'Uncovering the reciprocal complementarity between product and process innovation'

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Abstract

The purpose of this paper is to provide a starting point in examining the relationship between product and process innovation beyond the industry and company level. This is the first study to integrate perspectives from contingency theory and the resource-based view of the firm to show how differences in resources and capabilities combined with the specific needs of the New Product and Process Development Projects, will influence the type of complementarity between product and process innovation. We develop a classification that defines seven unique complementarities between product and process innovation and illustrate them in a Product-Process Complementarity Map. This helps Product and Process Development Managers to visualize the variety of options companies have in their New Product and Process Development Projects. We advance our argument by identifying three contingency factors: technology trajectories, power of supply chain, potential and realized absorptive capacity. These three discrete, but interrelated resources and capabilities are widely referenced in the context of process industries that are likely to lead to different complementarity types. Finally, these two contributions are brought together in The Complementarity-Capability Matrix, where we propose seven complementarity strategies and resources and capabilities necessary to achieve them. The matrix was designed to contribute to our understanding of complementarities beyond the industry and company level and serve as a useful tool in decision making for managers that are facing New Product and Process Development Projects.

Keywords: complementarity, product innovation, process innovation, contingency approach, resource based view, process industries

1. Introduction

Product and process development are commonly interrelated. The introduction of a cost-reducing process is often accompanied by changes in product design and materials, while new products frequently require the development of new equipment (Lager, 2002; Reichstein and Salter, 2006; Tang, 2006). Companies that are able to develop a tighter relationship between product and process innovation will enhance the cost efficiency of production, effect the smoother launch of new products, and create new opportunities for product and process development (Pisano and Wheelwright, 1995; Pisano, 1997). Despite all of these benefits, over the past decades, the understanding of complementarity between these two types of innovative activities has been a rare theme in the innovation literature (e.g. Damanpour and Gopalakrishnan, 2001; Damanpour, 2010; Kotabe and Murray, 1990).

Models of the dynamics of product and process innovations were mainly developed at the industry level (Abernathy and Utterback, 1978; Barras, 1986). Given the limited number of models developed at the company level (Damanpour and Gopalakrishnan, 2001) the majority of studies have focused on studying these two phenomenon separately. Researchers have claimed, that product and process innovation are two different ways of contributing to the competitiveness of the company, which are influenced by environmental and organizational factors, such as intensity of competition (Kotabe, 1990; Weiss, 2003), company size (Cabagnols and Le Bas, 2002; Fritsch and Meschede, 2001) and the industrial context (Berchicci et al., 2013).

The stream of research investigating complementarities has followed two different perspectives. One group of researchers directly tested the economic value of combining different activities and practices on organizational performance, termed and defined by Ballot et al. (2015) as *complementarities-in-performance* (Pisano and Wheelwright, 1995; Pisano, 1997). The other group of researchers took the approach of *complementarities-in-*

use, they linked between two sets of activities and argued that one practice often requires the other practice. These authors identified “mutual and beneficial integration between two sets of activities” (Ballot et al., 2015, p.218). Three sub-categories emerged following the second approach, i) product and process innovations are interrelated often implying expressions such as “brothers” (Reichstein and Salter, 2006) or “fuzzy set” (Lim et al., 2006), ii) product innovation creates a need for process innovation (Damanpour and Gopalakrishnan, 2001; Kraft, 1990), iii) process innovation creates a need for product innovation (Kurkkio et al., 2011; Novotny and Laestadius, 2014).

These studies frequently proclaimed that the synchronous adoption of product and process innovation is the “single best complementarity strategy” (Lager, 2002; Damanpour, 2010). It was also common for these studies to generalize their findings to a single industry sector, i.e. companies operating in the metal manufacturing industry should follow the product-process sequential pattern in their innovation strategies (Kraft, 1990). It may be that these two common features of prior studies have resulted in the “fallacy of the wrong level”, as companies operating within a single industry sector could differ in their complementarity strategies. Moreover the literature does not account for the fact that companies are likely to be working on a portfolio of New Product and Process Development Projects that have different aims and require different set of resources and capabilities (Bruch and Bellgran, 2014; Cooper et al., 1997). A review of prior studies also reveals that they have adopted a wide variety approaches and methodologies, and explore different industries, sectors and structures. This reflects the immaturity of this research field, which has not progressed sufficiently to constitute a theory that would offer specific scenarios defining different types of complementarities or conditions for their emergence (Ennen and Richter, 2010). Our intent in this article is to provide a starting point in this research area. We position our article in the context of process industries. Within these industries this relationship is of particular pertinence as they are often characterized by tightness between product and process innovation in New Product and Process Development Projects (Kurkkio et al., 2011; Storm et al., 2013). We argue that New Product and Process Development Projects have different aims and require different resources and capabilities, in terms of technology trajectories, relationships among the supply chain members and companies' ability to absorb the knowledge from the external environment (Bunduchi and Smart, 2010; Lager and Storm, 2013; Huang and Rice, 2009). This will lead to different types of complementarities between product and process innovation. In our analysis of these empirical findings, we show a need for a contingency approach and argue that there is no 'winning strategy' in terms of development of complementarity between product and process innovation (Ballot et al., 2015; Storm et al., 2013). This leads to the following research questions: *What are the different types of complementarities that occur between product and process innovation within the portfolio of New Product and Process Development Projects of companies within process industries? What are the different contingencies, in terms of resources and capabilities that influence the adoption of different complementarities?*

This article makes three unique contributions to the literature. First, using a contingency theory (Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Thompson, 1967) we provide a first attempt at the New Product and Process Development Project level to identify seven different complementarities between product and process innovation: *Reciprocal, Product* and *Process Sequential, Product* and *Process Amensalism* and *Product* and *Process Pooled*. Second, we illustrate this classification in the form of conceptual framework "The Product-Process Complementarity Map," providing Product and Process Managers with a tool to position a portfolio of their Projects. Third, we relate the perspectives from contingency theory with the resource based view (Barney, 2001; Barney and Clark, 2007; Helfat and Peteraf, 2003; El Shafeey and Trott, 2014) and build upon three discrete, but inter-related contingency factors that are widely referenced in process industries. In doing so, we provide new insights into development of complementarities that can be influenced by: *Technology trajectories, Supply chain rigidities and Absorptive capacity*. To orient our work, we include three empirically testable propositions; hence opening up new paths to future empirical research. Finally, we present a "Complementarity-Capability Matrix", where we relate the seven types of complementarities between product and process innovation with contingencies that are necessary to move towards achieving each complementarity type. This conceptual framework is the first conceptual attempt to provide guidance on complementarity strategies at the New Product and Process Development Project level. It is aimed to bring more insights for academics and help for Product and Process Innovation Managers by identifying different types of projects that they may choose from and what types of resources and capabilities this would require.

