Determining how internal and external process connectivity affect supply chain agility: a life-cycle theory perspective

Article (Accepted Version)

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Abstract

The purpose of this paper is to determine how organisations can connect internal and external processes to enable an agile response to continuous change. Drawing on life cycle theory, a hypothetical model is developed regarding the independent and combinative effects of internal and external process connectivity on supply chain agility. The research is further extended by investigating the effect of product and supply complexity as moderators of this relationship. The model is tested using hierarchical regression analysis based on survey data from 143 managers at German manufacturing firms. Our findings suggest that internal and external process connectivity have a positive effect on supply chain agility independently and collectively. By differentiating between internal and external process connectivity, we build on prior research regarding the process-related enablers of supply chain agility; research that has yet to clearly differentiate between internal and external processes or uses the terms interchangeably. In doing so, we address the interactive effects and show how complexity only plays a moderating role in some instances. This is an important contribution as the theoretical meaning of interaction effects remains under researched. The theoretical contribution of the paper rests on its extension of life cycle theory to the supply chain.

Keywords: Supply chain agility; Process connectivity; Product Complexity; Supply Complexity; Life cycle theory

Word Count: 10,899 (including references)

1. Introduction

Organisations are in a constant state of change (Tsoukas and Chia 2002; Van de Ven and Poole 1995, 2005; Weick and Quinn 1999). An organisation is comprised of countervailing processes that strive to achieve stability in the face of continuous change (Rescher 1996). Processes are defined as the progression (i.e. the order and sequence) of events in an organizational entity's existence over time (Van de Ven and Poole 1995 p. 512). An agile organisation is one that is capable of the rapid adaptation of its processes in response to change events (Kidd 2000).

Scholars have long contended that the processes underpinning an agile organisation are not confined to firm boundaries but extend upstream to suppliers and downstream to customers (Cooper, Lambert, and Pagh 1997; Lambert, García-Dastugue, and Croxton 2005; Swafford, Ghosh, and Murthy 2006). Indeed, a supply chain can be perceived as a connected set of processes that begins with the sourcing of raw materials and extends through to the manufacture and delivery of finished goods to customers (Trkman et al. 2007). Process connectivity is defined as "the management of various sets of activities that aims at seamlessly linking relevant business process within and across firms, (Chen, Daugherty, and Roath 2009 p. 66). By connecting processes within the organization and externally with supply chain partners, the firm can enable an agile supply chain response to change events.

Many scholars examining supply chain agility do so from a Resource Based perspective (see Blome et al., 2013; Chiang et al., 2012; Eckstein et al., 2015; Swafford et al., 2006; Tse et al., 2016; Vickery et al., 2010). The Resource Based View (RBV) provides a lens on the internal resources and capabilities that give companies a competitive advantage (Barney 1991; Penrose 1959; Peteraf 1993; Wernerfelt 1984). Yet, such a firm-centric perspective can create ambiguity in understanding supply chain level phenomenon. We suggest process based theories, and life cycle theory in particular, provide a more compelling theoretical foundation for understanding the factors that contribute to supply chain agility.

Life cycle theory argues that organizational entities have an underlying form, logic and code that guides the entity from a given state towards its inevitable end (Flavell 2013; Nisbet 1970). This suggests an element of path dependence (Nelson and Winter 1982) where a future series of events is dictated by decisions made in the past. In this paper, we set out to extend life cycle theory beyond organisational boundaries, to the supply chain. Viewed through a life cycle theory lens, supply chain agility relates to how supply chain actors connect their internal and external processes to adapt to continuous change. While decisions may be path dependent, connected processes allow for agility to be embedded in the supply chain; permitting a quick response to disruptive events.

Complexity in the supply chain has been recognized as a crucial factor enabling or inhibiting the effectiveness of processes (Azadegan et al. 2013; Browning and Heath 2009). Understanding the effects of supply chain complexity is increasingly important in our current environment of heightened competition, rapid technological change, high product variety, and shorter product lifecycles (Daft 2015; Mitchell, Shepherd, and Sharfman 2011). Turbulent environments create increasingly complex connectivity requirements both within an organization and externally with supply chain members (Doz and Hamel 1998; Espinosa et al. 2007). In this paper, we consider how two key facets of supply chain complexity, product complexity and supply complexity, affect the relationship between internal/external process connectivity and supply chain agility. While product complexity derives from the customization, intricacy, and variety of the firm's products (cf. Schoenherr et al. 2010), supply complexity stems from a high number of suppliers, dynamic supply markets and unreliable suppliers (cf. Kraljic 1983).

We set out to answer the following research questions: 1) *how does internal and external process connectivity affect supply chain agility?* And*: 2) how does supply and product complexity affect the relationship between internal/external process connectivity and supply* *chain agility?* To answer these questions, we begin by examining life cycle theory and its application within the supply chain domain. We then review the literature on supply chain agility and process connectivity before moving on to an examination of supply and product complexity. By synthesizing these bodies of literature, we develop a hypothetical model of the relationships between internal and external process connectivity and supply chain agility. In section three, we present the research methodology, including a discussion of data collection and analysis procedures. In section four, we test the validity of our model using data gathered from a sample of 143 German manufacturing firms; data that is then is analyzed using hierarchical regression analysis. Section five outlines the study's theoretical and managerial contributions and section 6 concludes by highlighting promising avenues for future research.

2. Literature Review and Hypothetical Model

2.1 Life Cycle Theory

Life cycle theory is used as a lens to understand the development stages of human beings (Levinson 1978; Piaget 2007), products (Cao and Folan 2012; Klepper 1996) and organisations (Behrendt et al. 2012; Kimberly and Miles 1980). According to life cycle theory, change is inherent within an organisation (Lester, Parnell, and Carraher 2003). Organisations develop according to an underlying logic that regulates the process of change and moves the organisation from a beginning stage to a predetermined end (Van de Ven and Poole 1995). Organisations are born, they grow in various forms, and eventually they die (Kimberly and Miles 1980; Mintzberg 1984).

External events can influence how the organisation matures, but this development is always mediated by the inherent logic and rules that govern the organisation's development (Van de Ven and Poole 1988). An organisation's development is therefore path dependent, in that its development follows a single sequence of stages that are cumulative and derive from a common underlying process (Kimberly and Miles 1980; Nisbet 1970; Van de Ven and Poole 1995). Processes maintain the organisation by continuously structuring it and maintaining its boundaries therefore providing stability. At the same time, opposing processes continuously break down the organisation and its boundaries creating change (Van de Ven and Poole 2005). Importantly, change not only occurs within the organisation but also across organisational entities including the individual, team, organisation, and even across groups of organisations (Van de Ven and Poole 1995).

