

**Brokerage and Balance: Creating an Effective Organizational Interface for
Product Modularization in Multinational R&D**

Yang Liu *

Management School
Queen's University Belfast
Riddel Hall, 185 Stranmillis Road
Belfast, BT9 5EE, UK
yang_liu2011@yahoo.com

Xingkun Liang

Department of Information Management
Peking University
5 Yiheyuan Road
Beijing, 100871, China
lxk@pku.edu.cn

Yongjiang Shi

Institute for Manufacturing
University of Cambridge
17 Charles Babbage Road
Cambridge, CB3 0FS, UK
ys@eng.cam.ac.uk

* Corresponding author.

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ABSTRACT

Despite numerous studies on modularity, the modularization processes have received less attention. In the global context, product modularity can be leveraged to satisfy heterogeneous market requirements across countries with low costs. Through a longitudinal case study of HomeTech, we examined how multinational R&D created an effective organizational interface to facilitate recombination of its organizational units, and thus product modularization. We found that three elements of an organizational interface were established through a process composed of three phases in HomeTech R&D: regional concentration, establishing a module pool, and creating architecture leader posts. We also found that the three elements exerted the balancing effect and the brokerage effect so that the organizational interface was effective in facilitating recombination of organizational units. We contribute to the literature through showing how organizational modularity can affect product modularity within a firm. We also reveal the critical role of architecture leaders in product modularization. Finally, we enrich the organizational interface concept by highlighting the combination of elements.

Keywords: modularization, organizational interface, new product development, multinational corporations, mirroring hypothesis

1. Introduction

Product modularity has received considerable attention over the years (Baldwin and Clark, 1997; Fixson, 2005; Lau et al., 2011). One important benefit of product modularity is that it can provide product variety for heterogeneous market requirements with component commonality (Robertson and Ulrich, 1998; Ulrich, 1995). While modularity-as-property and modularization-as-process have been clearly differentiated (MacDuffie, 2013), prior studies have mainly focused on modularity-as-property from a rather static perspective (Fixson, 2005; Sanchez and Mahoney, 1996; Zeschky et al., 2014). The product modularization process – how product designs evolve towards higher modularity and the related organizational dynamics – within a firm has received less attention. In many industries, there is no industrial standard for the designs of physical interfaces of components, the benefit being freedom to experiment with product designs without the constraint of the standards (Baldwin and Clark, 1997). In such industries, many firms conduct intra-firm product modularization for competitiveness (Gunzenhauser and Bongulielmi, 2008; Li et al., 2013), but it is quite challenging due to compatibility and coordination issues (MacDuffie, 2013).

Studies have acknowledged the relationship between product modularity and organizational modularity, which is referred to as the mirroring hypothesis (Hoetker, 2006). The predominant argument in this area is that products design organizations – modular products lead to modular organizations (Henderson and Clark, 1990; Sanchez and Mahoney, 1996). However, research also indicates that organizations may design products under certain conditions (Gunzenhauser and Bongulielmi, 2008), which sheds some light on intra-firm product modularization. Through achieving organizational modularity of R&D with

recombination of (loosely coupled) organizational units, physical interfaces can be decoupled and modules made compatible with each other (MacCormack et al., 2012). Such recombination (loose-coupling) of organizational units needs to be facilitated by an effective organizational interface providing opportunities for collaboration (Campagnolo and Camuffo, 2010). However, prior studies could not fully explain this relationship – how an effective organizational interface could facilitate organizational modularization and thus product modularization. A (dynamic) process view is also missing, which hinders our understanding.

We define ‘organizational interface’ as the media or platform (with certain protocols) through which organizational units with boundaries can connect, interact, and coordinate with each other (Brown, 1983; Moenaert and Souder, 1996; Raes et al., 2011). An organizational interface, including tangible and intangible aspects, can be designed to promote interaction and coordination (Brown, 1983). Previous studies have suggested possible elements of an organizational interface, such as forums, electronic databases, and procedures for information exchange (Campagnolo and Camuffo, 2010). However, these studies have not analyzed the combination of elements – the minimum set of elements needed and the sequence of establishing these elements – for creating an effective organizational interface. The combination of elements of an organizational interface can possibly influence organizational modularization and thus product modularization, which needs investigation.

This study explores the *process* of creating an organizational interface for product modularization in the context of globally dispersed R&D centers in a multinational corporation (MNC). Multinational R&D is an ideal context for exploring the organizational interface for product modularization for three reasons. First, multinational R&D needs to

meet heterogeneous market conditions across countries, calling for product modularization (Gunzenhauser and Bongulielmi, 2008; Zeschky et al., 2014). Secondly, dispersed R&D centers and their engineering teams/units (for product components) have clear geographic and functional boundaries, so they may have different objectives, tasks, and habits (Birkinshaw and Morrison, 1995; Mäkelä et al., 2012). Creating an effective organizational interface is challenging but has great potential benefits in this context. Thirdly, previous studies have indicated that one important issue in designing an organizational interface is centralization vs. decentralization (Lei et al., 1996; Wren, 1967). Likewise, centralization-decentralization is important to R&D centers of MNCs, affecting innovation capabilities (Chen et al., 2012; Gassmann and von Zedwitz, 1999).

To fill the research gaps identified above, we set the following research question: *How could multinational R&D create an effective organizational interface to facilitate product modularization (to satisfy heterogeneous requirements across countries)?* To be specific, we aim to examine the process of creating an organizational interface; the key elements; the sequence of creating them; their contributions to the effectiveness of the organizational interface for product modularization. Through a longitudinal case study of HomeTech, we identified a three-phase process creating three key elements of an organizational interface, and we analyzed the effect(s) of each element.

Our findings make three important contributions. First, we advance our understanding of the mirroring hypothesis through a dynamic view showing how organizations could design products. Second, we show the critical role of architecture leaders (ALs) in product modularization. Finally, we enrich the concept of organizational interface by highlighting the

combination of elements which have not been analyzed in prior studies.

2. Theoretical Background

2.1. Product Modularity and Modularization

Product modularity is defined by Ulrich (1995) as a one-to-one mapping from functions to components and decoupled interfaces. Modular products are decomposable into modules (Campagnolo and Camuffo, 2010; Ulrich, 1995) and these modules are interchangeable, which enables mixing-and-matching to build different product variants (Baldwin and Clark, 1997; Schilling, 2000). Modularity can be the open type (industry-level) or the closed type (firm-level) (Fujimoto, 2007; Pil and Cohen, 2006).

Studies on product modularity are abundant. However, most of these studies are static in nature, exploring the antecedents and consequences of product modularity at the firm or industry level (Pil and Cohen, 2006; Schilling, 2000; Worren et al., 2002). As a consequence of the static perspective, many studies have used ‘modularity’ and ‘modularization’ almost interchangeably (Brun and Zorzini, 2009; Doran, 2003; Kotabe et al., 2007; McDermott et al., 2013). MacDuffie (2013) clearly differentiated the two as modularity-as-property and modularization-as-process. The former refers to the design property and the latter reflects a process-based view – how product designs evolve towards higher modularity.

Scholars have identified the importance of understanding the product modularization process. Its complexity lies in the contingencies that can influence the level of product modularity during the process (MacDuffie, 2013; Schilling, 2000). It is quite challenging as it involves not only technical factors, but also organizational factors, such as interactions between different organizational units (Cabigiosu and Camuffo, 2012; Persson and Åhlström,

2006). When decoupling physical interfaces, engineers (working as organizational units) in R&D centers need to understand cross-module interdependencies (Fixson, 2005; MacDuffie, 2013). Coordination and communication are likely to affect the interchangeability or compatibility of product modules (MacDuffie, 2013). However, despite their importance, very few studies have revealed the organizational dynamics and efforts that facilitate product modularization.