We structure the rest of the article as follows. We begin with a description of common characteristics, as well as differences among sectors of process industries to set the context for this paper. This is followed by a synthesis of four streams of research that have investigated *complementarities-in-use* between product and process innovation. Building on this synthesis we argue that there is limited conceptual work, which has contributed to a paucity of theory. Thus the section that follows proposes a classification of complementarities in product and process innovation followed by a positioning map. We identify three contingency factors that are likely to lead to these complementarities and bring both contributions into a single conceptual framework. Finally, we discuss implications for theory, future research and managerial implications.

2. Defining and characterizing process industries

Given the theory-building purposes of this research, we position our paper within the context of process industries in order to help us demonstrate the relationship between product and process innovation. Previous research has emphasized that within these industries product innovation is related to process innovation (Lager, 2002; Lim et al., 2006; Storm et al., 2013). A number of definitions of product and process innovation exist within the literature, for the purposes of our study we adopt the widely accepted definitions from The Organisation for Economic Co-operation and Development (OECD). OECD defines product innovation as *"a good or service that is new or significantly improved. This includes significant improvements in technological specifications components and materials, software in the product, user friendliness or other functional characteristics."* Process innovation is defined *as "a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software"* (OECD, 2015).

Surprisingly, little attention has been given to studying the complementarity between product and process innovation. A few studies have taken place in high-technology industries (e.g. pharmaceutical, biopharmaceutical industry), in which both product and process technology are rapidly evolving and therefore must be well synchronized (Feldman and Ronzio, 2001; Pisano and Wheelwright, 1995; Pisano, 1997). There is, however, a lack of academic attention to low-medium-technology (LMT) sectors of process industries (e.g. food and beverage, metal, mineral, pulp and paper). A systematic literature review conducted by Keupp et al. (2012) identifies the large gap in the academic literature on strategic management of innovation paid to low-and medium-low technology (LMT) industries in comparison to medium-high technology industries. This gap is particularly interesting because in most developed and developing countries, LMT industries account for more than 90% of the economic output and are more likely to contribute to economic growth (Robertson et al., 2009). Consistent with this concern, the R&D Management journal published a special issue dedicated to 'Managing Innovation and Technology in the Process industries' (2013, issue 3) and Research Policy featured a special issue aimed at 'Low- and Medium-Technology Industries' (2009, issue 3).

Extant literature lacks an agreed upon definition for process industries, for the purposes of this study we adopt Lager's (2011, p.20) definition: *"Process industry is a production industry using (raw) materials to manufacture non-assembled products in a production process where the (raw) materials are processed in a production plant where different unit operations often take place in a fluid form and the different processes are connected in a continuous flow."* A major difference between process and other manufacturing industries is that the products supplied to them and delivered from them are materials rather than components (Frishammar et al., 2012). These industries are also characterized by large fixed items of capital equipment (Kurkkio et al., 2011; Lager et al., 2013; Novotny and Laestadius, 2014), development work that is done in laboratories or pilot plants, and long and interconnected production chains that often create obstacles and prevent product and process development. Product and process development often take place in collaboration with manufacturers of process equipment, suppliers of raw material and reagents (Lager and Frishammar, 2012).

We note that, in positioning our research in process industries, we do not argue that the findings of prior research in the innovation management field in general are not relevant to process industries. Rather, we believe that the features of this industry are likely to significantly influence the way R&D and innovation are leading strategic decision making and thus we contribute to this field of research. In the next section we turn our attention to major studies searching for a complementarity between product and process innovation.

3. Synthesizing major studies investigating complementarities between product and process innovation

Complementarity studies have applied two different approaches to measure and understand linkages between product and process innovation. Ballot et al. (2015) term these *complementarities-in-use* and *complementarities-in-performance*. Studies belonging to the first approach searched for relationship in product and process innovation with an aim to prove a link (e.g. Damanpour and Gopalakrishnan, 2001; Martínez-Ros and Labeaga, 2009). The second approach investigated the effects on performance when combining these innovation activities (e.g. Kotabe and Murray, 1990; Pisano, 1997). For the purposes of this research we focus on studies that identified *complementarities-in-use* and further divide them into four sub-categories. We begin with an area of research that identified only a one-way relationship, either *product-process pattern* of relationship or *process-product pattern*. This will be followed by a stream of research, which argued that product and process innovation are interdependent and any distinction between them is arbitrary. Lastly, and the most significant in terms of volume is a stream that examined product and process innovation as two separate types of innovation.

3.1 Product innovation creates a need for process innovation

The starting point in the *product-process pattern* research area was Abernathy and Utterback's (1978) 'Industry life cycle model'(PLC), a three-stage model that suggests changing rates of product and process innovation depending on the developmental stage of the industry. Starting with radical product innovation in the *fluid* phase, followed by radical process innovation in *transitional phase* and ending with incremental product and process innovation in the *specific* phase. Later studies confirmed the pattern of the first two stages, a central study by Kraft (1990, p.1029), undertaken in the context of medium sized German metal-working firms, points to a recursive model of only a one-way relationship, while the reverse effect cannot be proven. A similar finding was observed by Damanpour and Gopalakrishnan (2001, p.45) with a sample of commercial banks in the United States. They argued that studies on product and process innovation were mainly conducted in the manufacturing sector and hence investigated the applicability of the product-process model to the service sector. According to their findings, one of the reasons banks tend to first introduce product innovation (e.g. credit cards) over process innovation is greater appropriability. Product innovations are based on technologies, which can be more easily protected by patents and other legal mechanisms.

3.2 Process innovation creates a need for product innovation

The *process-product pattern* is seldom seen in the literature on evolution of innovation. It followed the logic of the 'Reverse product cycle model' proposed by Barras (1986) for service industries. This was later improved and confirmed using the vanguard sector of financial and business services (Barras, 1990). He argued that among user industries such as services, that commonly adopt technology developed in physical goods industries, the cycle operates in an opposite direction. It begins with incremental process innovations leading to radical process innovations and radical product innovations in terms of new services (Barras, 1986). One of the few studies proving this relationship was a multiple case study of process firms conducted by Kurkkio et al. (2011), who indicated that process development practices may be necessary to achieve high product development performance. Most recently, Novotny and Laestadius (2014) have identified, based on case studies among pulp and paper process-based industries in Sweden, that when a significant change occurs in process technology, the product subsequently changes.