The supply chain, conceived as a collection of buyer, supplier and customer organisational entities, can thus be considered a level at which change occurs. In a world where supply chains compete and not companies, change occurs due to collision with other supply chain entities and an ensuing fight for domination and control in particular markets (Christopher 2000; Lee 2004). Change can also be externally triggered due to competition between supply chains for scarce resources (Gotthelf 2012). Indeed, the supply chain often has to respond to change events that result from the strategic decisions made by senior management (Gotthelf 2012; Woodfield 2010). To effectively manage continuous change, the supply chain requires processes that provide stability, as well as agile processes that permit a rapid response to unexpected change events.

2.2 Supply Chain Agility

The concept of agility first emerged in the management literature in the early 1990s and was positioned as an underpinning construct of flexible manufacturing systems (Nagel and Dove 1991). Four years later, Goldman (1995) extended the concept to the wider enterprise arguing that companies should become more agile to thrive in a competitive environment of constant and unpredictable change. Operations Management scholars then applied the principles of agility to manufacturing organisations in order to develop methodologies for agile manufacturing (Sharifi and Zhang 1999; Yusuf, Sarhadi, and Gunasekaran 1999; Katayama and Bennett 1999). At the same time, Naylor et al. (1999) introduced the concept of ‘leagility’ which called upon firms to integrate lean and agile manufacturing paradigms in their operations. Shortly afterwards, scholars applied agility to the supply chain, arguing that competition is no longer between companies, but between global supply chains that must adapt and respond to changes in the business environment (Aitken, Christopher, and Towill 2002; Christopher 2000; Christopher and Towill 2000; Mason-Jones, Naylor, and Towill 2000).

Since this time, much of the supply chain literature has centred on the enablers and antecedents of supply chain agility or its effects on business performance (Altay et al. 2018; Blome, Schoenherr, and Rexhausen 2013; Braunscheidel and Suresh 2009; Eckstein et al. 2015; Gligor and Holcomb 2012b; Swafford, Ghosh, and Murthy 2008, 2006; Tse et al. 2016). Some antecedents that have since been identified include behavioural aspects such as coordination and communication (Gligor and Holcomb 2012a), supply and demand-side competencies (Blome, Schoenherr, and Rexhausen 2013) and supply chain integration and external learning (Tse et al. 2016).

Other scholars have concentrated on identifying the enablers of supply chain agility. For example, Gligor and Holcomb (2012b) highlight manufacturing flexibility, lean manufacturing and logistics capabilities as key enablers. Two other studies pinpoint strategic sourcing and a firm’s strategic flexibility as important enablers (Chiang, Kocabasoglu-Hillmer, and Suresh 2012; Khan and Pillania 2008). Kim and Chai (2017) found that supplier innovativeness positively affects information sharing and, in turn, supply chain agility.

The relationship between agility and business performance has also been examined (Ifandoudas and Chapman 2009; Jain, Benyoucef, and Deshmukh 2008; Loss and Crave 2011; Soni and Kodali 2012). For example, Tse et al. (2016) study how supply chain agility mediates the relationship between supply chain integration and firm performance. Fayezi et al (2017) argue that supply chain stakeholders need to address the issue of relationship integration when participating in agility development programmes so as to maximise supply chain performance. Tarafdar and Qrunfleh (2017) examine the mediating effect of supply chain practices on the relationship between agile supply chain strategy and supply chain performance. In a recent study, Altay et al. (2018) position agility and resilience as antecedents of supply chain performance.

In the main, these scholars use Resource-based theories (RBV, dynamic capabilities, theory of resource complementarities) to identify the antecedents and enablers of supply chain agility (see Blome et al., 2013; Chiang et al., 2012; Dubey et al., 2017; Eckstein et al., 2015; Swafford et al., 2006; Tse et al., 2016; Vickery et al., 2010). Indeed, only a handful of authors adopt process-based perspectives to study the linkages between supply chain activities (Barratt and Barratt 2011; Cooper, Lambert, and Pagh 1997; Craighead, Hult, and Ketchen 2009; Lambert 2004; Narayanan et al. 2011; Swafford, Ghosh, and Murthy 2006; Trkman et al. 2007). This is interesting because many scholars argue that the supply chain is essentially a process, from raw material extraction, to manufacturing to delivery to the final customer (Cooper, Lambert, and Pagh 1997; Lambert 2004).

Chen et al. (2009) did study the integration of supply chain processes, arguing that integration is comprised of two underpinning constructs; internal/external process connectivity and internal/external process simplification. Process simplification is a given because managers that implement processes will logically seek to keep them as simple as possible to allow for replication with supply chain partners. What is more interesting is how internally and externally connected processes allow supply chain members to provide an agile response to continuous change. But, while Chen et al. (2009) examined internal and external process connectivity, they did not extend their examination to supply chain agility. Our paper thus makes an important contribution because we study how internal and external process connectivity affects supply chain agility.

2.3 Internal Process Connectivity and Supply Chain Agility

In many firms, departments and business units operate in silos where information and communication are often confined within discrete organisational entities (Barratt 2004; Spekman, Kamauff, and Myhr 1998). The organisational barriers created by this compartmentalization disrupt knowledge exchange and act as inhibitors to collaboration (Fawcett, Magnan, and McCarter 2008). Successful organisations are ones that instil robust communication between entities and place a high value on interdepartmental cooperation (Weick and Quinn 1999). Indeed, building intentional links between teams helps to reduce discontinuity and preserve organisational direction (ibid). Connecting processes between internal organisational entities can therefore allow for early and quick exchange of information as employees in different departments use formal and informal ties to discuss and resolve project-related issues (Menon, Jaworski, and Kohli 1997). In this regard, internal process connectivity enables firm-wide sensing of changes and more rapid evaluation of changes with respect to certain internal restrictions (e.g., production technology, production capacity) (Narayanan et al. 2011). Moreover, internal process connectivity enables a rapid and flexible response to change by changing product design, manufacturing new products, and connecting production processes (Jain, Benyoucef, and Deshmukh 2008)..