While focusing on the effect of the modularity property (i.e. what will happen after a certain level of product modularity is achieved), some studies have shown how clearly defined physical interfaces between modules can serve as an embedded coordination mechanism that reduces the coordination cost for organizational units of R&D (Tiwana, 2008; Zeschky et al., 2014). However, this stream of studies has also indicated that physical interfaces – if not defined by industrial standards – can change over time within firms (Kar et al., 2009; Sanchez and Mahoney, 1996), which requires coordination between organizational units of R&D to realize high product variety and module interchangeability when designing physical interfaces (MacDuffie, 2013). Such flexibility of physical interfaces is desirable as it offers freedom to experiment with product designs for innovation (Baldwin and Clark, 1997; Pil and Cohen, 2006). Therefore, a process view of product modularization is needed to advance our understanding of how the interchangeability of modules can be progressively enhanced as a result of certain organizational changes within firms.

2.2. Product and Organizational Modularity

Studies of the mirroring hypothesis suggest that modular products lead to modular (loosely-coupled) organizations (Hoetker, 2006; Karim, 2006). With clearly defined product

modules and decoupled physical interfaces, organizational units of R&D are loosely coupled allowing concurrent and autonomous activities of designing modules (Cabigiosu and Camuffo, 2012; Furlan et al., 2014; Sanchez and Mahoney, 1996).

However, some studies also indicate that the opposite direction of the effect – modular organizations lead to modular products – may happen when physical interfaces are not defined by industrial standards. Modular (loosely coupled) organizations are characterized by recombination or reconfigurability of organizational units (Galunic and Eisenhardt, 2001; Helfat and Eisenhardt, 2004; Schilling and Steensma, 2001). This provides favorable conditions for decoupling physical interfaces when designing modular products (MacCormack et al., 2012; MacDuffie, 2013). Recombination of organizational units of R&D allows engineers to better address cross-module interdependencies and increase module interchangeability or compatibility through communication (MacDuffie, 2013). However, we still have limited knowledge regarding how recombination of organizational units of R&D – with geographic and functional boundaries (Birkinshaw and Morrison, 1995; MacCormack et al., 2012) – can be promoted over time. A (dynamic) process view could advance our understanding of how to facilitate product modularization through organizational modularization over time.

2.3. Organizational Interface

Organizational interface can be conceptualized broadly as a place where separate worlds intersect (Raes et al., 2011). Organizational units are separate worlds because they have functional or geographic boundaries (Birkinshaw and Morrison, 1995), and each of them has its own interests, activities, and habits (Wren, 1967). However, organizational units can

potentially be connected in some ways (e.g. working with each other) due to task interdependencies in achieving collective or common interests (Andersson and Pedersen, 2010; Wren, 1967). An organizational interface needs to be well designed to promote communication and coordination between organizational units. Organizational interface can also be conceptualized narrowly as the media or platform for communication between organizational units (Jansen et al., 2009; Jansen et al., 2005; Moenaert and Souder, 1996). In support of this, Lei et al. (1996) explored how software systems facilitate communication. Raes et al. (2011) also offered examples of phone calls and written communication as the media.

Through refining previous conceptualizations, we define ‘organizational interface’ as the media or platform with certain protocols to facilitate communication, interaction, and coordination across organizational units with boundaries. Designing an organizational interface includes both the tangible aspect (e.g. tools and people) and the intangible aspect (i.e. protocols of using it) (Campagnolo and Camuffo, 2010; Jansen et al., 2005). Protocols (also called regulatory mechanisms) can specify what organizational units should use the media or platform, when and how to use them for communication, and the objectives of communication. Protocols could influence the relationships between organizational units such as the reporting structure and the decision-making power, because protocols can shape expectations of units (Brown, 1983).

An organizational interface can have different formats, and a firm needs to design its organizational interface to suit its own conditions (Brown, 1983). Previous studies have pointed out possible elements of an organizational interface. These elements include group

meetings (Moenaert and Souder, 1996), liaison personnel (Jansen et al., 2005), Internet-based software (Cabigiosu et al., 2015), and procedures for information exchange (Campagnolo and Camuffo, 2010). However, the conceptual development of organizational interface is incomplete in the literature. We still have limited knowledge regarding the combination of elements – the minimum set of elements and the sequence of creating these elements – for an organizational interface to be effective.

For product modularization, an effective organizational interface is critical for recombination of organizational units, as it maximizes the opportunities for collaboration and communication between all different units (Campagnolo and Camuffo, 2010; Jansen et al., 2009). However, prior studies have not indicated how the combination of elements of an organizational interface can contribute to recombination of organizational units.

One important issue in designing an organizational interface (in terms of protocols) is centralization vs. decentralization of power (Brown, 1983; Lei et al., 1996). To design an organizational interface achieving high power centralization is mainly to design control mechanisms to obtain information from and compliance of lower-level units (Raes et al., 2011). To design an organizational interface achieving high power decentralization is to design self-coordination mechanisms between highly autonomous units, promoting voluntary collaboration for self-interests through negotiation, persuasion, and information exchange (Wren, 1967). More studies are needed to explore how firms could manage centralization-decentralization through leveraging the two mechanisms when designing an organizational interface for product modularization.

2.4. The Context of Multinational R&D

R&D of MNCs provides a good context for studying product modularization and the organizational interface. MNCs operate in the global context. In many industries, MNCs face the challenge of heterogeneous market conditions across countries (Fischer and Behrman, 1979; Kotler, 1986). Under such conditions, the benefits of designing modular products are obvious – MNCs can realize high product variety for different local conditions while maintaining low R&D costs due to module sharing (Bartlett and Ghoshal, 1998; Kar et al., 2009).

The dispersion of organizational units is another characteristic of MNCs. Dispersed R&D centers are beneficial regarding local knowledge access and market proximity (Filippaios et al., 2009; Kurokawa et al., 2007). However, geographic boundaries of organizational units of R&D could diminish communication between them and increase coordination costs (Haas and Cummings, 2015). Within each R&D center, there are different functional units (engineering teams for different components) (Clark and Fujimoto, 1991). The functional boundary exists due to different tasks of engineering teams/units.

Multinational R&D could enjoy the benefits of recombination of organizational units globally, but realizing such recombination is challenging due to geographic and functional boundaries. Also, centralization-decentralization can influence innovation performances of MNCs (Chen et al., 2012). Centralization-decentralization can refer to geographic dispersion or decision-making power (Chen et al., 2012; Chiesa, 1996; von Zedtwitz and Gassmann, 2002), which is likely to affect product modularization in MNCs.

3. Research Methods

The research method is a qualitative, longitudinal, single-case study. We adopted a

qualitative method in order to understand the complex phenomenon. Through theoretical sampling, a single case can be particularly revealing and thus make contributions to the literature (Eisenhardt and Graebner, 2007; Siggelkow, 2007). There has been growth in interest in dynamic phenomena and process studies (Langley, 1999; Langley et al., 2013; Mackay and Chia, 2013; Siggelkow, 2007; van de Ven and Huber, 1990). In process studies, theories are developed from qualitative process data comprised of sequences of events or actions (Langley, 1999). In this study, we adopt the process study approach, and aim to understand how an effective organizational interface has been created over time for product modularization.

Using a theoretical sampling approach, we set the sampling criteria: the MNC (or its business unit) should be in an industry with heterogeneous market requirements across countries/regions, calling for product modularization at the global level; there is no industry-level standard of modularity; the MNC should have globally dispersed R&D and each R&D center should commit to serving its local market; the MNC should be successful in achieving product modularization (more modules shared globally). Based on these criteria, the case of HomeTech (the refrigerator business unit) was selected.

3.1. Research Setting

We focused on R&D of the refrigerator business unit of HomeTech – a home appliance MNC headquartered in Europe – as the research setting to study the organizational interface and product modularization. Meeting our sampling criteria, it provides an ideal and revealing setting to answer the research question. Firstly, for refrigerators, there are evident heterogeneous requirements across countries and regions that call for product variety. Such

heterogeneous requirements include the type, size, style, and regulation of products. For example, in North America, side-by-side and French-door refrigerators are the predominant types while their sales volumes are very low in Europe. Similarly, bottom-freezer and top-freezer refrigerators are very popular in Europe and South America (in bigger sizes), but less so in North America. There are clear benefits of pursuing product modularization in this industry to achieve product variety with shared modules.