3.3 Product and process are interdependent

The synergistic benefits of reciprocal complementarity have been identified by the *complementarities-in-performance* stream of research. Academics have argued that it leads to improvements in the cost efficiency of production, enhancement of launch of new products, easier commercialization of new products (Pisano and Wheelwright, 1995), high return on capital (Capon et al., 1992) and helps in identifying opportunities in product and process development (Milgrom and Roberts, 1995). However achieving this competitive advantage in the turbulent environment would require dynamic capabilities in order to shift the focus on both types of innovation (Teece et al., 1997).

To begin, the simultaneous execution of both products and processes is demonstrated in the third phase of Abernathy and Utterback's (1978) Industry life cycle theory, in which the innovation is stimulated by objectives to reduce cost and enhance quality of the products. Other studies go further by claiming that congruence between these two types of innovation is especially important during competitive times (Ettlie, 1988). Kim et al. (1992) concluded that integrated decision making of product planning and process design performs better than non-linked decisions when the environment is more complex, less uncertain and tighter. This finding is supported by Martínez-Ros (2000), who found strong complementarities between product and process innovation among Spanish manufacturing firms. The knowledge accumulated through product innovation increased the profitability of process innovations by 36%, and companies that innovated in their processes were 27% more likely to be product innovators. Lager (2002) analyzed a wide spectrum of sectors in European Process Industries and concluded that development of a new product is related to the introduction of an improved process. He argues that this characteristic is specific to process industries. In other manufacturing industries a new product can be developed in the design office and the manufacturing of the product can occur later.

A more recent study by Reichstein and Salter (2006) considers product innovation and process innovation separately, focusing on the different behavior of companies engaging in each activity. Ultimately, however, they conclude that at both industry and firm level, they are interdependent. Moreover they suggest that each should be viewed as "brothers" rather than "distant cousins" (Reichstein and Salter 2006, p.677). In contrast, Lim et al. (2006, p.31) build on the research within process industries, specifically in biopharmaceuticals, and show that product and process innovation cannot be viewed as "discrete entities" due to the unique development path, consisting of untried techniques that make the development process iterative. In working to understand this relationship, Martínez-Ros and Labeaga (2009) have acknowledged persistence in a company's commitment to implement product and process innovation as important for both innovation types.

3.4 Product and process innovation are two separate types of innovation

The majority of studies have focused on studying product and process innovation as two separate phenomenon. Researchers have claimed, particularly in the manufacturing sector, that product and process innovations are two different streams contributing to the competitiveness of the company, which are influenced variously by environmental and organizational factors (Damanpour, 2010). Ettlie et al. (1984) viewed the distinction between them as crucial because adoption requires different organizational skills. Traill and Meulenberg (2002) studied food manufacturing companies across Europe and suggested that companies have a dominant orientation, either product, process or market. This determines their core strategy and the company will only keep basic standards with respect to the other two innovation types. Weiss (2003) was more specific and argued that companies will favor process innovation when products are less differentiated and there is a low level of competition. Whereas in situations with high product differentiation and intense competition the emphasis will be on product innovation.

The above literature review exemplifies a poor understanding of the different scenarios of complementarities between product and process innovation. The immaturity of the field may be one of the reasons why conceptual work on the relationship between product and process innovation has not progressed sufficiently to constitute a theory that would offer specific scenarios defining different types of complementarities or conditions for their emergence. To advance our understanding of complementarities, the following section provides a starting point in this research area by proposing a classification of complementarities between product and process innovation.

4. A classification of complementarities between product and process innovation

Following the classical management theory, known as "scientific management," academics started to question the assumption of "the one best way" and application of "the golden rules" of managing organizations (van de Ven et al., 2013). They started to proclaim the idea that companies do not follow the best practices that were given by the dominant model of the time, but carefully select their innovation practices on the basis of the specific context in which they operate (Ortt and van der Duin, 2008). This stream of research has evolved into contingency theory. Contingency theory represents one of the most well-known theories of organizational integration. It has been applied in many areas of management, for example: strategic management (Semadeni and Cannella, 2011), production management (Kim et al., 1992) and innovation management (Bergfors and Lager, 2011; Van der Duin et al., 2013). Scholars, who belong to this stream of research argue that firm-to-firm variances in structure and strategy are the result of environmental demands (e.g. market, competitive, technology) (Duncan, 1972; Miles and Snow, 1978). Donaldson (2001, p.1) defines the essence of the contingency theory as "organizational effectiveness that results from fitting characteristics of the organization to contingencies that reflect the situation of the organization."

Significantly, Child (2005) stressed the importance of expanding the boundary conditions in applying the contingency theory in order to address changes in organizations that occurred throughout the past 20 years. Van de Ven et al. (2013) argued that due to the organizational complexity applying the organizational contingency theory is a way to uncover it. For the purposes of the current research the contingency perspective is perceived as the most relevant as prior studies have argued that the complementarity between product and process innovation does not resemble a common pattern across organizations, even when they belong to the same industry. Due to the differences in organizational contingencies the fit between product and process innovation may be unique, even across types of organizations (Damanpour, 2010). Therefore the aim of this paper is to provide a starting point in this research area.

To understand complementarity between product and process innovation, industry, company and project levels of analysis are required. Nonetheless, research has predominantly favored the perspectives portrayed in the two industry level models (Abernathy and Utterback, 1978; Barras, 1986) that argued for sequential complementarity between product and process innovation. However, it was soon noticed that these models oversimplified the industrial reality (Pisano, 1997; Lager, 2011). “The fallacy of the wrong level” has been recognized by Utterback (1994) in his book Mastering the Dynamics of Innovation, where he also referred to the company level. Models such as The Product-process matrix (Hayes and Wheelwright, 1979a; Hayes and Wheelwright, 1979b) and The Modularity-maturity matrix (Pisano and Shih, 2012) published in the Harvard Business Review moved away from the industry level and tried to portray the different complementarity options at the company level. On the other hand studies based on the Community Innovation Survey (CIS) tended to classify the complementarity innovation strategies of companies (Battisti and Stoneman, 2010). For example, Evangelista and Vezzani’s (2010) study identified four innovation modes with an aim to synthesize the highly heterogeneous nature of firm's innovation behavior (product oriented/process oriented/organizational and complex innovation modes).

All of these classifications fail to take account of the possibility that companies within a single industry sector could differ in the types of complementarities they adopt in their New Product and Process Development Projects. We build on the assumptions of Bruch and Bellgran (2014) and Cooper et al. (1997) and argue that companies can be working on a portfolio of projects. In these portfolios more breakthrough innovations with a high degree of risk, but a potential for development of a competitive advantage, are combined with "safer" projects with a high success ratio. Perhaps the most commonly cited model in this area is the typology of development projects by Clark and Wheelwright (1993) where they differentiate between New Product Development (NPD) projects based on the extent of product change and manufacturing process change, but failed to uncover the pattern in which the product and process innovation take place within these projects.