Connecting internal organizational processes is said to improve the seamless flow of transactions through the firm, resulting in fewer bottlenecks (Lambert, García-Dastugue, and Croxton 2005). Smoothly linked processes in product development and customer order fulfillment can reduce time to market of products and reduce delivery delays to customers (Flynn, Huo, and Zhao 2010), enabling an agile response to changes in customer demand. With these factors in mind, we hypothesize the following:

Hypothesis 1: *Internal process connectivity has a positive effect on supply chain agility.*

2.4 External Process Connectivity and Supply Chain Agility

Change events are rarely isolated within a discrete organisational entity, but occur across multiple entities simultaneously (Van de Ven and Poole 1995). In such an interconnected system, there is no such thing as marginal change (Weick and Quinn 1999). Interconnected organisational entities therefore need the ability to collectively respond to disruptive change events as they ripple across the supply chain. Perceiving the supply chain as a process heightens the need for external connectivity amongst supply chain partners(Lambert, García-Dastugue, and Croxton 2005). Developing a mutual understanding of processes enables buyers and suppliers to identify and evaluate complementarities, improving their ability to reconfigure their processes for an agile response (Gligor and Holcomb 2012b). Using connected processes enables supply chain members to share data on customer demand, resulting in an enhanced ability to flexibly respond to marketplace changes (Christopher 2000). Connecting processes with suppliers can allow manufacturing firms to adjust delivery times, amend inventories, and reduce damage and errors through enhanced supplier flexibility (Omar et al. 2012).

Moreover, greater connectedness among supply chain actors enables the achievement of coordinated risk mitigation tactics and faster response to supply chain disruptions (Braunscheidel and Suresh 2009). Process connectivity therefore allows organizational entities in the supply chain to rapidly synchronize supply with demand; a key aspect of supply chain agility (Swafford, Ghosh, and Murthy 2006). Connected processes among buyers and suppliers enables the supply chain process to more effectively meet customer requirements and better respond to changes (Koufteros 2005). Based on this reasoning, we propose the following:

Hypothesis 2: *External process connectivity has a positive effect on supply chain agility.*

2.5 The interactive effects of internal and external process connectivity

Connecting processes internally with supply chain partners can contribute to quick exchange of information, enabling early sensing and rapid evaluation of changes (Barratt and Barratt, 2011). For example, connected process allow buyers and suppliers to simultaneously change production capacity in response to fluctuations in customer demand (Barratt and Barratt 2011; Lambert, Cooper, and Pagh 1998). Indeed, the ability to synchronize supply and demand hinges on the ability of an organisational entity to connect internal functions as well as connecting externally with suppliers and customers (Narasimhan 1997).Furthermore, coordinating internal and external processes allows organisational entities to better understand the interdependent impact of activities, enabling a rapid combination and reconfiguration of processes for an agile response (Braunscheidel and Suresh 2009). Mutual understanding of both internal and external processes enables firms to detect failures quicker, contributing to their sensing ability and their flexibility in response to changes (Narayanan et al. 2011). Given the value of internal process connectivity and external process connectivity independently, it stands to reason that collectively these factors will enhance supply chain agility. The following hypothesis is thus made:

Hypothesis 3: *The interaction of internal process connectivity and external process connectivity has a positive effect on supply chain agility.*

2.5 The Indirect Effects of Supply and Product Complexity

While direct effects are often crucial, they seem incapable of fully capturing the complexity of business reality (Boyd et al. 2011). In fact, scholars have acknowledged that the performance outcomes of supply chain practices depends on the context (Jayaram, Ahire, and Dreyfus 2010; Sousa and Voss 2008). As such, research should not only justify the direct effects of processes, but rather examine the specific conditions under which they are effective (Sousa and Voss

2008). Despite the increasing interest in the investigation of contingencies for operations and supply chain management research (Sousa and Voss 2008), scholars have investigated to a limited extent the contextual factors that facilitate or hamper supply chain agility (Blome, Schoenherr, and Rexhausen 2013).

We focus here on supply chain complexity as it has been recognized as a key area of managerial concern (Blome, Schoenherr, and Eckstein 2014; Choi, Dooley, and Rungtusanatham 2001; Choi and Krause 2006) and as a crucial factor enabling or inhibiting the effectiveness of supply chain processes (Azadegan et al. 2013; Browning and Heath 2009). Supply chain complexity is comprised of two key constructs; product complexity and supply complexity, both of which provide significant challenges for managers when coping with change. While the former stems from the customization, intricacy, and variety of the firm's products (cf. Schoenherr et al. 2010), the latter stems from dynamic supply markets, unreliable suppliers, and a high supplier numbers (cf. Kraljic 1983).

Prior research has shown that product complexity impacts the effectiveness of practices like developing common standards across supply chain processes or connecting procurement and production processes internally (Azadegan et al. 2013). As product complexity increases, it becomes more difficult for firms to assess and predict what factors impact their operations and thus more difficult to identify, diagnose and respond to problems (Azadegan et al. 2013). Product complexity gives rise to ambiguity and coordination challenges during product development and manufacturing (Novak and Eppinger 2001; Koufteros 2005; Bozarth et al. 2009). Product complexity also increases the likelihood of operational errors in forecasting raw material requirements and managing in-bound logistics (Azadegan et al. 2013). Connected processes that enable firms to detect failures more quickly contribute to the development of sensing abilities and an increased operational flexibility to respond to change (Jacobs and Swink 2011). We therefore hypothesize that under conditions of high product complexity, processes characterized by common goals and a high degree of internal and external coordination will enable firms to provide an agile response to change events:

Hypothesis 4a: *Product complexity positively moderates the relationships between internal process connectivity and supply chain agility.*

Hypothesis 4b: *Product complexity positively moderates the relationships between external process connectivity and supply chain agility.*

Supply complexity can similarly impact the effectiveness of internal and external process connectivity in enabling supply chain agility. Supply chain agility involves continuously exchanging data with suppliers so that they can respond promptly to demand (Aitken, Christopher, and Towill 2002; Lee 2004), making data accuracy a key factor for competitive success (Agarwal, Shankar, and Tiwari 2007). However, supply complexity makes it difficult for the firm to anticipate and assess change as well as forecast and prepare for the effects of change events (Azadegan et al. 2013). Unreliable suppliers can seriously hamper a supply chain's end-to-end lead time, which is considered critical to a quick response to changing demand (Aitken, Christopher, and Towill 2002). Under high supply complexity, the firm also faces a higher operational load in managing its supply base (Choi and Hong 2002; Choi and Krause 2006). Connecting processes internally and externally to facilitate seamless physical and information flows along the supply chain, thus contributes to sensing and flexibly responding to change, under conditions of high supply complexity. For example, in a more complex supply environment, joint standards for production and procurement processes allow for orderly interactions with a high number of diverse suppliers (Azadegan et al. 2013). Similarly, process connectivity can enable agile practices such as fast replacement of materials and suppliers' orders or contingency planning, all of which are essential in handling supply disruptions (Lee 2004).