Secondly, product modularization remains a great challenge in the home appliance industry. Unlike the computer industry, where the designs of physical interfaces between modules are already well defined by the industrial standards (Baldwin and Clark, 1997), the home appliance industry does not have such an industrial standard (Worren et al., 2002). Firms define the functions and interfaces of components/modules at the firm level. Very often, the physical interfaces need to be changed for innovative product functions and features (Pil and Cohen, 2006).

Thirdly, in HomeTech, there were dispersed R&D centers with different engineering habits. The geographic boundaries of organizational units diminished communication and collaboration across boundaries. Historically, HomeTech acquired companies with R&D centers in different countries. The dispersed R&D centers (in the U.K., Sweden, Italy, Germany, Spain, the U.S., and Brazil) had the capability to develop products for the local market and they were locally autonomous (i.e. decentralized R&D). Different engineering habits formed which made recombination of organizational units difficult. There were also functional boundaries within each R&D center, with each unit focusing on different tasks (e.g. body development, control board development, condenser development, and compressor

development). Recombination of organizational units of R&D at the global level was challenging, but could offer great benefits. Therefore, HomeTech needed an effective organizational interface to facilitate recombination of organizational units of R&D globally.

Finally, HomeTech had been successful in product modularization through creating an organizational interface to facilitate recombination of organizational units of R&D. Initially, the components were specific to local products, so there was no sharing across countries. Through three phases of creating an effective organizational interface, HomeTech achieved modular product designs at the global level. Over 80% of modules (excluding bodies) were interchangeable globally. Product variety was achieved with lower R&D costs. An effective organizational interface facilitated recombination of organizational units of R&D in different new product development (NPD) projects globally. Fig. 1 shows how HomeTech changed from no recombination to low recombination to high recombination of R&D units.

Insert Fig. 1 about here

3.2. Data Collection

Data were collected mainly through semi-structured interviews, supplemented by on-site observation and secondary sources, such as news articles, annual reports, and internal documents. The interviewees were involved in R&D activities and/or the change of the R&D organization. They included different levels of positions (e.g. executives, R&D managers, and engineers), which provided complementary views and mitigated against potential bias. During the interviews, we explored how the R&D organization evolved from 1990 to 2016. We paid attention to changes in the organization, how the changes created an effective organizational interface, and their effects on product modularization at the global level. The

main interview topics included: How did the R&D organization change over the years? Why was the change done in a certain way? What was the NPD process at different times? How did R&D centers communicate/collaborate with each other? How were market requirements handled in product development? How did the change contribute to product modularization? In total, we conducted 20 in-depth interviews with 14 interviewees employed at the company (Table 1 shows a detailed list of the interviewees). Notes were taken during the interviews. All interviews were recorded and transcribed for analysis. We also collected annual reports and news articles from 1990 to 2016 and analyzed the changes in the firm's strategies.

Insert Table 1 about here

We adopted the following measures to ensure the quality of the study. Whenever possible, we checked company documents, management tools, and other data sources to achieve data triangulation (Eisenhardt, 1989; Yin, 2009). We also cross-checked the responses across interviewees to mitigate against potential bias. We used member check as well (Lobo and Whyte, 2017; Nag et al., 2007). On the company site, we did a presentation summarizing the information gained and our understanding of the relevant issues and asked for feedback. At the end of the study, we wrote a case report detailing the process of creating an organizational interface for product modularization in HomeTech and other research findings, and then sent it to the company for review and feedback.

3.3. Data Analysis

We first described the series of actions in HomeTech and then analyzed these actions (Miles and Huberman, 1994) using the 'temporal bracketing strategy' (Langley, 1999). Overall, we conducted data analysis in three stages which is iterative. First, we constructed a

‘thick description’ (Smith, 2014) of the case, detailing what happened in the company and the R&D organization in the period from 1990 to 2016. In this stage, we tracked the corporate strategy, R&D organizational structure, R&D activities, and product portfolio and identified key events or actions.

Second, we focused on phases and periods of change over time. We conducted an analysis with respect to the influence of these events or actions on the organizational interface and product modularization. We refined the process of actions focusing on those that are related to the organizational interface or product modularization. Then, we identified three phases of creating an organizational interface based on discontinuities in the events or actions (Langley, 1999). We also discovered how events or actions in one phase influenced those in the subsequent phase(s) and found errors, dead-ends, and alternatives along the way.

Next, we focused on explanations and causality (Miles and Huberman, 1994). We analyzed what the three phases mean for an organizational interface, and how they facilitated recombination of the R&D units globally. Three elements emerged at this stage (i.e. a moderation number of organizational units, a module pool, and architecture leaders). Through reviewing the interview data, we analyzed the relationships between the three elements and the sequence of creating them. We further analyzed how the element(s) could affect recombination in each phase, and identified balancing and brokerage effects of these elements. We compared between these effects in order to clarify their differences. In this stage, we went back and forth between the data, the findings, and the literature to refine our findings (Eisenhardt, 1989; Lok and De Rond, 2013). The field notes, transcripts and other data were revisited when new insights emerged (Bresman, 2013).

4. Findings: The Process of Creating an Organizational Interface for Product

Modularization in Home Tech

Over two and a half decades, HomeTech underwent a process that composed of three phases in an effort to create an effective organizational interface for organizational units of R&D. These efforts enhanced product modularity overall. The first phase (1992-2009) shows concentration of regional R&D resources. The second phase (2009-2012) captures the creation of a web-based module pool. The third phase (2012-2016) captures the creation of the architecture leader positions to coordinate product development across regions. The three phases are related to three elements of the organizational interface. The module pool and architecture leaders denote the media or platform for communication. A moderate number of organizational units of R&D and relevant policies of module pool and architecture leaders denote protocols of using the media or platform. Fig. 2 shows the details of the three elements.

Insert Fig. 2 about here

The organizational interface facilitated recombination of organizational units of R&D (and thus product modularization) through the balancing effect and the brokerage effect. Balancing refers to achieving a balance between centralization and decentralization in terms of geographic dispersion and decision making. Brokerage means connecting different parties that are otherwise not connected (Fleming and Waguespack, 2007). Table 2 explains in detail the effect(s) of each element on enhancing organizational modularity. Detailed findings are elaborated next.

Insert Table 2 about here

4.1. Phase 1: Regional Concentration of R&D Resources

In the early 1990s, the R&D centers of HomeTech were widely dispersed and autonomous. The first phase of the change was to concentrate the R&D resources in one location in each region. This happened in Europe and North America. In South America, since the Brazilian R&D center was the only one, there was no need to change. The result was that eight R&D centers were reduced to three, one in each geographic region.

4.1.1. Concentration in Europe and North America

In Europe, HomeTech owned factories with R&D centers in Italy, Spain, Sweden, Germany, and the U.K. The five R&D centers operated autonomously. Each of them had the capability to develop a whole product and mainly considered the local market requirements in product development. These R&D centers rarely communicated with each other. Each center developed its own products without sharing components with the other centers. An R&D manager in HomeTech explained the situation with examples:

The focus of the R&D here was to develop parts for the two factories in Italy. The [Italian] R&D was only for Italy ... Sweden had a private R&D in the past ... They were independent.

Starting from 1992, the Italian R&D center was designated by the company headquarters as the regional center for the European market. Then the process began of concentrating R&D resources in that center. A product director described the aim as “to put everything under the same roof.” Instead of closing the other four R&D centers directly, the company conducted the change gradually so as not to disrupt operations. The Italian center became bigger while

the other four centers were reduced over the years, as described by an R&D manager in Italy:

We increased, they reduced, gradually ... it was not easy to find people that moved from other countries to here easily, so we had [the number of] people growing here, the people that stayed there left the company.

In 2009, the concentration of R&D resources was largely completed in Europe. The Italian center became responsible for developing products for the whole of Europe. The other four centers lost the capability to develop products. An R&D manager explained their roles:

They [the other four centers] moved from development to applications [production], so they developed, in the past, the drawer, now they are not developing anymore, but they are asking to have the drawer from here [Italian R&D].