We aim to provide a starting point in this research field by bringing the contingency perspective into the complementarity studies area and to develop a classification of complementarities between product and process innovation that are available to companies in their New Product and Process Development Projects (See Table 1.). Within this Table we re-conceptualize the terminology from one of the most commonly cited publications in the contingency theory field Thompson (1967) to describe complementarities occurring between product and process innovation. These are: *Reciprocal interdependence*, *Sequential interdependence* and *Pooled interdependence* (Thompson 1967, p. 54). We argue that depending on the aims of the New Product and Process Development Projects there could occur *Product* or *Process Pooled* complementarity as well as *Product* and *Process Sequential* complementarity. Moreover we contribute with two unique complementarity types that define a low extent of complementarity, *Product* and *Process Amensalism*. We also include suggested examples of New Product and Process Development Projects from a range of process industry sectors. The following part describes these complementarity types from high to low extent of complementarity.

Reciprocal complementarity is the highest extent of complementarity and is defined as a synchronous adoption of product and process innovation often creating opportunities for other product and process innovations. New Product and Process Development Projects that adopt this complementarity aim to develop radically new products that require the development of new product and production technology, which was not previously used within the company. In these types of projects teams usually get much more freedom in choosing and developing resources and capabilities instead of using existing equipment and operating techniques. They work closely in all New Product and Process Development stages as every change in the product has to be tightly integrated to the production process and the other way round.

Product Sequential complementarity occurs when companies start the project with a dominant focus on product innovation. This subsequently necessitates (triggers) changes in process innovation. These types of projects typically follow the pattern described in the Stage-Gate NPD model (Cooper, 2008). Specifically, there is a lack of collaboration between different departments at the beginning of the project.

Process Sequential complementarity takes place in New Product and Process Development Projects with a dominant focus on process innovation. The project commences with development or adoption of a new manufacturing process technology. This results in the recognition of an opportunity for a new product and its subsequent development.

The term *Amensalism* is taken from biology and is defined as “a relationship between two species of organisms in which the individuals of one species adversely affect those of the other and are unaffected themselves” (Encyclopaedia Britannica, 2015). We apply this to our context in terms of established process or product technology trajectories that companies keep for many years. Such situations hinder the development of complementarity with the other innovation type, leading to either *Product Amensalism* or *Process Amensalism*. These types of project are characteristic of the utilization of existing resources with minimal changes where the main aim is to maximize return on investment.

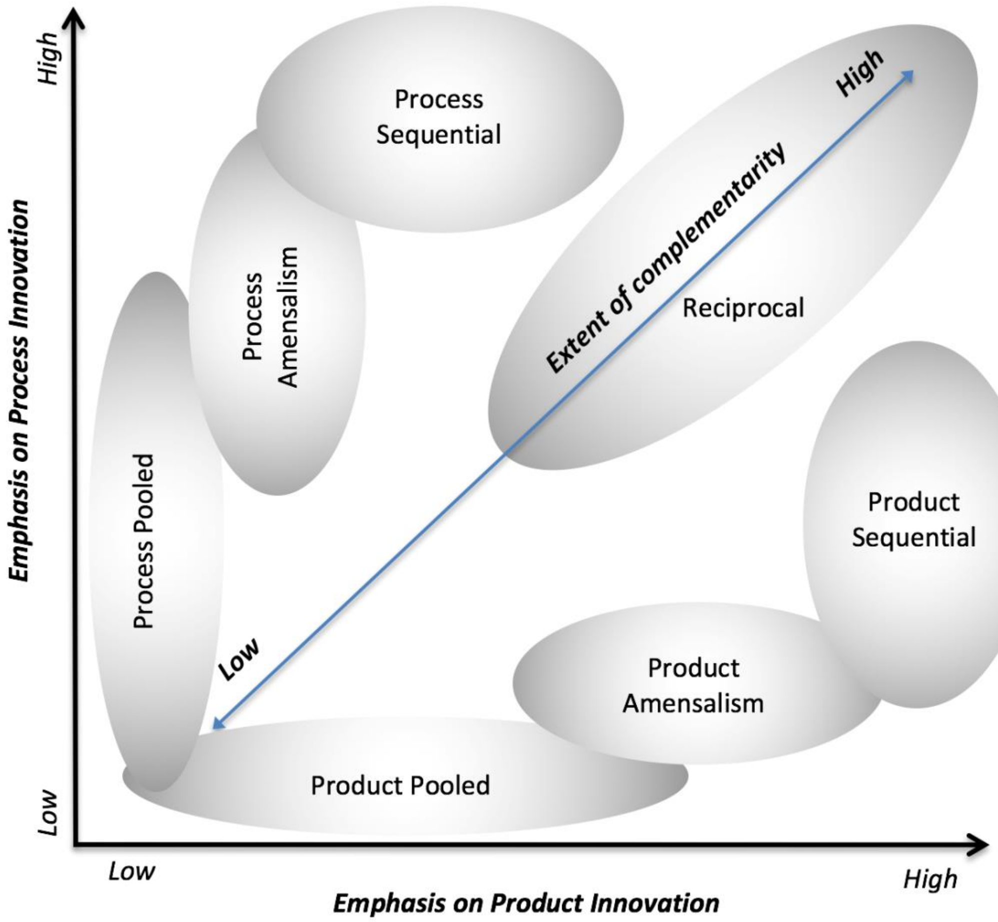
Product or *Process Pooled* complementarity types are characteristic with the lowest extent of complementarity between product and process innovation. The primary focus is typically either on product or process innovation and the development of resources and capabilities without any impact on the other type of the complementarity. In such situations meaningful discussions between the New Product and Process Development teams are limited. The emphasis is on using the existing resources to produce the product without any change to the process.