In fact, Integrative practices among supply chain members, including connected processes, are considered to be more effective in environments characterized by high supply complexity (Gimenez, van der Vaart, and Pieter van Donk 2012). Supply complexity has been found to positively impact the effectiveness of process variance reduction, internal process improvement efforts, and supplier involvement in process improvements (Azadegan et al. 2013) Thus, seamlessly connecting processes externally with suppliers to detect quality and delivery issues becomes even more effective for enabling an agile response to changes in supply and demand (Azadegan et al. 2013). We therefore hypothesize that:

Hypothesis 5a *Supply complexity positively moderates the relationships between internal process connectivity and supply chain agility.*

Hypothesis 5b: *Supply complexity positively moderates the relationships between external process connectivity and supply chain agility.*

Drawing together these hypotheses, we now advance a hypothetical model of the positive effects of internal and external process connectivity on supply chain agility and the moderating effects of product complexity and supply complexity (see Figure 1).

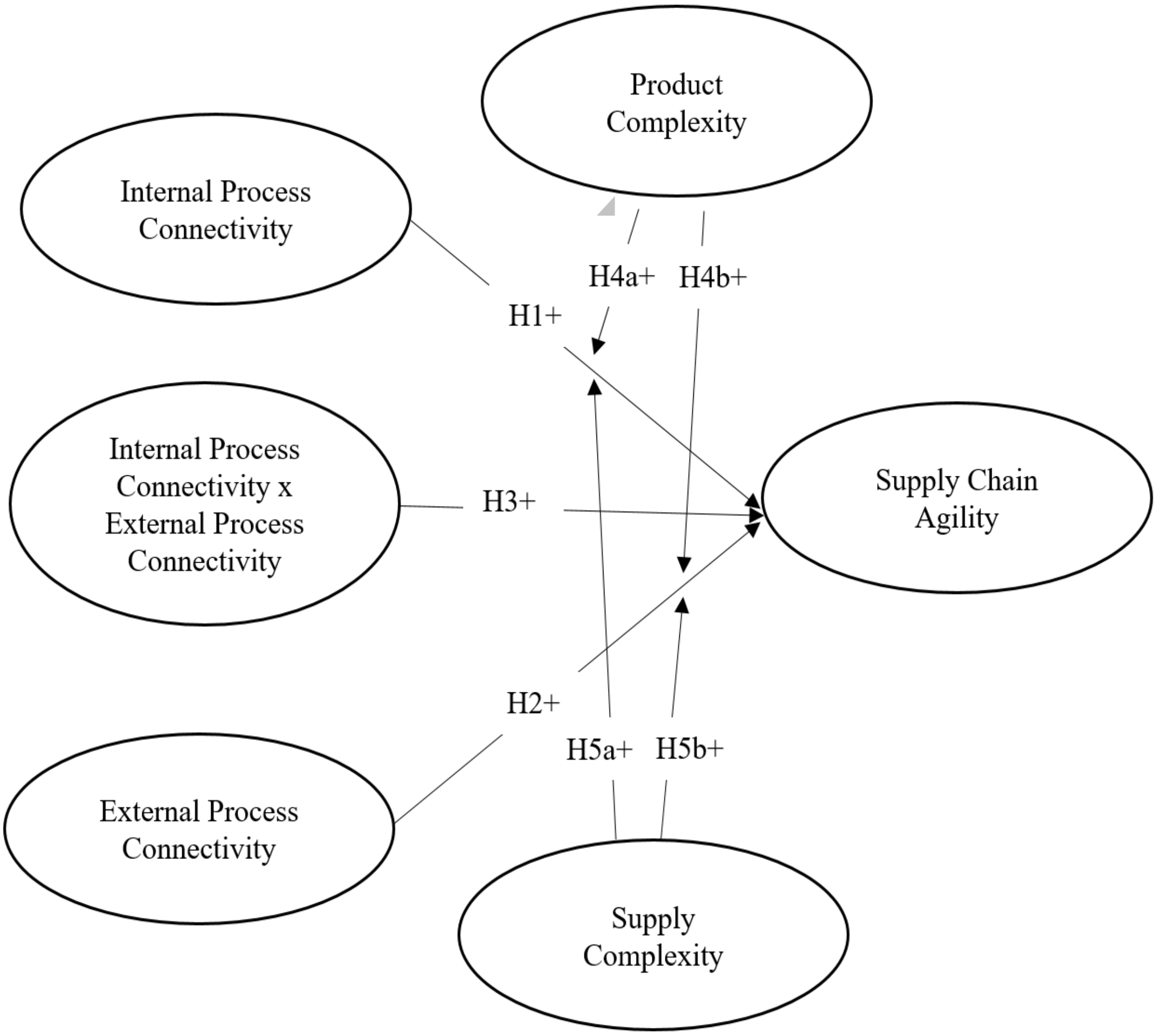

FIGURE 1: Hypothetical Model

3. Research Design

3.1 Data and Method

Our research design is based on a deductive, theory-testing approach. As with earlier studies on supply chain agility (Blome, Schoenherr, and Rexhausen 2013; Eckstein et al. 2015; Swafford, Ghosh, and Murthy 2006, 2008), we relied on surveys to collect data as the variables of our research are latent constructs that are difficult to observe. An electronic survey was targeted at individuals in supply chain management positions in German manufacturing firms. Germany is generally perceived as one of the strongest players in global manufacturing and we therefore felt the German manufacturing sector was a suitable setting to study supply chain agility, particularly as the sector survived the 2008 economic crisis in good form (Coman 2013). Our study focuses on manufacturing firms because these companies are considered to be crucial in global supply chains in terms of providing responsiveness and agility when delivering finished goods to the final customer (Frohlich and Westbrook 2001).

