2
Supply Chain Flexibility (SCF)

Flexibility is a multi-dimensional concept with various facets (Slack, 1987; De Toni & Tonchia, 1998; Sánchez & Pérez, 2005; Stevenson & Spring, 2007; Gosling et al., 2010; Fatemi, 2010; Christopher & Holweg, 2011). To understand which aspects of flexibility are within the scope of the current investigation, this literature review begins by reviewing the key contributions of the concept of flexibility. Subsequently, previous contributions on SCF are discussed and gaps in the current context are highlighted.

2.1.
Introduction to the Flexibility Concept

In recent decades, several contributions have been made to the flexibility subject, including important contributions to the concept itself. Four key aspects of flexibility have been suggested: (1) its types (see, for example, Slack, 1987; Upton, 1994), (2) its dimensions (see, for example, Slack, 1987; Upton, 1994; Koste et al., 2004), (3) its timeframe (see, for example, Zelenović, 1982; Carlsson, 1989; Upton, 1994), and (4) its uses (see, for example, Gerwin, 1993; Sawhney, 2006; Hallgren & Olhager, 2009).

Because flexibility is commonly associated with the ability to change or react (Upton, 1994; De Toni & Tonchia, 1998), a central aspect of flexibility is the object of change (i.e., "What is it that changes?"). This aspect is commonly referred to as the flexibility type (Slack, 1987; Suarez et al., 1996). According to Slack (1987), there are four types of flexibility in a manufacturing system: product, mix, volume and delivery. Product flexibility refers to the system's ability to introduce new products or make modifications to existing ones. Mix flexibility denotes the ability of a system to alter its product mix (keeping overall output stable), while volume flexibility refers to a system's ability to change its

overall production volume. Finally, delivery flexibility denotes a system's ability to change planned delivery times (or sequences) for existing orders. Upton (1994) suggested a distinction between "external" and "internal" flexibility. External flexibility refers to the flexibility types that matter to the system's customers (i.e., "What the customer sees", Upton, 1994, p. 75), while internal flexibility comprises all types that are internal to the system and are used to deliver external flexibility (i.e., "What can we do", Upton, 1994, p. 75). External flexibility is commonly understood to include the four types originally suggested by Slack (see, for example, Suarez et al., 1996; Pagell & Krause, 2004; Sawhney, 2006), while the number of internal flexibility types appears to depend on the specific operational setting.

In addition to different types, flexibility has three different dimensions: range, response (cf. Slack, 1987) and uniformity (cf. Upton, 1994). Flexibility range denotes the spectrum of states that a system can take, such as the total number of products a manufacturing system can produce (i.e., its product variety) or the range of output volumes at which it can operate. Flexibility response refers to the ease (in terms of time and/or cost) with which the system can adjust within its given range (e.g., how long it takes to switch production from product A to product B). Finally, flexibility uniformity measures the performance distribution of the system over its range (e.g., the ability of the system to produce similar unit costs at different output levels). Koste et al. (2004) have suggested dividing the range dimension into range-number and range-heterogeneity to account for the degree of differences between the states a system can take. While range-number continues to be a measure for the absolute number of states (e.g., the absolute product variants a system can produce), range-heterogeneity denotes the differences between these states (e.g., a system that produces 100 different variants of the same product may be less flexible than a system that produces five completely different single-variant products).

Another key characteristic is the timeframe (Zelenović, 1982; Carlsson, 1989; Upton, 1994). For example, a system may be very flexible in the long term but show almost no flexibility within an operational time horizon of a few days. Carlsson (1989) provides a discussion of three key timeframes, operational, tactical and strategic flexibility. Furthermore, some authors have pointed out the difference between a proactive and reactive use of flexibility. Traditionally,

flexibility has been seen as a measure of reaction to uncertainty (both internal and external to the system's operations). However, flexibility can also be used to seize opportunities in the marketplace without waiting to react to a stimulus (Gerwin, 1993; Upton, 1994; Sawhney, 2006). Finally, there can be two references of flexibility: it can refer to a system's potential to react (or act) or its demonstrated level of flexibility at any point in time (Slack, 1987; Upton, 1994). While the latter can be observed, it is difficult to assess the former as long as it exceeds what the system is actually demonstrating.

2.2.
Supply Chain Flexibility Concept

In the academic literature there is no unanimous definition for SCF. The literature offers different definitions. The main SCF definitions are depicted in Table 1. The first column displays the considered references, while the second presents the definitions themselves and the third provides the other papers that have adopted the mentioned definition in their work.

Reference	**Definition**	**Papers that adopted the definition**
Vickery et al. (1999)	"...is an amalgamation of product flexibility, volume flexibility, new product flexibility, distribution flexibility and responsiveness flexibility"	Duclos et al. (2003); Gosling et al. (2010); Malhotra & Mackelprang (2012); Qrunfleh et al. (2012)
Das & Abdel-Malek (2003)	"...is defined as the robustness of the buyer–supplier relationship under changing supply conditions"	Gosling et al. (2010)
Duclos et al. (2003)	".. include the flexibility dimensions required by all the participants in the supply chain to successfully meet customer demand"	Coronado & Lyons (2007); Yi et al. (2011)