Table 1. A classification of complementarities between product and process innovation

Extent of complementarity				
HIGH	Reciprocal		Synchronous adoption of product and process innovation often creating opportunities for other product and process innovations.	**Suggested example:** Development of Guinness 'in-can' system in the 1980's, required the development of the new plastic 'widget' and new process equipment to insert the system and gases into the can (Trott, 2010).
	Sequential	**Product Sequential**	The dominant focus is on product developments. The project commences with the development of a new product concept, this subsequently necessitates (triggers) changes in process innovation.	**Suggested example:** Billerud is largely focused on satisfying their customers and developing a wider product range, e.g. malleable formable board for packaging project; subsequently leading to a focus on innovations in the production technology and processes (Bergfors and Larsson, 2009).
		Process Sequential	The dominant focus is on process developments. The project commences with the development or adoption of a new manufacturing process technology. This results in the recognition of an opportunity for a new product and its subsequent development.	**Suggested example:** The development of complex manufacturing float process enabled Pilkington to produce the float glass (Anderson and Tushman, 1991).
	Amensalism	**Product Amensalism**	A New Product and Process Development Project where the presence of a constraining factor, such as incumbent product technology or a lack of capacity to understand new technologies, could hinder process innovation.	**Suggested example:** The cork product closure for wine in its traditional form dominated industry for 100 years, because of this dominance emergence of new production technology was hindered (Pereira, 2007).
		Process Amensalism	A New Product and Process Development Project where the presence of a constraining factor, such as incumbent process technology, sunk investments, or a lack of capacity to understand new technologies, could hinder product innovation.	**Suggested example:** Extractive industry saw only about 12 revolutionary developments in the 20th century (Bartos, 2007). Rio Tinto HIsmelt® iron smelting technology for production of steel took more than 20 years and millions of dollars before the plant was constructed in Western Australia (Leczo, 2009).
	Pooled	**Product Pooled**	A New Product and Process Development Project in which product innovation takes place irrespective of process innovation. The only connection between them is that they belong to the same organization.	**Suggested example:** Ingredients changes to food products, such as flavorings used in potato chips, requiring no change to the manufacturing process (Bigliardi and Galati, 2013).
LOW		**Process Pooled**	A New Product and Process Development Project in which process innovation takes place irrespective of product innovation. The only connection between them is that they belong to the same organization.	**Suggested example:** Continuous wide strip rolling technology for steel moved through five generations of incremental process improvements from its inception in 1926, with few resulting in changes to the core product (Aylen, 2010; Aylen, 2013).

We use the seven different types of relationships described in the classification of complementarity between product and process innovation, to develop our conceptual framework: “Product-Process Complementarity Map.” Figure 1. shows graphically the classification of relationships in the Product-Process Complementarity Map. The vertical axis represents an emphasis on process innovation and the horizontal axis product innovation, from a high to low extent. The axis in the center of the map represents the extent of complementarity between product and process innovation, from a low to high extent. The blurred lines between different complementarities are intended to reflect our current thinking, and offer an initial conceptualization of these complementarities within our map. The Product-Process Complementarity Map should be perceived as a map to position a portfolio of projects from which companies could choose the most suitable complementarity strategy for their current project. It was created to serve as an aid for managers, who want to visualize the positioning of their company in terms of utilization of the interrelation between product and process innovation. The proposed map is aimed to be a starting point in the research area, therefore the uncovered spaces should be perceived as areas, where other possible complementarities might be identified by future empirical research.

Figure 1. Product-Process Complementarity Map to position a portfolio of projects



5. Contingent factors

Within the contingency approach, there seems to be a broadly shared view that we need to understand those contingencies that may influence the types of complementarities evident inside the company (Lager, 2002; Lim et al., 2006; Damanpour, 2010; Storm et al., 2013). A recent empirical study conducted by Ballot et al. (2015), identified great firm-to-firm variances in different complementarity strategies among UK and French companies based on the Community Innovation Surveys (CIS). They concluded that *"the effectiveness of the various combinatorial strategies is dependent on the institutional context and firm characteristics in which these combinatorial strategies are embedded"* (Ballot et al., 2015, p. 13). Further factors identified by these studies include "financial knowledge and market obstacles" (Ballot et al., 2015), "firm characteristics" (Battisti and Stoneman, 2010; Evangelista and Vezzani, 2010; Storm et al. 2013; Lim et al., 2006), "different phases of product and process development" and "customers" (Lager, 2002), but also "complex, less uncertain and tighter environment" (Kim et al., 1992). The majority of these studies were based on the results of Community Innovation Survey, a questionnaire among manufacturing and service companies that takes place every two years in all EU member countries (e.g. Battisti and Stoneman, 2010; Evangelista and Vezzani, 2010; Ballot et al., 2015). Due to the differences among the sectors investigated the results are difficult to generalize. Furthermore, the contingencies identified were based on assumptions and hypotheses that were developed without a clear guidance on the type of complementarity likely to result. To resolve this we combine the perspectives from contingency theory and resource based view (RBV), which contends that resources across companies are unevenly distributed and there are considerable differences in ways companies are able to deploy them and achieve new product and process development strategies (Barney, 2001; Fredericks, 2005). Moreover, companies do not achieve success only due to their superior resources, but rather because of distinctive capabilities that enable them to utilize organizational resources in order to achieve a certain end result (Helfat and Peteraf, 2003; Mahoney, 1995).

In principle, the relation between the contingency theory and the RBV is quiet straightforward:

1. Companies are operating in different contexts, their New Product and Process Development Projects have different aims and require different resources and capabilities to achieve desired innovation strategy (Lager, 2011).
2. The most important task in the RBV approach to the strategy of the firm is choosing the best combination of resources and capabilities (Grant, 1991).

In the sections that follow we demonstrate how certain contingencies (company' resources and capabilities) could lead companies operating in sectors of process industries closer to a certain type of complementarity between product and process innovation in their New Product and Process Development Projects. Our conceptual approach to understanding the linkages between product and process innovation is under pinned by three constructs: i) Absorptive capacity; ii) Technological trajectories and iii) Supply chain relationships. In reviewing the literature these discrete but inter-related themes emerged. Product and process innovation success relies upon the ability of firms to acquire and utilize complex knowledge; hence absorptive capacity has become one of the most influential concepts within the innovation literature (See Martin, 2012). The ability of firms to manage and allocate their resources determines why and how firms develop competencies in particular areas of their activities. Thus, for all firms movement along a technology trajectory is associated with research and development. A firm's product and process technologies can become locked-in to a trajectory thus making it difficult to adopt ideas and innovation from outside. Abernathy and Utterback's (1975) industry lifecycle model reflects this challenge. It illustrates the importance of switching and learning costs and sunk capital equipment costs and how these influence the relationship between product and process innovation. Both absorptive capacity and technology trajectories are affected by the pivotal role played by external linkages. The seminal paper by Pavitt (1984) on industrial classification of firms underpins the role of supplier dominated firms as a significant driver of innovation. Further, within process industries the supply chain has been found to play a particularly influential role in both innovation types (Lager and Frishammar, 2010; Soosay et al., 2008; Storm et al., 2013). In our view these three themes are interwoven and inextricably linked to one another when attempting to understand product and process innovation. The following sections further demonstrate the impact of these three contingency factors on the complementarity between product and process innovation within the process industries, leading to development of propositions.