We instructed survey respondents to focus on the most important product supply chain at their company, in terms of revenue generation. Because the survey was completed in German, we followed a rigorous process of translation and re-translation to ensure clarity of the survey items. A pretest was conducted with twelve academics and business professionals following personal discussions on proposed survey questions. Based on the results of these discussions, survey questions were adjusted to confirm that questions were not vague, ambiguous, or difficult to answer (Dillman 2011).

The initial sample frame was comprised of 1,161 firms and was compiled randomly from databases of the German Logistics Association, the German Association for Materials Management, Purchasing and Logistics and Dun & Bradstreet. A randomized sample is suitable to achieve high levels of generalizability which is important for survey research as the observed phenomena for the sample should also be applicable for the population of the study (i.e. manufacturing firms in Germany) (Dillman 2011).

Data collection was conducted following a modified version of Dillman's (2011) total design method. Overall, we received 143 complete and usable responses. The response rate is thus 143/1.161 = 12.3%. Nonresponse bias tests did not indicate statistically significant differences of early and late respondents ($p > 0.05$). In total, 66.7% of the respondents indicated that they belonged to top management, 25.6% to middle management, and 7.8% to lower management. This split between respondents is ideal for a process based assessment of supply chain agility because lower management can comment on how internal processes are operationalized in the daily activities of operational employees (internal process connectivity), middle managers can comment on the company's processes and procedures for managing buyer-supplier relationships (external process connectivity) and senior management have an end-to-end view of the requisite processes needed to source, manufacture and deliver goods at each step of the supply chain and within their own organization (internal and external process connectivity). Table 1 provides an overview of the standard industrial classification (SIC) codes and firm sizes according to number of employees, as represented in our survey.

SIC Code	Description	Percentage distribution
20-39	Manufacturing	71.3%
40-49	Transportation, Communications, Electric, Gas and Sanitary Services	23.0%
	Others	7.4%

Number of employees	Percentage distribution
<250	19.6%
250-1,000	21.7%
1,000-10,000	34.1%
>10,000	24.6%

TABLE 1: Respondent Profile: SIC Codes

3.2. Measures

Table 2 summarizes the scales for the framework in Figure 1. Measures were adopted or modified from scales established in extant research to avoid scale proliferation.

Internal process connectivity was measured according to Chen et al. (2009) where process connectivity is assessed based on human skills, common goals, compatibility, and common standards. For example, in our survey we asked respondents to assess the degree to which: 1) their firm designates people with particular skills to coordinate various internal processes; 2) their firm develops a common goal to align the efforts of all process and setting specific objectives for each process; 3) their firm ensures compatibility among all relevant internal processes and; 4) their firm uses common standards for all internal processes to ensure all process can be linked smoothly (see Table 3)

External process connectivity was also measured following Chen et al. (2009), and addressed process connectivity related to coordination, mutual understanding, common standards, and long-term collaboration between the firm and its suppliers. For example, we asked respondents how their company coordinates processes with suppliers, whether suppliers have a mutual understanding of each other's processes, whether common standards link processes across firms and the degree to which processes between their firm and suppliers build towards long-term collaboration (see Table 3). Based on the pre-test, we substituted some of the items from the Chen et al. (2009) measurements that were less ambiguous to our pre-test audience.

Product complexity consists of items addressing the customization of products and value-added services, the number of product components, and the offering of product variants (Novak and Eppinger 2001; Vachon and Klassen 2002).

Supply complexity includes items that measure the number of direct suppliers, the existence of a high market dynamism on the supply side, and the reliability of the supply base (Vachon and Klassen 2002; Bozarth et al. 2009).

Supply chain agility was measured as per the earlier work of Eckstein et al. (2015). We measured supply chain agility as a secondary construct, consisting of three underpinning constructs including sensing, flexibility and speed (Eckstein et al. 2015). *Sensing* measures the ability of the firm to sense short-term, temporary changes in the supply chain and market environment by measuring latent variable explanations towards changes in technology, competition, demand, and supply (Li, Goldsby, and Holsapple 2009; Overby, Bharadwaj, and Sambamurthy 2009) (see Table 3). *Flexibility* measures the ability of the firm to flexibly respond to short-term, temporary changes in the supply chain and market environment with the existing supply chain (i.e., manufacturing, demand, and supply). Items refer, for example, to the firm's flexibility in throughput times, production processes, or delivery times (Swafford, Ghosh, and Murthy 2006). *Speed* refers to ability of the firm to rapidly respond to short-term, temporary changes in the supply chain and market environment with the existing supply chain (i.e., manufacturing, demand, and supply), indicating the speediness in, for example set-up times or delivery times (Swafford, Ghosh, and Murthy 2008). Indicators representing independent variables in our model were captured using a 5-point Likert scale, from *strongly disagree* to *strongly agree*. Additional control variables were utilized to account for extraneous effects. Specifically, firm size as the logarithmic values of the firm's number of employees and environmental uncertainty (i.e., average percentage of sales volatility per year within the last 5 years) were applied to the model. Furthermore, we tested for the influence of industry on our model, using sets of industry dummy variables. We did not identify any case in which industry significantly influenced ($p > 0.05$) or distorted our model results.