In North America, R&D resources in two independent R&D centers in the U.S. were concentrated in one center by the mid-2000s. The process was similar to Europe.

After regional concentration, three R&D centers (in Italy, the U.S., and Brazil) existed globally. Each R&D center focused on serving the regional market by developing the specific products needed. These R&D centers did not report to each other and communication was rare.

4.1.2. The Balancing Effect of Regional Concentration

Upon completion of regional concentration, recombination of organizational units of R&D at the global level was not yet realized. However, through regional concentration, an important element of the effective organizational interface – a moderate number of organizational units developing products for three regions – was formed. This element functioned as part of protocols of the organizational interface regarding which organizational units could use the module pool and architecture leaders created later. It exerted a balancing effect (in terms of geographic centralization and decentralization) contributing to

recombination of organizational units of R&D which happened later. This is because HomeTech reduced *duplication* through some degree of geographic centralization while maintaining the *product variety* through some degree of geographic decentralization.

Before regional concentration, there were eight R&D centers in three regions. High geographic decentralization characterized by a large number of organizational units of R&D can aggravate duplication (Chen et al., 2012). High duplication could greatly enhance the cost of using the module pool and architecture leaders. With eight R&D centers instead of three, all eight R&D centers could design modules with different knowledge and habits, causing more modules of duplicated efforts in the module pool. A project manager explained how a very long list of modules could affect the efficiency of using the module pool (to facilitate recombination):

If there are too many modules there, it can be a distraction, and we would use the [module pool] system less when developing products. There is a lot of information for each module, and it takes time to understand its technology, features, and versions.

Therefore, HomeTech conducted regional concentration to reduce duplication. The number of R&D centers was reduced from eight to three. Although not yet eliminated, duplication was significantly reduced (in the next two phases, duplication was further reduced).

The result of regional concentration was one R&D center in each region, with clear responsibilities of developing products for its region. This is because market requirements were similar within regions, but very different across regions. Locating an R&D center in each region ensured that local market requirements were well attended to. With high geographic centralization (e.g. R&D concentrated in one center globally), the product variety

(for customers) would be lowered, which could diminish the necessity for recombination. An R&D manager explained why HomeTech did not pursue high geographic centralization:

We need some flexibility ... In our industry, there are benefits of having R&D centers focusing on local markets, and duplication can be mitigated through international collaboration. They [R&D centers in three regions] are committed to serving local markets. That drives variety, and that is important for modularization.

Therefore, a moderate number of organizational units developing for three regions, with the balancing effect, became one essential element (as part of protocols) of an effective organizational interface.

4.1.3. Errors, Dead-ends, and Alternatives

With regional concentration, there was still no recombination of organizational units of R&D globally. As a consequence, physical interfaces were not able to be decoupled, so product components were not yet interchangeable at the global level. An important reason of this is lack of communication across R&D centers. Without communication, organizational units could not find collaboration opportunities beyond regions (thus achieving recombination globally). HomeTech tried to facilitate cross-border collaboration and a telephone list was provided to everybody, but there was still very little communication across R&D centers. An R&D manager explained the difficulty:

We didn't communicate [at that time] because we are in different regions. Think about it. Colleagues are very far away with time difference ... Product development is a very technical thing, not likely to be crystal clear with one telephone call.

The company had considered alternatives regarding how to move forward. For example, one option was to further concentrate R&D resources in one global R&D center. In HomeTech, this was deemed as undesirable both practically and strategically. An R&D

manager explained why it was undesirable practically:

When you centralize [concentrate], you can get some of them [R&D employees], not all, this for a company is a problem because you are losing knowledge ... the company tried to move [people], only [a] few [people] said to move.

Strategically, global concentration was not desirable due to the importance of (centralization-decentralization) balancing of geographic dispersion, as mentioned in section 4.1.2.

Another option was to introduce a hierarchy of R&D centers, assign an R&D headquarters, and make other two centers report to the R&D headquarters. Again, it is strategically undesirable as it would lead to tightly coupled organizational units which were likely to develop more integral products (MacCormack et al., 2012) and reduce product variety. One executive mentioned: “One of our competitive advantages is being locally responsive, and we want to maintain that.”

Under this situation, HomeTech experienced a dead-end in a sense that the firm was not able to further conduct the structural change (in terms of dispersion or power). Therefore, the firm needed to shift the focus and create a new element of the organizational interface. Then, the company chose to maintain the structure of three R&D centers, but established a web-based module pool (as Phase 2) to address the issue of communication for recombination.

4.2. Phase 2: Establishing a Web-based Module Pool

With R&D resources concentrated at the regional level, in 2009 HomeTech started to introduce a web-based module pool. Modules were clearly defined and developed. Relevant policies (i.e. protocols of the organizational interface) were also established to manage the

use of the pool.

4.2.1. Defining Modules and Shifting the Mindset

In 2009, HomeTech started to define modules and then developed the modules for its refrigerators. Electronic modules (e.g. the main control boards, power supply boards, and user interfaces) and mechanical modules (e.g. compressors, condensers, and chassis) were defined.

The components, such as the control board, existed before but “they were not defined as modules previously” according to an R&D manager. Formally defining them as modules denoted a change in the mindset that a component was not for a specific product locally but for sharing across products globally. Essentially, this was a change of the term from “component” to “module” to foster sharing of components globally. The R&D manager noted that they defined modules in order to “have really exchangeable modules from one country to another.” An engineer noted the changed mindset: “With modularization, we are able to have shared knowledge, shared work, and also have as much as possible standardization.” Therefore, each module came with detailed documents describing the design parameters and physical interfaces, which were helpful for information exchange and module reuse.

Previously, a control board was designed and used for one product only.

4.2.2. Creating a Web-based Module Pool

A web-based module pool (or a module management system) was established in order to store and share the developed modules. The module pool could be accessed through HomeTech’s encrypted internal network. Every R&D employee had an account and password to access the module pool. The R&D centers were required to put any modules they

developed into the pool. It contained detailed information about each module, including a bill of materials, qualifications, schematics, specifications, and insertion reports. An engineer noted:

We have a system shared globally by VPN [virtual private network] on the servers, and you can find the modules developed by them [engineers]. They updated the list with the log file, so improvements, with comments.

This online module pool was built to promote the visibility of any developed modules with detailed documents to the three R&D centers so that “everybody that needs [to develop] a new product comes and takes [modules for reuse],” according to an R&D manager.

4.2.3. Policies of Module Use

As an important part of protocols of the organizational interface, policies were established regarding how to use the web-based module pool to develop new products. R&D centers could no longer develop new modules at will. In a product development project, the new workflow required project managers (focusing on architectural designs for their regions) and engineers (focusing on component designs) to check the module pool and reuse any modules that were suitable, as stated by an engineer:

I will show you what the workflow is now ... If on the shelf [the module pool], we already have valuable modules, means also boards, means the door, that are ready, that are fitting the requirements, we use that.

However, often the modules needed modifications for new products to realize new features (and sometimes modifications cannot work, so a new module must be developed; see details in section 4.2.5). The engineering team leader who created a module would be identified in the pool as the contact person for this module. When the module was needed by any one region, he/she would be contacted (through the module pool system) for necessary

modifications. An engineer mentioned an example:

They [a North American team] were managing the board, [the board] started regionally, became global [for products] ... We asked them to modify the board for our use.

There was also a requirement for a certain percentage of modules in the pool to be used in NPD projects. According to an R&D manager, the policy suggested that a project “has to have 80% of the green module [modules from the pool]” for the interior components (i.e. excluding bodies) of refrigerators. Any projects below this level would be flagged and reviewed by headquarters.

During the review meeting, project managers and engineers would justify the necessity of developing more new modules than expected for successful products. Senior managers in headquarters would remain as challengers, but in the end, they would approve projects below the 80% threshold if they were well justified.