5.1 Complacent technology trajectories

The existing innovation literature has highlighted that for organizations, particularly well-established ones, the current capabilities and technological trajectory impact on their ability to innovate. The existing product and process technologies are some of the most important intangible resources of the company (El Shafeey and Trott, 2014).

The commonly held view of technological change is that it begins with a technological discontinuity (Tushman and Anderson, 1986). Abernathy and Utterback (1978) illustrate this in their Industry Life Cycle theory. Within this conceptualization product and process innovation are closely interlinked with competitive environment and organizational structure through each of the three phases: *fluid, transitional and specific*. The *specific* phase is of particular relevance to low technology intensive sectors of process industries, which are characterized by a high path-dependency continuously stabilized by incremental innovation activities. The literature on technology management shows that companies tend to employ technologies that are well-known and established, while processes and products are embedded in routines (Bauer and Leker, 2013; Benner and Tushman, 2003; Henderson and Clark, 1990; Tushman and O'Reilly, 1997). This constrains innovation and reinforces the development paths (technology trajectories) due to the high capital costs, development costs and a reluctance to pass away the preceding investments into the established technology (Bunduchi and Smart, 2010). Kauffman et al. (2000) studied how companies search for more efficient production recipes and refer to this as a "walk" on a technology landscape. They claim that once the company succeeds in finding technological improvements it restricts the search for other improvements to a local region of the technology landscape. This leads to incremental adaptation and decreasing interdependencies with other actors (Levinthal and Warglien, 1999). A commonly cited example is the one of Rio Tinto's HIsmelt® iron smelting technology, that took hundreds of millions of dollars in R&D and twenty years before a full-scale plant was constructed in Western Australia (Fillippou and King, 2011; Leczo, 2009). These factors hinder discontinuous technical change because their change would require the development of new plant or premature scrapping of technology, and are thus frequently avoided (Aylen, 2013). The above scenario leads to a position whereby it is difficult for R&D managers to achieve a "well-balanced portfolio" between exploration and exploitation (Bauer and Leker, 2013, p. 196). Hereafter we refer to this reluctance towards disruptive innovation as *complacent technology trajectory*.

The *complacency technology trajectory* creates an environment in which complementarity between product and process innovation may be impeded. Novotny and Laestadius (2014) demonstrated this within pulp and paper industry, where the equipment (e.g. paper machines) has been in use for over 30 years due to resistance to radical technical change that was perceived as a threat towards the established technology system, hence limiting the opportunities for product innovation.

Therefore, we propose that this scenario is likely to lead to an environment where following the initial phase of radical product or process innovation, the company learns and at the same time increases its efficiency through replication in its existing technology trajectories leading to decreased level of complementarity with the subsequent innovation.

In summary we posit the following:

1. *A complacent technology trajectory, caused by an incumbent product or process technology, will lead to a lower extent of complementarity.*

5.2 Power of supply chains and rigidities imposed by them

We now turn our attention to powerful supply chain members and their impact on the relationship between product and process innovation. We focus on the link between supplier and buyer, from both perspectives, and the ability of the dominant member to exert supply chain rigidities that can negatively influence the extent of complementarity.

In general, scholars agree that improved innovation performance cannot be achieved by the company on its own and there is an increased need for supply-chain collaboration (Soosay et al., 2008; Nieto and Santamaría, 2007; Kibbeling et al., 2013). In particular, there is a growing body of literature highlighting the increased use of upstream external members (e.g. suppliers) as one of the main sources of process and product innovation (e.g. Cabagnols and Le Bas, 2002; Monczka et al., 2000; Rouvinen, 2002). This leads to speed and product quality improvements within the Product and Process Development Projects (Gupta and Souder, 1998; Primo and Amundson, 2002). The above mentioned practices are of a particular pertinence within process industries, where innovation is influenced by their characteristic long and rigid supply chains (Lager and Storm, 2013). Starting with raw materials, the chain often includes intermediate deliveries of other finished products before introduction of the final product and delivery to the end consumer (Tottie and Lager, 1995).

For organizations within process industries ‘upgrading’, to the development of added value products, has been identified as a critical challenge (Tottie and Lager, 1995; Simms and Trott, 2014). Hence new product innovations provide the opportunity to improve margins. This is illustrated in Lager (2011, p.43), which shows the never-ending interaction between customers and suppliers in the product development cycle. This concept also reveals the significant linkages between product and process innovation. Lager (2011) argues that process development projects can offer opportunities for product development, while the introduction of a new product could be combined with a new, more efficient production process. Instances when suppliers and customers are able to integrate these two parts of innovation, they will find themselves in a “highly desirable position in the world of innovation in the process industries” (Lager 2011, p.43).

Whilst the benefits of supply chain collaboration are well established, the literature reveals that network players often possess differing and unequal levels of power and influence (Järvensivu and Möller, 2009). An unequal relationship can be caused by the lack of commitment to the relationship from the large buyer, who is not dependent on a single supplier. It utilizes its bargaining power and does not devote sufficient resources to the relationship, while extracting the most from it (Christopher and Jüttner, 2000). As stated by Porter (1980, p. 123), “In purchasing, then, the goal is to find mechanisms to offset or surmount these sources of supplier’s power” by spreading purchases of items among alternate suppliers. The buyer often lacks interest in the way products are manufactured, beyond environmental and ethical issues (Storm et al., 2013). For example, a small food producer that is supplying retailers, who are exerting price pressure and the same time facing the rising costs from the world markets, will focus its efforts on cutting production costs or making incremental changes to the existing products rather than undertaking product and process innovation projects (Gautié and Schmitt, 2009). An inverted scenario takes place when the supplier is the dominant member. For instance, Pavitt (1984) identified a category of supplier-dominated firms, common in sectors such as wood and paper mill products, which make only minor contribution to their product or process technology. In this case, the majority of the innovations come from suppliers of equipment and materials.

This consequently leads to an environment with *supply chain rigidities* in which incremental and exploitative innovation dominate over long term substantial technological changes (Teichert and Bouncken 2011, p.96). Activities of the subordinate supply chain member, such as product and process objectives, frame specifications and target prices are confronted with pre-settings of the dominant supply chain member. While under these circumstances the subordinate member will have to accept the contractual conditions with little opportunity for disagreement (Teichert and Bouncken, 2011).

The above analysis gives rise to the following proposition:

2. An increase in supply chain rigidities will lead to a lower extent of complementarity.

5.3 Potential and realized absorptive capacity

Product and process innovation within process industries often takes place in collaboration with manufacturers of process equipment and suppliers of raw materials. Therefore, our final proposition reflects the role played by the third contingency, absorptive capacity, in building relationships between these two innovative activities.