Indicator ***(Cronbach's Alpha; Composite Reliability; Average Variance Extracted)***	**Standard Coefficient**
Supply Chain Agility Measurement Model (model fit: χ2/df = 1.350; RMSEA = 0.049; NNFI = 0.981; CFI = 0.985)	
A.1. Sensing *(α = 0.66; CR = 0.66; AVE = 0.33)*	
Ability to sense short-term, temporary changes in terms of:	
1. Changes in technology (e.g., revisions of existing technologies)	0.51
2. Changes in competition (e.g., fluctuations in competitors' product pricing)	0.68
3. Changes in demand (e.g., demand fluctuations)	0.50
4. Changes in supply (e.g., changes in suppliers' offers)	0.58
A.2. Flexibility *(α = 0.82; CR = 0.82; AVE = 0.40)*	
Ability to flexibly respond to short-term, temporary changes with the existing supply chain in terms of:	
1. Reduce manufacturing throughput times	0.66
2. Adjust production processes	0.54
3. Adjust inventory turnover	0.55
4. Adjust worldwide delivery capacities	0.60
5. Reduce delivery times	0.76
6. Enhance delivery reliability	0.66
7. Reduce replacement times of purchases	0.65
8. Adjust ordered of goods and services in the short-term[a]	
A.3. Speed *(α = 0.76; CR = 0.75; AVE = 0.50)*	
Ability to speedily respond to short-term, temporary changes with the existing supply chain in terms of:	
1. Manufacturing throughput times	
2. Customer delivery times	0.73
3. Replacement times of purchases	0.74
4. Manufacturing set-up times[a]	0.64
Antecedent Measurement Model (model fit: χ2/df = 1.206; RMSEA = 0.031; NNFI = 0.963; CFI = 0.972)	
B. Internal Process Connectivity *(α = 0.86; CR = 0.86; AVE = 0.61)*	
1. Our firm designates people with particular skills to coordinate various internal processes.	0.71
2. Our firm develops a common goal to align the efforts of all processes, in addition to setting specific objectives for each process.	0.88
3. Our firm ensures compatibility among all relevant internal processes.	0.78
4. Our firm uses common standards for all internal processes so that processes can be linked smoothly.	0.74
C. External Process Connectivity *(α =0.86; CR = 0.86; AVE = 0.60)*	
1. Our firm coordinates related processes with suppliers.	0.76
2. Our firm and our suppliers have a high mutual understanding of each other's processes.	0.85
3. Our firm along with our suppliers use common standards to link processes smoothly across firms.	0.77
4. Processes between our firm and suppliers are built towards long-term collaboration.	0.71
D. Product Complexity (*α =0.74; CR = 0.74; AVE = 0.49*)	
1. We offer our customers diverse add-ons and the option of production individualization.	0.70
2. Our products consist of a high number of components.	0.78
3. We frequently offer new product variants.	0.62
E. Supply Complexity (*α =0.58; CR = 0.60; AVE = 0.33*)	
1. The number of our direct suppliers is very high.	0.50
2. Long-term plans of our procurement activities are hampered by high market dynamism.	0.50
3. Our suppliers often do not supply on time or at the desired quality.	0.69

[a] Items dropped due to low loadings.
[b] All *t*-values are significant at $p < 0.05$ level.

TABLE 2: Measurement Instruments

4. Findings

4.1 Assessment of psychometric properties

Before evaluating the reliability and validity of the measurement items, the indicators were tested for the assumption of constant variance, existence of outliers, and normality. To ensure that multi-collinearity was not a problem, we calculated variance inflation factors (VIF). All VIFs were less than 1.29 and therefore considerably lower than the recommended threshold of 10.0, suggesting that multicollinearity was not a problem (Hair et al. 2016).

We used confirmatory factor analysis (CFA) to establish convergent validity and unidimensionality of factors. Table 3 shows an overview of the measurement instruments showing acceptable convergent and divergent validity. The fit indices were as follows for the overall measurement model: Normed Chi-Square = 1.283; RMSEA = 0.045; NNFI = 0.948; CFI = 0.956. The fit indices met or exceeded the minimum threshold value of 0.09 suggested by Hu and Bentler (1999). As illustrated in Table 3, standard loadings were in all cases greater or very close to 0.50 with considerably high t-values ($p < 0.01$), and composite reliability values of constructs were all above 0.60. Therefore, we can assume that convergent validity exists in our measurement model.

Discriminant validity was established by comparing the squared correlation between two latent constructs to their average variance extracted (AVE) (Fornell and Larcker 1981). As outlined in Table 4, none of the correlations was found to be higher than the square root of the AVE for each individual construct, further establishing discriminant validity. However, as common method bias could still occur, we applied the marker variable technique (Lindell and Whitney 2001) which attempts to control for common method variance by including a variable to the measurement model that is theoretically unrelated to the focal constructs of the study. In doing so, we could not determine any potential effects that would indicate a significant amount of common method variance (see Table 3).

Factors	Mean	S.D.	AG	PC	SC	IPC	EPC
Supply Chain Agility (AG)	3.33	0.56	**0.64**				
Product Complexity (PC)	3.59	1.02	0.05	**0.70**			
Supply Complexity (SC)	3.01	1.16	-0.23**	0,24**	**0.57**		
Internal Process Connectivity (IPC)	3.31	1.19	0.39**	0.10	-0.15	**0.78**	
External Process Connectivity (EPC)	3.22	1.01	0.38**	0.09	-0.06	0.44**	**0.77**

[a] The square root of the construct's AVE is provided along the diagonal (given in bold).
[b] Off-diagonal numbers are the Pearson correlation between the constructs.
**significant at $p \leq 0.01$; *significant at $p \leq 0.05$

TABLE 3: Descriptive Statistics and Pearson Correlation Coefficients

4.2 Hypotheses tests

We tested our hypotheses using hierarchical regression analysis. Three models, each with supply chain agility as the dependent variable, were tested. Model 1 (M1) consisted of the control and contingency variables. In Model 2 (M2), the direct effects of internal process connectivity and external process connectivity were added. Table 4 shows the results of the regression analysis.

	Determinants of Supply Chain Agility		
	M1	M2	M3
Control and Contingency Variables			
Firm Size	-0.02	-0.07	-0.10
Environmental Uncertainty	-0.16	-0.11	-0.12
Product Complexity (PC)	0.14	0.07	0.09
Supply Complexity (SC)	-0.25**	-0.19*	-0.17*
Direct Effects			
Internal Process Connectivity (IPC)		0.24**	0.26**
External Process Connectivity (EPC)		0.25**	0.26**
Interaction Effects			
IPC x EPC			0.20**
IPC x PC			-0.01
EPC x PC			0.23*
IPC x SC			-0.02
EPC x SC			-0.02
R2	0.06	0.22	0.27
Model F	3.30*	7.37**	5.62**
Delta R2		0.15	0.05
Delta model F		14.21**	2.88*

* $p < 0.05$; ** $p < 0.01$

TABLE 4: Results of Hierarchical Regression Analysis on Supply Chain Agility

The results show that both internal process connectivity (H1: *ß* = 0.24; $p < 0.01$) and external process connectivity (H2: *ß* = 0.25; $p < 0.01$) have a positive effect on supply chain agility. Therefore, H1 and H2 are supported. Therefore, both internal and external process connectivity play a significant role for achieving supply chain agility. However, most importantly, in Model 3 (M3), the interaction effect between internal process connectivity and external process connectivity on supply chain agility were tested. Results provide a significant positive relationship (H3: *ß* = 0.20; $p < 0.01$). Thus, H3 is supported. This result suggests that, in accordance with process theory, both internal connectivity and external connectivity play an important role in achieving supply chain agility and that fully interconnected processes allow firms to better respond to continuous change.