4.2.4. The Balancing Effect of the Module Pool

The web-based module pool with relevant policies/protocols (see section 4.2.3) denotes balancing of the decision-making power. Power was to some extent centralized as all R&D centers were required to use the module pool in NPD projects as part of the standard process/protocols. Another aspect of power centralization was the 80% rule of module adoption. In other words, R&D centers could no longer develop any modules at will and they must follow protocols set by headquarters. However, there was also the aspect of decentralization as the 80% rule could be waived by high-level management in headquarters if NPD project managers and engineers could justify the necessity of developing more new modules than expected. They still had some freedom.

Such power balancing contributed to recombination of R&D units at the global level.

Prior studies indicate that for highly decentralized R&D, local independence can impede coordination across borders (Chen et al., 2012; Gerybadze and Reger, 1999) which is critical for decoupling of physical interfaces and module sharing. In HomeTech, high power decentralization could lead to each R&D center maintaining the old habits of developing the whole products without checking the module pool (nor cooperating with architecture leaders later). Therefore, R&D centers could not identify modules to share, and recombination would be impossible. An R&D manager explained the tendency of following the old habits:

So we preferred to use what we already knew, developed in the past, to apply the past solutions in the new product ... We were not used to going inside the basket to see what was available, because [many modules] were different compared to what we did in the past.

Prior studies also indicate that for highly centralized R&D, organizational units are tightly coupled, having less motivation to decouple physical interfaces for modular products (MacCormack et al., 2012). An organizational interface with rigid control is less likely to cause recombination of organizational units due to its emphasis on efficiency (Bartlett and Ghoshal, 1998; Gassmann and von Zedwitz, 1999). In HomeTech, high power centralization could lead to high-level management simply rejecting/stopping any project proposals below the 80% threshold for efficiency, which could block recombination opportunities. Rejecting all these project proposals could deprive R&D centers of freedom and flexibility to combine modules for local requirements. Therefore, R&D centers would stick to only a few “model designs” to pass the 80% rule according to a project manager, undermining recombination and innovation. An executive explained: “R&D centers should have some freedom, as they

are committed to serving local markets.”

4.2.5. The Brokerage Effect of the Module Pool

In this phase, the web-based module pool as an element of the organizational interface had some brokerage effect (i.e. connecting otherwise unconnected three R&D centers), but the effect was low due to some limitations.

In HomeTech, the module pool had some brokerage effect as it linked three R&D centers (which otherwise cannot be connected) to find opportunities for module sharing, and it facilitated recombination of organizational units to some extent. A project manager in Italy recalled a project: “On the shelf, we found an interesting module [compressor] developed by the U.S. and then the collaboration began.” Through the modules (with detailed documents of designs and functions) in the pool, different R&D centers had the information flow to find common interests of certain modules to collaborate in NPD projects. An R&D manager said:

We need a common language, so [there are] different facilities, and the common language is the module, because the module is the defined area that we use to deliver projects to the other factories.

However, recombination was lower than expected as shown in Fig. 1(b) because of the low brokerage effect of the module pool. This was because, with the module pool, the information flow was too late for each module, so that the information exchange was not sufficient. The modules in the pool were the completed designs, but the project managers and engineers did not have the access to any information in the module design process (which is a critical stage for decoupling the physical interfaces) in other R&D centers.

Each R&D center possessed different knowledge and had different engineering habits, which influenced module designs in some way, as an R&D manager noted:

If we have a different R&D, we have also different experience, so everybody wants to develop in a different way.

R&D centers did not take into account the requirements in other regions. This reduced module compatibility. Sometimes, this cannot even be fixed through late modification. An engineer offered an example of the board size in a project:

North America used to have big boards, and it is very difficult to reduce the size ... The micro-processor must be smaller, SMD components must be used instead of PTH ... It did not fit the [board] case in our products.

However, the module pool was essential for architecture leaders (created later) to perform their tasks. An AL mentioned that he needed to “fully leverage the module designs in the pool” to complete his tasks. The modules in the pool served as part of their memory system to perform the brokerage tasks. With this handy tool, ALs could better utilize existing modules when designing the architecture. This tool was also useful when discussing with project managers and engineers.

4.2.6. Errors, Dead-ends, and Alternatives

With the use of the module pool, module sharing was still far below expectations. It was quite common for the projects to fall below the 80% threshold set by the policy. Most of the time, as mentioned in section 4.2.4, headquarters had to approve the projects as project managers and engineers argued with evidence (such as the board size issue mentioned above) that it was not their fault that more new modules had been developed than expected. Many modules in the pool were not suitable as their physical interfaces could no longer be properly decoupled.

Regarding how to move forward, HomeTech considered several options. One option was

to tighten the rule of 80% as the percentage of modules to use in the pool, and to reject more project proposals below that level. However, tightening the rule would break the power balance important for recombination, as analyzed in Section 4.2.4.

Another option was to encourage engineers to communicate across regions when developing any modules. However, the engineers did not usually know the right persons to talk to. An engineer explained why they opposed to this idea:

As we didn't work together at that time, we had no idea whom to talk to. We also had no idea what they were doing.

With nobody responsible for facilitating such communication, the brokerage effect was low. Encountering another dead-end (i.e. the firm not able to further enhance modularity through this element of the organizational interface), HomeTech decided to move on and create a new element of the organizational interface.

Besides the communication issue, one important issue was that power balancing was not achieved for making the architectural/system-level designs. Regional project managers who designed the product systems were not assigned global responsibility. An R&D manager explained:

It used to be that project managers in each region had total freedom of designing the systems of products ... so they designed in different ways with different habits.

HomeTech figured out that the next step should be to “leverage persons with such architectural design capability to bridge the three R&D centers” according to an executive. Therefore, HomeTech entered Phase 3.

4.3. Phase 3: Creating the Architecture Leader Positions

In 2012, HomeTech created a new kind of positions – architecture leader – with global

responsibility for suggesting architectural designs and coordinating NPD of certain types of products. ALs, through leveraging the web-based module pool, bridged R&D centers for module development and usage.

4.3.1. Definition and Selection of Architecture Leaders

HomeTech created AL positions with respect to the different types of products (i.e. bottom-freezer, top-freezer, side-by-side, French-door, and single-door). In total, there were five architecture leaders based in different regions. However, location did not matter as ALs were global positions. They reported to headquarters directly, not to an R&D center. An AL mentioned that the purpose of creating the AL position was to “support the execution of modularization ... while ensuring product variety [at the global level].” ALs had global responsibility for coordinating product development for that type by suggesting architectural (system-level) designs of new products and connecting different NPD projects in different regions for module sharing. As AL was a demanding job, it was specialized in one type of refrigerators, but different ALs maintained communication for better module sharing.

The ALs were chosen based on the expertise of designing specific types of refrigerators and a global view. For expertise, ALs needed to have extensive experience as NPD project managers who had a system view of products, rather than focused on a component/module. A system view was essential for making the architectural designs to connect the three R&D centers. An engineer explained the career route to an AL:

[ALs are] people that started to work in the technology domain, any domain, then they started to work on the system, so application engineer [project manager]; they can understand from a wide perspective of the products.

In addition, he/she should be knowledgeable about the functions and designs of modules

in the pool to be able to communicate with NPD project managers and engineers and to suggest the system-level designs of products. Sound technical knowledge was essential for ALs to have analogic thinking – detecting non-obvious similarities of different problems so as to adopt same solutions (Hargadon, 1998). In this way, ALs could find common modules to share for different projects in different R&D centers.

Additionally, ALs should have a global view in order to effectively work with colleagues all over the world. An engineer noted: “Architecture leaders, even if sitting here, should understand different conditions in different regions.” This global view would be important for maintaining a neutral position needed by an AL to earn the trust (Klerkx and Leeuwis, 2009), understand different engineering habits, and communicate with different R&D centers effectively.

4.3.2. Responsibilities of Architecture Leaders

The ALs’ main responsibilities were to make preliminary architectural designs for a certain type of refrigerators based on each R&D center’s objectives, discuss the architectural designs with NPD project managers and engineers in all R&D centers, and identify module sharing opportunities from an early stage of NPD. Being knowledgeable and having a global view helped them communicate effectively. ALs of different product types also discussed module sharing with each other (details in section 4.3.4).