The increasing availability of external knowledge sources in today's dynamic economies, makes a company's ability to identify, absorb and exploit this knowledge for the purpose of innovation an important source of competitive advantage (Fosfuri and Tribó, 2008). Zahra and George (2002), one of the most commonly cited conceptualizations of AC (Jansen et al., 2005; Lane et al., 2006; Todorova and Durisin, 2007), suggested four dimensions of absorptive capacity: *acquisition* and *assimilation*, known as potential absorptive capacity (PAC); *transformation* and *exploitation*, called realized absorptive capacity (RAC). Each component playing complementary role in explaining how absorptive capacity influences innovation.

Coevolution with external environment enhances company's PAC, a path-dependent capability that builds upon past experience and is kept as "organizational memory" (Zahra and George, 2002). For example, a company that repeatedly licenses in technology from other firms will develop better routines for searching and identifying new external knowledge and is able to utilize these when required (Fosfuri and Tribó, 2008). However, they should not be seen as substituting internal efforts for the creation of new value. These efforts are an essential catalyst to transform and exploit this knowledge (RAC) and consequently develop linkages between product and process innovation in new product and process development projects (Caloghirou, 2004; Laursen and Salter, 2006).

For example, practices among US biotechnology companies prove that they prefer to own and control their product development and manufacturing facilities, while collaborating with prominent research universities and "star scientists," as they have identified only disadvantages when separating them (Feldman and Ronzio, 2001; Powel et al., 1996; Zucker and Darby, 1996). Therefore, we argue that firms endowed with well-developed PAC and RAC in both types of innovation, will be able to achieve high complementarity and hence reach a highly desirable position in process industries by outperforming their rivals (Huang and Rice, 2012; Riis et al., 2007). This argument relates to the research into internal organizational innovation, which has shown that companies need to balance exploratory learning (PAC) with exploitation learning (RAC) leading to so called transformative learning, maintaining knowledge over time (Garud and Nayyar, 1994; Tushman and O'Reilly, 1996).

This leads us to develop the following proposition:

3. *Highly developed absorptive capacity in product and process innovation will lead to a higher extent of complementarity.*

This, together with the arguments about complacency technology trajectories and supply chain rigidities, further confirm the need to combine the contingency and resource based view perspectives when searching for the linkages between product and process innovation in the New Product and Process Development Projects. The following section will aim to provide a starting point in combining these two perspectives in a matrix that reflects the complexity of real-life business environment.

6. Conceptual framework: The Complementarity-Capability Matrix

At present, the academic literature provides little guidance or understanding about the different complementarity types that may exist between product and process innovation within organizations' New Product and Process Development Projects. Further, it lacks guidance on the allocation of resources and capabilities that are necessary to achieve them. Our aim in this paper is to overcome these limitations and provide academics and managers with a useful tool for analysis and decision making, within the context of the process industry sectors

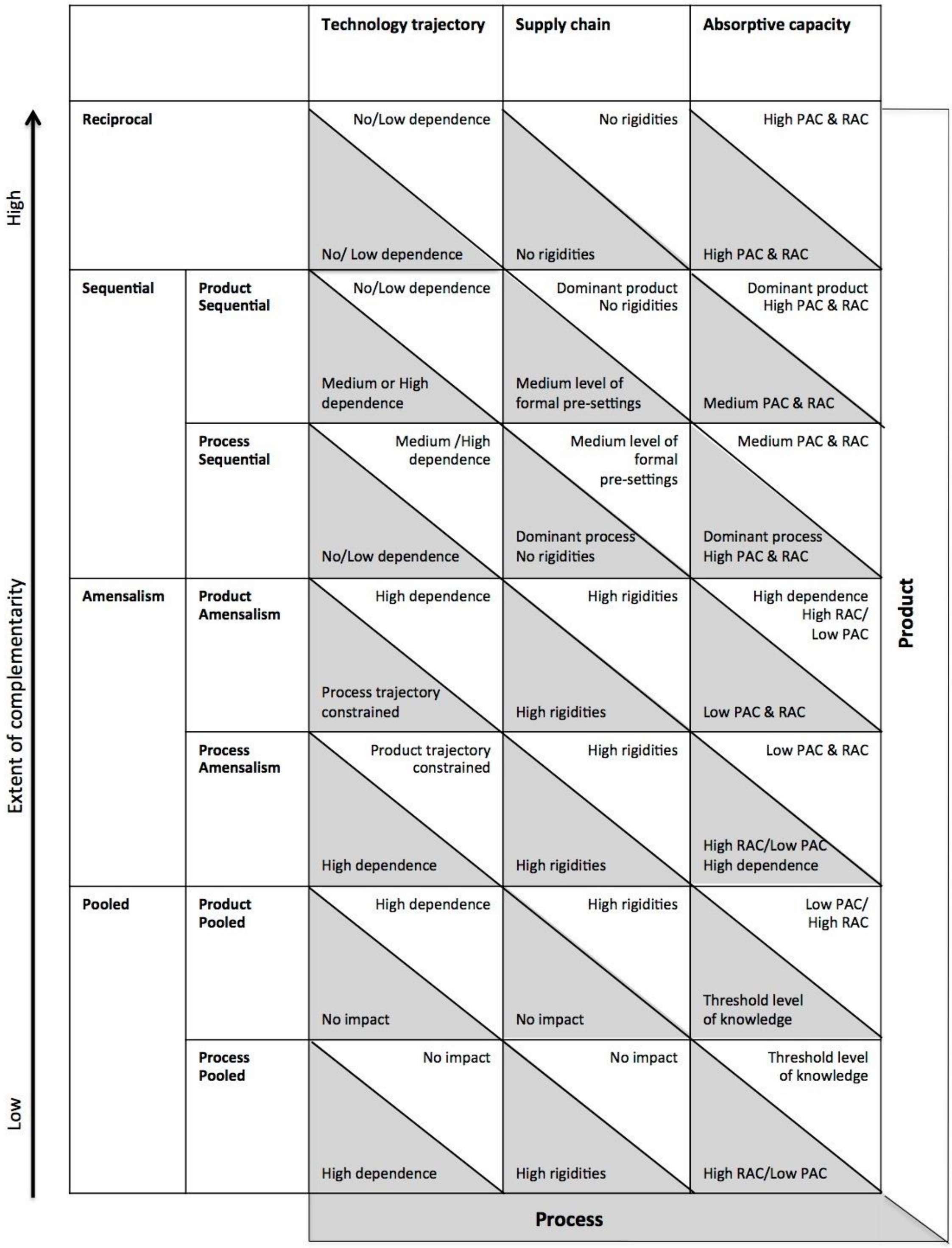
We present a novel conceptual framework "The Complementarity-Capability Matrix" to portray the relationship between complementarity types, ranging from high to low extent of complementarity between product and process innovation. We then relate this to the resources and capabilities in product and process innovation required to achieve (move closer towards) these complementarities (See Figure 2.). This comprehensive conceptual framework explains different innovation strategies that are open to companies and enables them to understand the necessary resources and capabilities to achieve them.