The moderation of product complexity on the path between internal process connectivity and supply chain agility showed no significant impact (ß = -0.01; $p > 0.05$). However, product complexity had a significant impact on the path between external process connectivity and supply chain agility (*ß* = 0.23; $p < 0.05$). The moderation of supply complexity showed neither impact on the path between internal process connectivity and supply chain agility (*ß* = -0.02; $p > 0.05$), nor between external process connectivity and supply chain agility (*ß* = -0.02; $p > 0.05$). Though only one of the moderation effects is significant it provides interesting insights which we will debate in the discussion section.

To further illustrate the results of the moderating effects, we applied the procedure by Dawson and Richter (2006) to plot the interaction effects. The score plots for the investigated significant moderating effect is illustrated in Figure 2.

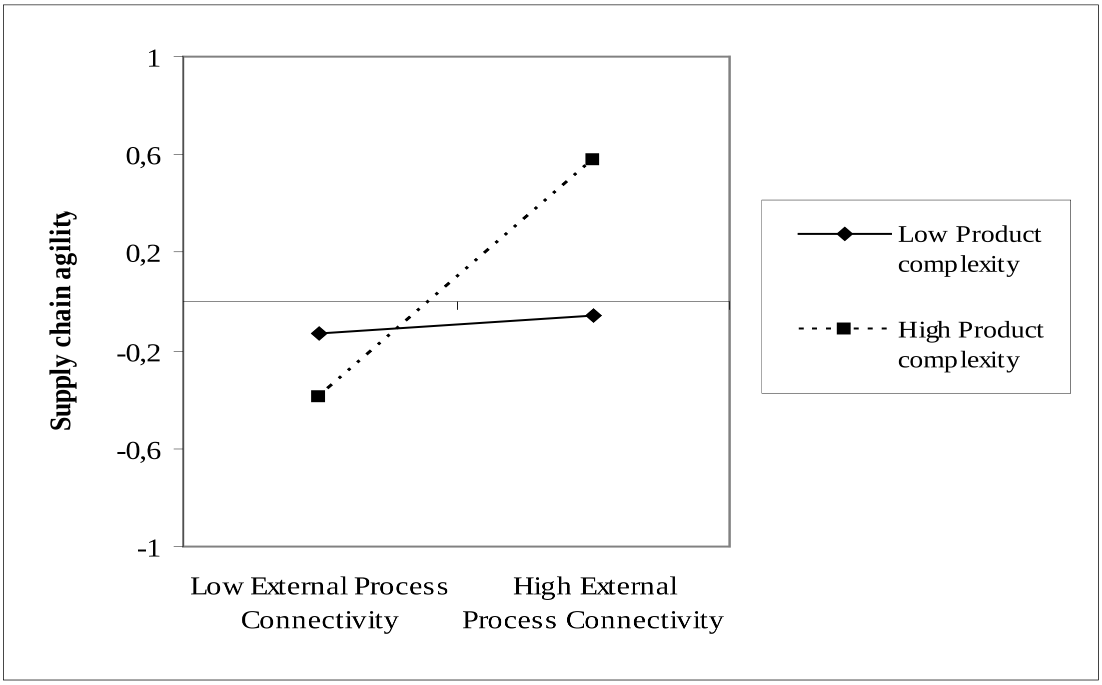

FIGURE 2: Moderating Effect of Product Complexity and External Process Connectivity

5. Discussion of Findings

5.1. Discussion of results and implications

In this paper, we examined how a focal organisation's processes can be connected internally and externally with supply chain partners to enable an agile supply chain response to change events. Specifically, we extended life cycle theory to the supply chain to propose and empirically test two models of supply chain agility. While the first model hypothesized separate direct effects of internal and external process connectivity on supply chain agility, the second model hypothesized an interaction effect of the two types of processes.

In the first instance, the results demonstrate that internal process connectivity positively impacts supply chain agility and helps firms to respond internally to change. The sensing aspect of supply chain agility considers how organisations are able to sense short-term changes in the competitive landscape as well as changes in demand and supply (Narayanan et al. 2011). Our results suggest that internal process connectivity, including the ability to develop common goals, ensure compatibility and align processes, positively affects the organisation's ability to sense and react to change.

Furthermore, our results provide evidence of a positive effect of external process connectivity on supply chain agility. We found that coordination and having a mutual understanding of the processes that exist between the focal firm and its suppliers, as well as developing common standards, allows for external processes to be connected smoothly. In turn, external process connectivity was found to have a significant and positive impact on the focal firm's ability to sense and react to technological and competitive change events.

These findings support our theoretical reasoning and validate prior conceptual and anecdotal evidence on the relationships among dimensions of process connectivity and supply chain agility (c.f. Chen, Daugherty, and Roath 2009). Connecting processes internally within the firm and externally with supply chain partners appears to be a crucial means of enhancing the responsiveness of the supply chain; elucidating the essence of life cycle theory which suggests that processes have to be connected in a logical order to allow for firms to find stability and adaptability (Schreyögg and Sydow 2011; Van de Ven and Poole 1995, 2005). In this regard, our results strengthen prior research suggesting that the ability of firms to connect internal and external supply chain processes is critical to achieving agility (Blome, Schoenherr, and Rexhausen 2013; Christopher 2000; van Hoek, Harrison, and Christopher 2001; Khan and Pillania 2008; Swafford, Ghosh, and Murthy 2006). We thus provide further evidence that a life cycle view provides a compelling means for understanding the intricacies of the supply chain as a process (Lambert et al. 2005; Narayanan et al. 2011).

In addition to finding evidence of the direct effects of internal and external process connectivity, we found that their interactive affects were significantly and positively related to supply chain agility. In this regard, we contribute to research emphasizing the importance of examining interaction effects for understanding relationships among supply chain concepts (Flynn, Huo, and Zhao 2010; Germain and Iyer 2006; Vickery et al. 2010). Our findings suggest that for firms developing supply chain agility, it may be more valuable to follow a balanced approach by equally establishing internal and external process connectivity, rather than placing emphasis on one dimension of process connectivity over the other.