The NPD projects were still operated and managed in different regional R&D centers due to the heterogeneous market requirements across regions (i.e. R&D centers were serving their own regions), but protocols of the organizational interface required them to contact an AL before project initiation. ALs linked and coordinated these projects by suggesting

architectural designs (i.e. brokerage effect) from an early stage. When making preliminary architectural designs, ALs needed to know and respect each R&D center's objectives. An AL expressed how to identify common modules when doing architectural designs:

Each region has those things that are unique ... you have to fit in certain boundaries ... there will be certain constraints based on the global modular design that we'll have to adhere to.

ALs also needed to discuss the architectural designs with different R&D centers and decide together. An engineer gave an example of how an AL communicated with R&D centers:

He [an AL] is speaking with domain leaders [module engineering team leaders] ... suggesting proper solutions ... North America the system engineer [project manager], these are the people that he is able to [get] together to say: 'Yes, I put that compressor together with that power board.'

Also, ALs were responsible for NPD projects throughout the whole processes. ALs were involved in all relevant projects to ensure the interchangeability of modules. ALs did not simply specify the module interfaces at an early stage of NPD, but first identified module sharing opportunities, and then gradually decoupled the interfaces in NPD projects through discussions with engineers and project managers. ALs were involved in NPD projects for the whole processes to ensure well decoupling of physical interfaces. An engineer noted: "We keep communication with the architecture leader in our projects to get feedback on the module design."

4.3.3. The Balancing Effect of Architecture Leaders

The ALs as an element of the organizational interface had power balancing. As a part of protocols of the organizational interface, R&D centers were required to contact an AL before

any NPD project was initiated, which reflects some degree of centralization. An R&D manager offered an example: “So every R&D center that has a request to have a new bottom-mount, they have to call this guy [bottom-freezer AL] ...” However, according to protocols, ALs needed to decide together with NPD project managers and engineers for the system-level designs and module sharing, which reflects some degree of decentralization. An AL explained his interaction with R&D centers:

I make a plan for the architectures [system-level designs] of new products [considering projects in all regions], and I present my plan to R&D centers ... I discuss with them and we may change the plan.

Power balancing contributed to recombination of organizational units of R&D. ALs possessed information of relevant projects in other regions. The requirement to contact an AL ensured more module sharing opportunities were spotted early on, as a module may not be able to be shared once the design was complete and put in the module pool. Without such a requirement, each R&D center could maintain the old habit of developing products without discussing with ALs, thus losing the opportunities for module sharing and recombination.

Regional NPD project managers and engineers still had power in determining the function, feature, and modules of the products. This is because ALs with unquestioned authority on architectural designs could diminish the flexibility of product designs and overlook local requirements. A project manager in the U.S. noted: “We know the local market ... We have served the North American market for many, many years.” With the unquestioned authority of ALs, organizational units of R&D could be more tightly coupled to implement the ALs’ designs with less product variety, thus losing many recombination opportunities.

4.3.4. The Brokerage Effect of Architecture Leaders

ALs as a critical element of the organizational interface also exerted the brokerage effect, contributing to high recombination of organizational units of R&D as shown in Fig. 1(c). ALs served as a bridge connecting three R&D centers which were not well connected before.

ALs, through using the web-based module pool, realized effective early communication in module development across R&D centers in different regions, which could not be achieved through the module pool alone. As ALs were involved from an early stage of NPD, they were aware of all ongoing and potential projects in all regions. ALs were in the best position to find opportunities for module sharing through linking projects' requirements and modules. An engineer noted:

So the architecture leader is the person aware of ... capabilities in HomeTech, meaning people, skills, and also modules that he can use to build up the appliance.

ALs made preliminary architectural designs based on each R&D center's objectives and discussed the designs with R&D centers. The preliminary architectural designs contained module sharing opportunities across regions (quotes in section 4.3.2). Through discussing with R&D centers, ALs decided together with project managers and engineers on architectural designs and how modules would be shared (quotes in section 4.3.2), based on which organizational units of R&D were recombined for different projects. The architectural designs may be modified and discussed again.

Due to high recombination, modules were developed by different R&D centers within a single NPD project. As collaborating organizational units were in different regions, module compatibility (interface decoupling) was a challenge. This is because module interfaces could

be affected by uncertainty and unexpected problems (Cabigiosu and Camuffo, 2012), and different engineering habits across regions. Another important task of brokerage was to facilitate communication across regions in the whole NPD process to ensure physical interfaces were well decoupled (i.e. good compatibility of modules). ALs performed this task through communicating all regional requirements for the module interface designs. An engineer explained:

The regional inputs are very important ... we try to agree with the [other] regions ... a common solution.

ALs' communication was also very helpful for overcoming the challenges of different operations, knowledge, and engineering habits across R&D centers. An R&D manager stated:

... in the past, there were different approaches, and was linked to the region ... if the top-mount is one [approach from one person], we can achieve really better optimization of the module.

For even better information sharing, ALs of different product types maintained frequent communication with each other through regular meetings, as formally required by HomeTech, to discuss and find common technical solutions across product types for better module sharing. This promoted the transparency of ongoing NPD projects for different product types and mitigated the differences in knowledge and engineering habits between these ALs. As a result, the modules could even fit different types of products. An R&D manager explained:

The secret is always to talk, to share ... top-mount [AL] talks more with bottom-mount [AL], with French-door architecture leader, they can also share solutions.

5. Discussion

Through a case study of HomeTech, we examined a process of creating an effective

organizational interface for product modularization in the context of multinational R&D with no industrial standard on modularity. Our findings contribute to the literature in three ways as elaborated next.

5.1. Mirroring Hypothesis as a Process

Enlightened by the mirroring hypothesis, we explored product modularization by focusing on the relationship between organizations and products. However, most studies of the mirroring hypothesis mainly adopted a static view and focused on the mirroring relationship without revealing complex organizational dynamics. In contrast, this study focuses on the process of mirroring – how products become more modular as organizational modularity is gradually enhanced (due to a more effective organizational interface). The process denotes significant organizational efforts with errors, dead-ends, and alternatives along the way, which were not revealed in prior studies (see Fig. 3 for more details).

Insert Fig. 3 about here

In contrast to the majority of studies of the mirroring hypothesis indicating that products design organizations (Hoetker, 2006; Karim, 2006; Sanchez and Mahoney, 1996), this study shows that organizations can design products. We argue that which relationship holds depends on the specific aspect of product designs (a product feature or physical interfaces) in question. For the aspect determined by the industry – a feature required by industrial standards (Hoetker, 2006) or becoming an industrial trend like a dominant design (Henderson and Clark, 1990) – firms need to change organizational designs accordingly to survive or become more competitive (so products design organizations). In contrast, for the aspect

determined by each firm (e.g. physical interfaces in the home appliance industry, as shown in this study), a firm has the freedom to provide a certain feature. The firm will make a certain organizational design to produce products with the feature (thus organizations design products). Therefore, both relationships may exist for a whole product. However, for modularity (or physical interfaces) as one specific aspect of product designs, one relationship is predominant.

Brusoni and Prencipe (2006) conducted a case study of production process technology modularization in a tires company. Our findings (about product modularization) are consistent with that paper in a sense that the organizational design could influence modularization of products or production, and both studies demonstrate a dynamic (process) view of modularization. However, our study is different in that it has a geographic dimension – we focused on relationships between R&D centers serving different regions and highlighted the role of the organizational interface (see section 5.3 for detailed discussion), while Brusoni and Prencipe (2006) focused on relationships between different design processes and highlighted integration of the organization.

5.2. The Critical Role of Architecture Leaders

In this study, we found that ALs played a critical role in product modularization in HomeTech, which has not been reported in the modularity/modularization literature. ALs bridged organizational units of R&D with different objectives and engineering habits. Through the information flow, they helped to identify module sharing opportunities and decouple physical interfaces in NPD projects.