The far left vertical axis reflects our seven complementarity types between product and process innovation, ranging from low to high extent of complementarity. Across the top of the framework, the horizontal axis captures our three contingencies (resources and capabilities) influencing the complementarity between product and process innovation. The lower left shaded area relates to process innovation, the upper right area relates to product innovation (the former is also reflected in the shading in Figure 2.). We identify different degrees of technology trajectory, supply chain rigidity and realized and potential absorptive capacity that are necessary to move towards achieving each complementarity type. For example, if a company is facing a New Product and Process Development Project in which it aims to achieve reciprocal complementarity: managers need to make sure that the New Product and Process Development Project does not depend on the existing technology trajectories in product and process innovation, there are no supply chain rigidities that may prevent innovation, and the project team has well developed potential and realized absorptive capacity in both product and process innovation, in order to be able to utilize the existing knowledge inside the company and combine it with suitable knowledge in the external environment.

The matrix developed in this paper enables the identification of a portfolio of complementarities between product and process innovation and resources and capabilities necessary to achieve them in a more systematic way than has been evidenced in the past. This matrix should be seen as a preliminary attempt at addressing an issue that has significant implications for innovation strategy at the new product and process development project level. Empirical testing of the conceptual framework and propositions that have been put forward should follow.

It could also to serve as a useful tool for Product and Process Development managers in the decision making process and shed further light on the options companies have in their projects. We argue that companies should decide what type of complementarity would be suitable for a certain type of project and allocate sufficient resources and capabilities towards this. This matrix is equally applicable for companies following the completion of a new project or when a project has failed. They could reflect back on the type of complementarity between product and process innovation that was chosen or ended up by not making deliberate choices. They could evaluate suitability of adoption of certain complementarity in the specific New Product and Process Development Project and consider the mistakes they inadvertently made. The same applies to efficient utilization and development of resources and capabilities.

Figure 2. The Complementarity-Capability Matrix



Notes: Realized absorptive capacity (RAC); Potential absorptive capacity (PAC)

7. Discussions and conclusions

7.1 Discussion

This paper makes two main contributions: to have developed a classification of complementarities between product and process innovation that may occur in the NPD projects, and to have developed a new theoretical framework that relates complementarity types and contingencies (resources and capabilities) necessary to achieve them. Building on the contingency and resource-based view perspectives, we proposed that companies differ in the innovation strategies they adopt in their New Product and Process Development Projects. We argue that the aims of the project, context in which the company is operating as well as available resources and capabilities influence the complementarity strategy. We have identified three discrete, but inter-related contingency factors pertinent to the context of process industries and developed three testable propositions in which we describe different effects of these on the extent of complementarity between product and process innovation.

Conceptualizing the extent of complementarity between product and process innovation with the necessary resources and capabilities to achieve this possesses certain advantages. While it has built on the existing literatures, it has relaxed their most problematic assumptions: it does not claim that there is a single best complementarity type at an industry level- nor does it assume that companies operating within a single process industry sector would follow a common complementarity type. Instead our conceptual framework acknowledges that there remains a considerable variety in the complementarity strategies companies adopt in their NPD projects. Also, relating the complementarity types with specific resources (technology trajectories, supply chain rigidities, absorptive capacity) begins to provide a unified theoretical foundation on contingencies influencing a certain type of New Product and Process Development Project. In comparison to factors identified in previous research that were based on findings from large innovation surveys or author’s assumptions, often at an industry or company level, without a clear link to a concrete complementarity type (Battisti and Stoneman, 2010; Evangelista and Vezzani, 2010; Storm et al., 2013).

7.2 Managerial implications

Product and Process Development Managers face the important and difficult task of choosing the right innovation strategy for the needs of each New Product and Process Development project, while allocating the necessary time and resources to achieve this aim. As such, they are required to effectively lead a portfolio of new projects and cannot follow strategies defined in the simplified product-process complementarity models developed at industry/ company level (Abernathy and Utterback, 1978; Hayes and Wheelwright, 1979a; Hayes and Wheelwright, 1979b; Pisano and Shih, 2012). Neither assume that there is a consensus of the best practices at each process industry sector, e.g. high complementarity between product and process innovation should always be achieved in the biopharmaceutical industry (Lim et al., 2006). To achieve greater efficiency and competitiveness decisions must be made on the correct allocation of resources and capabilities to each New Product and Process Development Project separately. This implication is consistent with previous research by Ballot et al. (2015), Bruch and Bellgran (2014), Cooper et al. (1997), who argue that companies have different characteristics, operate in different institutional contexts and work on a portfolio of projects, hence there is no simple winning complementarity strategy between product and process innovation.

7.3 Future research recommendations

The proposed framework constitutes the first step in the direction of strengthening the theoretical foundations for research on complementarities between product and process innovation at the New Product and Process Development Project level, and provides avenues for further research.

Firstly, methods measuring the validity and applicability of this construct would need to be pioneered by future research. Each of our seven complementarities requires further exploration, while two stand out as particularly interesting. Amensalism, because of its ability to harm company's innovation capabilities that may be unwittingly damaged. Reciprocal complementarity, due to its favorable influence on company's performance, such as ability to control product mix more tightly and acquire flexible process equipment (Hayes and Wheelwright, 1979a; Kotabe and Murray, 1990), smoother launch of new products, more rapid penetration of new markets and ease of production ramp up process (Pisano and Wheelwright, 1995; Pisano 1997).

Secondly, the propositions developed here could be the source of a major empirical research effort designed to test them. Future investigations could not only test their applicability to different sectors of process industries, but also suggest contingencies that are particularly relevant for each of the sectors individually and hence follow our theoretical base: the contingency approach. For example, by considering different New Product and Process Development Projects they could attempt to answer the following questions; What type of complementarity was the company aiming for originally? Where did they end up? What factors influenced their decisions and behavior? Why did they play a dominant role in their decision making? Given the lack of academic focus on process industries, future research could provide more insights into innovation practices of both high and medium-low technology sectors.

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