Our analysis also provides evidence for the moderating impact of product complexity on the relationship between external process connectivity and supply chain agility. Under high product complexity, it seems crucial for a firm to establish connected processes with suppliers to successfully develop an agile supply chain, whereas firms with lower levels of product complexity might benefit less from internal and external process connectivity in terms of increasing their supply chain agility. In contrast, the other contingency effects had almost no impact on the relationships between the two competencies (internal and external process connectivity) and the capability (supply chain agility).

6. Implications for Theory and Practice

6.1 Theoretical Contribution

The theoretical contribution of our paper rests on its extension of life cycle theory to the supply chain, thereby permitting a better understanding of how connected processes enable an agile response to change events. To our knowledge, this is the first empirical assessment of the discrete and interactive effects of internal and external process connectivity on supply chain agility from a life cycle theory perspective. Our results show internal and external process connectivity interact to positively affect supply chain agility, underlining the boundary-spanning nature of supply chain agility. The findings suggest that using common standards to achieve seamlessly connected processes along the supply chain should position firms to better sense and rapidly respond to changing customer requirements and market conditions. Our paper contributes to the current thinking on supply chain agility, as we suggest that organisations should combine internal as well as external processes to provide an agile response to constant change.

By conceptually and empirically differentiating between internal and external process connectivity, we extend prior research on process-related enablers of supply chain agility which, to date, has not clearly differentiated between internal and external processes or has used the terms interchangeably (Vázquez-Bustelo, Avella, and Fernández 2007; Chiang, Kocabasoglu-Hillmer, and Suresh 2012; Gligor and Holcomb 2012a; Blome, Schoenherr, and Rexhausen 2013). In doing so, we explicitly address the interactive effects between the two dimensions of process connectivity. This is an important contribution to research, as the theoretical meaning and managerial implications of interaction effects remain under researched (Droge, Jayaram, and Vickery 2004). Moreover, we validate and extend prior research (e.g. Christopher 2000; van Hoek, Harrison, and Christopher 2001) in that we conduct rigorous empirical tests of the relationships between internal and external process connectivity and supply chain agility. In doing so, we answer calls for research to further engage in examinations of the inter-firm processes that enable supply chain agility and contribute to theory in this important area (Gligor and Holcomb 2012b).

Based on the analysis, we can conclude that external process connectivity is more effective in enabling supply chain agility under high product complexity than it is under low product complexity; it seems equally effective under high supply complexity and low supply complexity. Moreover, both dimensions of supply chain complexity seem to have limited impact on the effectiveness of internal process connectivity in enabling supply chain agility. These findings suggest that the enabling effect of process connectivity seems to exist irrespective of the complexity of the firm's environment.

Our results are indicative of the differential effects that the individual dimensions of product and supply complexity have on the relationships between internal and external process connectivity and supply chain agility. For example, while a high number of suppliers could increase the effectiveness of process connectivity in enabling supply chain agility, a high number of less reliable suppliers could have an impact in the opposite direction. For example, joint standards for production and procurement processes allow for orderly interactions with a high number of diverse suppliers (Azadegan et al. 2013), thus enabling supply chain agility. On the other hand, unreliable suppliers can seriously hamper a supply chain's end-to-end lead time, which is considered critical to quick response to changing demand (Aitken, Christopher, and Towill 2002). As Agarwal et al. (2007) note, firms cannot meet customer specifications and maximize value to customers if sourced components are defective or late. In this context, connecting processes with suppliers may not be the right strategy to enhance supply chain agility, given that the problems may be internal to the supplier or lie within the supplier's supply base, and not at the interface to the buying firm.

6.2 Managerial Contribution

From a practitioner perspective, our results provide insights for managers on the value of internal and external process connectivity when embedding agility in the supply chain. By conducting rigorous empirical tests, we go beyond anecdotal observations to provide empirical evidence that managers aiming to develop supply chain agility do indeed benefit from connecting processes along the supply chain. Specifically, our findings suggest that improving the mutual understanding of processes between a firm and its suppliers enables managers to detect failures more quickly, thereby contributing to the agility of the supply chain and its responsiveness to change. Our analyses demonstrate that once managers identify weaknesses associated with either internal or external process connectivity, corrective actions need to be taken to reduce these vulnerabilities, and increase the firm's level of supply chain agility.

We stress that managers require a thorough understanding of the business environment before connecting processes. We provide preliminary evidence that connecting processes across the supply chain may not necessarily result in effective supply chain agility for each and every firm and its particular environment. Specifically, our analysis suggests that internal and external process connectivity result in equally enhanced levels of supply chain agility, regardless of the level of supply complexity. This finding indicates that the effort to develop process connectivity is justified in both complex and simple supply environments, as it leads to improved supply chain agility. On the other hand, our results show that external process connectivity is more effective under high product complexity than under low product complexity. In this regard, we provide guidance for managers who need to allocate the resources required to develop external process connectivity as a competence that enables supply chain agility.

Depending on the level of product complexity, managers may want to place more emphasis on external process connectivity. While it may be more difficult to implement external process connectivity in a complex environment, the rewards gained from doing so may justify the efforts. Given the ability to connect processes externally with suppliers, managers may deliberately decide to cater to markets that, although they are less predictable, might nevertheless have higher demand for complex, higher-margin products. Our findings on the increased effectiveness of external process connectivity in a complex product environment further strengthens the notion that much of the conventional wisdom concerning the relationships between buyers and suppliers will need to be challenged if firms want to successfully develop supply chain agility.

6.3 Limitations and directions for future research

This paper takes an important first step in extending life cycle theory to the supply chain. Future research efforts could further expand on life cycle theory by providing a comprehensive understanding of the process-related enablers of supply chain agility. Also, it might be interesting to triangulate our findings with objective indicators for measuring supply chain agility and/or connectivity. Extending life cycle theory to the supply chain opens up a wide range of potentially fruitful areas for future research including an exploration of new product development, product design, order fulfillment, re-manufacturing and closed loop supply chains. Researchers could also apply life cycle theory to service-based industries to gain interesting insights on how services are configured and delivered to customers. Finally, as we investigated the hypothesized relationships in a German context, the results may not be transferable to other regions. Future research may extend the regional scope to include other important regions, such as Asia or North America. Moreover, researchers may want to look at different industries outside of manufacturing based sectors.

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