced view of the extent to which product architectures determine task, firm and knowledge architectures. An appreciation of how firm choices around product architectures may, under certain conditions, determine other organising principles is a central component in building a general theory of modularity (Schilling, 2000).

Further opportunities to progress research in this area are likely to be required as part of any general theory of modularity including (1) examining the precise value characteristics of product components in order to better understand how firms organize and manage different product development tasks, (2) examining the performance implications of mirroring or misting, and (3) the emergent perspective on the reverse mirroring hypothesis (ie, Sanchez, Galvin & Bach, 2013) suggests that products may not design organisations, and a reverse direction of causation may be possible. Although Sako (2003) and Fixson and Park (2008) examine the direction of causality in their work, further empirical work is required to unpack the precise paths of mirroring or misting. Invariably such research will require a retrospective or longitudinal perspective given that products, task boundaries and knowledge boundaries do not remain constant over time and may shift towards or away from modular architectures at different points in time.

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Knowledge boundary

Product component boundary

Product component boundary

Task boundary

Task boundary

Knowledge boundary

Firm boundaries

Across-firm

Within-firm

Figure 1: Within- and across-firm correspondence

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Mid-90s to 2000** | **2000-2005** | **2005-2014**  |
| **Product architecture** | **Hybrid (unit-linked)** | **Hybrid (fund supermarket)** | **Platform – open and modular (2005-2012) and Hybrid (2012-2014)** |
| **Product component type** | Some product components partitioned and loosely-coupled, within and across firm boundaries  | Some product components partitioned and loosely-coupled, within and across firm boundaries | Most product components partitioned and loosely-coupled, within and across firm boundaries, some reintegrated  |
| **Task and firm boundaries** | Where product/process components are loosely-coupled, product component, task and firm boundaries are partitioned (support) | Where product/process components are loosely-coupled, product component, task and firm boundaries are partitioned (support) | Where product/process components are loosely-coupled, product component, task and firm boundaries are partitioned (support)  |
| **Knowledge boundaries** | Architectural and product component knowledge held by systems integrator (no support). Product component knowledge held by component teams (support) | Architectural and product component knowledge held by systems integrator (no support). Product component knowledge held by component teams (support) | Architectural and product component knowledge held by platform systems integrator (no support). Product component knowledge held by component teams (support) |
| **Information-sharing (IS)** | Low between component development teams (support), but high with systems integration team (no support) | Low between component development teams (support) and high with systems integration team (no support). In some cases, ex-ante IS replaces ex-post IS (partial) | High between component development teams (no support), and high with platform systems integration team (no support). In some cases, ex-ante IS replaces ex-post IS (partial) |
| **Firm membership** | Integrated components = firm co-membership (support), modular components = no firm co-membership (support) | Integrated components = firm co-membership (support), modular components = no firm co-membership (support) | Integrated components = firm co-membership (support), modular components = no firm co-membership (support) |
| **Location** | Loosely-coupled component teams geographically-dispersed (support) | Geographical dispersion only where product component is loosely-coupled and low value add (partial) | Geographical dispersion only where product component is loosely-coupled and low value add (partial) |

Figure 2: Summary of mirroring