Over time, organizational units of R&D relied less on ALs for bridging cognitive gaps

(e.g. different engineering habits/norms) due to learning and changing engineering habits/norms. However, their reliance on ALs for bridging information gaps remained significant due to heterogeneous market requirements, different technological breakthroughs, and the structural holes across three R&D centers. It is also due to the adjustment of physical interfaces in the process of module development, which needed to be coordinated by ALs who possessed key information. Therefore, over time, ALs' brokerage role may diminish slightly (due to smaller cognitive gaps) but will remain significant (due to constant information gaps), which reflects sustained *iungens* (Obstfeld, 2005).

Prior studies have analyzed the role of systems integrators in coordinating a network of companies in industries (Brusoni and Prencipe, 2001, 2011). We found that while both system integrators and ALs have coordination roles and extensive system knowledge, they have some differences. System integrators have more power than ALs. They can configure the network of firms (e.g. removing a supplier) (Brusoni et al., 2001), whereas ALs cannot alter organizational units. System integrators exist because, for complex products, firms cannot maintain activities and knowledge of all components in-house (Brusoni et al., 2001), but they usually design a certain percentage of components in addition to defining the system (Brusoni and Prencipe, 2001). ALs were created not to design components, but to help project managers to find common modules and offer input to engineers who design components.

5.3. Organizational Interface

In this study, we show how multinational R&D created an effective organizational interface for product modularization. Prior studies have pointed out different elements of an organizational interface (Cabigiosu et al., 2015; Campagnolo and Camuffo, 2010; Jansen et

al., 2005; Moenaert and Souder, 1996), but have not sufficiently explored the combination of elements in forming an effective organizational interface (the minimum set and the sequence). Through studying the combination, we contribute through enriching the concept of organizational interface.

Our findings suggest that for an organizational interface to be effective, a minimum set of combined elements is needed. This is because an effective organizational interface must have multiple features – efficiency of using (Geyer and Davies, 2000), sufficient information exchange (Wren, 1967), and reconciliation of goals and habits through negotiation (Lobo and Whyte, 2017; Raes et al., 2011). One single element may not be able to realize all these features. Therefore, a firm is likely to need a set of elements to realize these features. In this study, three elements were a minimum set to realize these features (for product modularization through balancing and brokerage). A feature may require two or more elements to achieve and an element may also contribute to two or more features.

This study indicates that a firm is likely to follow a certain sequence for creating elements of an organizational interface for a smooth process. This is because one element may serve as the foundation of the other element(s), so that the other element(s) can serve the purpose. In other words, one element may influence the other(s), but such influence is likely to be one-way. For example, a moderate number of organizational units developing products for three regions (element 1) can influence the function of the module pool (element 2), making the module pool meaningful, but not the opposite. Without element 1, element 2 can hardly serve the purpose of facilitating recombination. With the cost of maintaining element 2 and no clear effect, it is likely that this element will be removed (causing shifting back). The

same is true for element 2 and 3. A firm is likely to follow the sequence based on such relationships between elements to have a smooth process and avoid shifting back.

6. Conclusions

We show that the multinational R&D organization of HomeTech went through three phases to create an effective organizational interface for product modularization – regional concentration of R&D resources, establishing a web-based module pool, and creating the architecture leader positions. These denote three elements as a minimum set for an effective organizational interface. The three elements exerted balancing and brokerage effects, which facilitated recombination of organizational units of R&D and modular product designs globally. These three elements were created in a certain sequence which shows that one element serves as the foundation of the other element(s), which have not been revealed in prior studies.

Our findings could draw implications for managers in multinational R&D organizations. To achieve a high level of product modularity for heterogeneous market requirements across countries, managers need to create an effective organizational interface for dispersed R&D centers. However, the process of creating an effective organizational interface can be complicated by issues of the number of elements, the sequence of creating them, and unexpected problems. While the trial-and-error approach is inevitable, managers could do the following analysis to make the process as smooth as possible. They could first list any possible elements which can exert (geographic and power) balancing and/or brokerage effects. Then they could map out the relationships between every two elements to determine possible sequences of creating the elements. Next, managers could figure out possible paths of the

change and analyze the strengths and weaknesses of each path. The analysis should be iterative. With more information available in the process, managers should repeat the analysis. Visual tools may be developed in companies to assist the analysis.

There are some limitations to this study that could be addressed by future research. This study adopted the single-case study approach and examined the organizational interface in a specific and revealing context that HomeTech provides. To explore to what extent the findings are generalizable, more case studies could be done in different contexts (i.e. different firms or industries). Future studies could explore to what extent our findings of the minimum set of elements, the sequence of creating them, and the (balancing and brokerage) effects can be generalized to different contexts. Besides, we examined a company which had high geographic and power decentralization as a starting point. Future studies could also investigate companies with high centralization as a starting point to see to what extent our findings hold and whether there are different challenges.

In addition, this study focuses on the role of the R&D department in facilitating product modularization. Future studies could explore the role of other functions (such as marketing and production) and their influence on product modularization. With the challenges of communication between R&D, marketing, and production departments due to different objectives and knowledge, it would be interesting to explore how other departments can facilitate or hinder product modularization.

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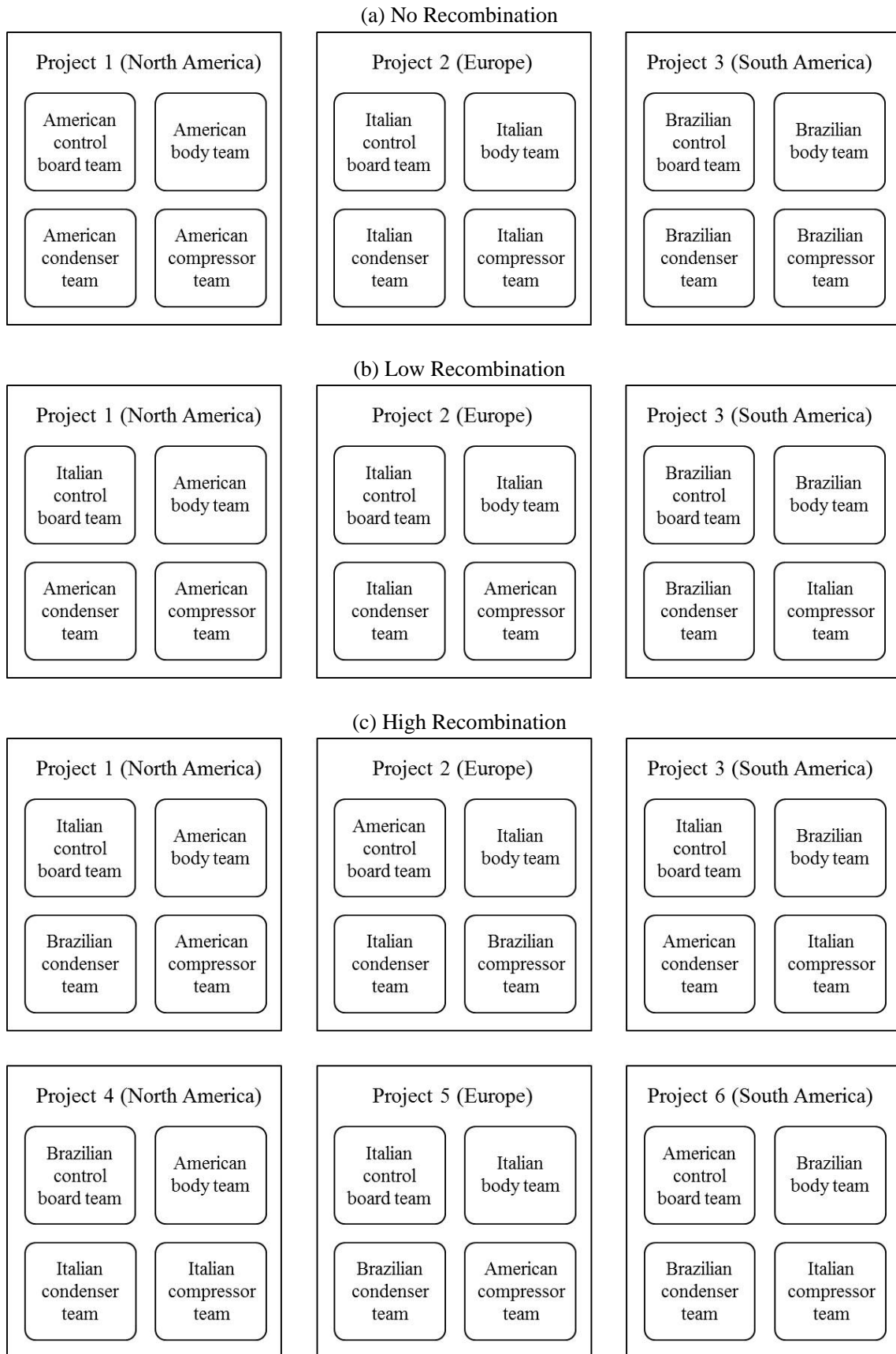
Table 1 Interviewees at HomeTech

Interviewee No.	Position	Key Job Responsibility	Interview Duration
1	Executive (VP R&D)	Managing the global R&D organization, developing global R&D strategies, and improving R&D efficiency.	55 min
2	Project Manager	Managing NPD projects and teams, and designing product architectures for Europe.	47min 36min
3	Project Manager	Managing NPD projects and teams, and designing product architectures for North America.	42min
4	Product Director	Managing the refrigerator product line and developing product strategies for Europe.	1h14min
5	Executive (VP Product Line)	Managing the refrigerator product line and developing product strategies globally.	40 min
6	Engineer	Designing control boards in Italy.	1h38min 1h24min
7	R&D Manager	Managing a team of control board engineers in Italy.	1h12min 1h27min
8	Engineer	Designing mechanical components in the U.S.	1h1min 1h2min
9	R&D Manager	Managing the electronic engineering team in Italy.	56min 1h11min
10	R&D Manager	Managing the mechanical engineering team in the U.S.	1h32min 53min
11	Architecture Leader	Managing product architectures and coordinating NPD tasks for single-door refrigerators globally.	45min
12	Architecture Leader	Managing product architectures and coordinating NPD tasks for side-by-side refrigerators globally.	49min
13	Engineer	Designing user interfaces in Brazil.	37min
14	R&D Manager	Managing the electronic engineering team in Brazil.	1h19min

Table 2 The Process of Creating an Organizational Interface in HomeTech: Phases, Elements, and Effects

Phase	Phase 1	Phase 2	Phase 3
The element of the organizational interface created	<ul style="list-style-type: none"> A moderate number of organizational units developing products for three regions (Protocols) 	<ul style="list-style-type: none"> A web-based module pool (Media/platform with protocols) 	<ul style="list-style-type: none"> Architecture leaders (Media/platform with protocols)
Effects of the element on organizational modularization	<ul style="list-style-type: none"> <i>Balancing</i>: A moderate number of organizational units of R&D with clearly defined roles were important for recombination of organizational units. With high geographic decentralization, information exchange across organizational units would be inefficient due to high duplication; with high geographic centralization, the product variety would be low, and the necessity of recombination would be diminished. 	<ul style="list-style-type: none"> <i>Balancing</i>: Power centralization and decentralization were balanced. R&D centers were asked to use the module pool in NPD projects and follow the 80% rule. However, the 80% rule could be waived subject to approval by headquarters. This was to make sure that project managers and engineers took full consideration of the modules in the pool to facilitate recombination, whereas not depriving R&D centers of freedom important for recombination. <i>Brokerage</i>: Modules in the pool created opportunities for R&D centers to spot common interests in certain modules and collaborate, which was essential for recombination. The module pool was also an important tool for ALs to perform their tasks. However, the module pool in this phase had limitations. Due to insufficient information exchange and different engineering habits at this stage, the brokerage effect was low. 	<ul style="list-style-type: none"> <i>Balancing</i>: For each NPD project, R&D centers were asked to make decisions together with ALs regarding which modules to use and develop. ALs conducted system-level designs through discussion with R&D centers. With certain power, it is easier for ALs to be involved in NPD projects to facilitate recombination, but ALs did not have unquestioned authority in order not to overlook local requirements and block recombination. <i>Brokerage</i>: ALs had the information of all modules, both ones in the pool and ones being developed. ALs bridged three R&D centers from an early stage of NPD to find common interests in modules. ALs, through communication, could overcome different engineering habits, which further promoted module sharing and recombination. The brokerage effect was high.
Organizational modularization	<ul style="list-style-type: none"> Recombination of organizational units not yet realized. Each of the three R&D centers worked independently. 	<ul style="list-style-type: none"> Low recombination of organizational units. R&D centers started to work with each other, but such opportunities were limited. 	<ul style="list-style-type: none"> High recombination of organizational units. R&D centers worked with each other (via ALs' help) in nearly all projects.
Product modularization	<ul style="list-style-type: none"> Components were non-interchangeable at the global level. Although product variety was high for the global market, the costs were also high. 	<ul style="list-style-type: none"> A medium level of modularity was realized. Below 40% of all modules (excluding bodies) were interchangeable globally. Costs were lowered for achieving high product variety for the global market. 	<ul style="list-style-type: none"> A high level of modularity was realized. Over 80% of all modules (excluding bodies) were interchangeable globally. Costs were further lowered for achieving high product variety for the global market.

Fig. 1 Levels of Recombination of R&D Organizational Units*



* Each engineering team is an organizational unit.

Fig. 2 Elements of an Effective Organizational Interface in HomeTech

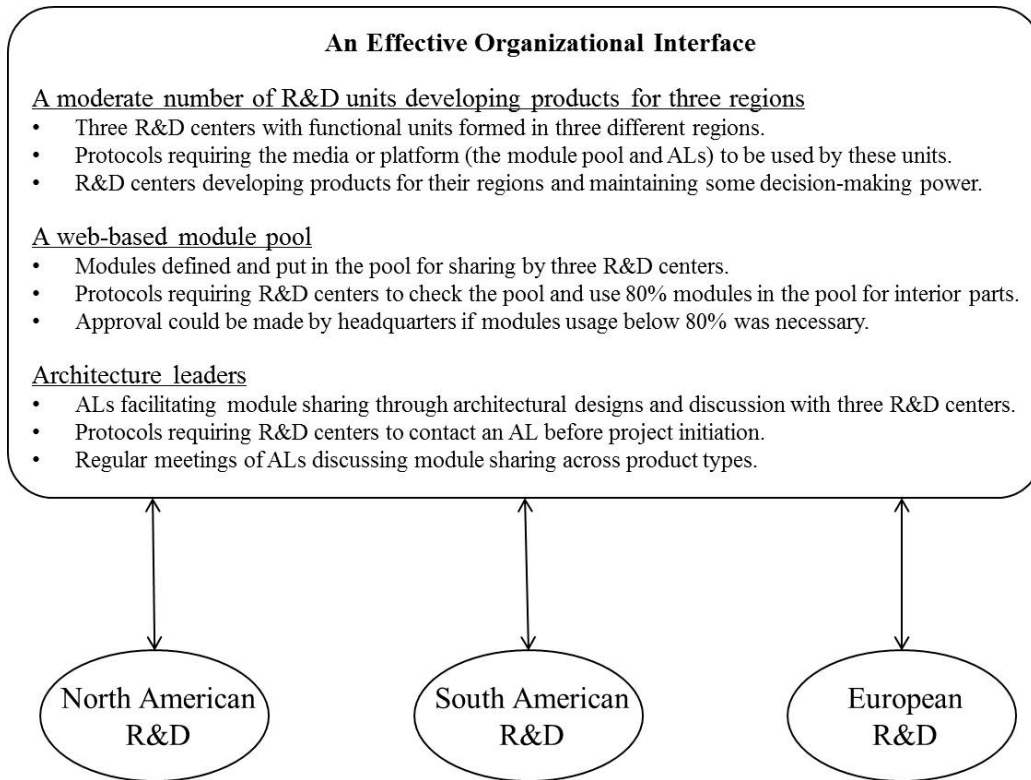


Fig. 3 Creating an Effective Organizational Interface for Product Modularization in HomeTech R&D: A Conceptual Framework