Gosain et al. (2004)	"...refers to the extent to which the supply chain linkages are able to adapt to changing business conditions rather than being forced into adapting to a given environment"	Choy et al. (2008); Gosling et al. (2010)
Sánchez & Pérez (2005)	"... is defined to encompass those flexibility dimensions that directly impact a firm's customers and are the shared responsibility of two or more functions along the supply chain, whether internal (marketing, manufacturing) or external (suppliers, channel members) to the firm"	Hua et al. (2009)
Swafford et al. (2006)	"... represents those abilities of reducing supply chain lead-time, ensuring production capacity, and providing product variety while fulfilling customer expectations"	Tachizawa & Thomsen (2007)
Kumar et al. (2006)	" ... is the ability of supply chain partners to restructure their operations, align their strategies, and share the responsibility to respond rapidly to customers' demand at each link of the chain, to produce a variety of products in the quantities, costs, and qualities that customers expect, while still maintaining high performance"	Qrunfleh et al. (2012)
Stevenson & Spring (2007)	"...is viewed as a system or network of interrelated external flexibilities (inbound and outbound) and internal manufacturing flexibilities, which taken together support the focal firm's performance outcomes from a customer	Malhotra & Mackelprang (2012)

	oriented perspective"	
Merschmann & Thonemann (2011)	"... enables a company to respond more quickly to changes in supply and demand"	
Chuu (2011)	"...is considered as the ability of a supply chain to effectively and efficiently cope with environmental uncertainties, which can provide various quality products at low cost"	
Moon et al. (2012)	"...represents the capability of firms to respond to unanticipated changes in customer needs and competitor actions"	

Table 1- Main SCF Definitions

The SCF definitions embraces the ability to respond to demand uncertainties through one systemic SC view, since flexibility dimensions is required by all the participants in different perspectives as internal and external dimensions (Das & Abdel-Malek, 2003; Duclos et al., 2003; Gosain et al., 2004; Sánchez & Pérez, 2005; Swafford et al., 2006; Kumar et al., 2006; Stevenson & Spring, 2007; Merschmann & Thonemann, 2011; Chuu 2011; Moon et al., 2012).

Stevenson & Spring (2007) point out the following five elements to provide a comprehensive definition of flexible SCs:

- Robust network (or rigid) flexibility: The range of events that the existing SC structure is able to cope with;
- Re-configuration flexibility: The ease (mobility) with which the SC can be re-configured (adaptability). The need to re-configure is largely determined by the range (or resilience) of the existing SC structure;
- Active flexibility: The ability to act as a chain either as a response to, or in anticipation of, changes/events (i.e. a reactive or proactive capability);

- Dormant (or potential) flexibility: The flexibility of the SC is partially a contingent resource, i.e. it does not have to be a demonstrable capability;
- Network alignment: Entities are focused on aligning their capabilities (internal flexibility) in order to meet the objectives of the SC and compete as a chain (external flexibility).

2.2.1.
Synthesis for the definition

Base on the different SCF definitions presented in table 1, one can notice the evolution of the concept, which starts focused on internal flexibility and dyadic relationship (Vickery et al., 1999; Das & Abdel-Malek, 2003), and extend, along the time, the scope of the definition to a SC view, where the flexibility dimensions are required by all the involved members in a SC dimensions (Duclos et al., 2003; Gosain et al., 2004; Sánchez & Pérez, 2005; Swafford et al., 2006; Kumar et al., 2006; Stevenson & Spring, 2007; Merschmann & Thonemann, 2011; Chuu 2011; Moon et al., 2012). The objective of SCF has also evolved from the idea of meeting customer demand to ones that aggregates the idea of performance beyond to respond to demand uncertainties.

2.3.
Advances on Supply Chain Flexibility

Research into the flexibility of SCs is relatively new, with the first contributions in this field appearing in the late 1990s (Fisher, 1997; Lowson et al., 1999; Vickery et al., 1999). The basic idea behind the extension of the flexibility into SCs can be described in the words of Fatemi (2010): "Now-a-days researchers emphasize it is important to look beyond the flexible factory to the flexible SC.... As the SC extends beyond the enterprise, SCF must also extend beyond one firm's internal flexibility (p. 140)". According to Moon et al. (2012), SCF involves the application of SC resources according to marketing dynamics, and requires firms to develop cross-functional and cross-company strategies that eliminate bottlenecks and create a level of performance that allows firms to strengthen their competitive advantage in an uncertain market. The current

literature on SCF covers a range of foci (for comprehensive literature reviews, see Stevenson & Spring, 2007 and Fatemi, 2010). For example, Fisher (1997), Randall & Ulrich (2001), Lee (2002), Qi et al. (2009) study the relationship between SC structure, product structure and external environment Similar to the literature on manufacturing flexibility (e.g., Swamidass & Newell, 1987; Berry & Cooper, 1999), these authors conclude that flexibility does not always lead to higher profitability; the level of flexibility needs to be aligned with the requirements placed upon the SC. Another focus of SCF is the design of SCs. Chandra & Grabis (2009) present potential tools and techniques for designing and modeling flexibility in SCs, and Graves & Tomlin (2003) study how SCs can cost efficiently deliver mix flexibility based on a mathematical model and subsequent simulation. Tsay & Lovejoy (1999) and Liao et al., (2010) have contributed to the topic of SCF measurement by studying how to quantify flexibility and its impact in the SC performance. Kumar & Desmukh (2006) present a model of manufacturing with attempts to enhance the SCF through a volume multiple assemble line to fulfill the objectives of customization along with timely delivery. Gosling et al., (2010) have examined how organizations can configure their supply networks to achieve SCF, while Lee et al., (2009) have studied supplier alliances in environment uncertainty, showing their impact on flexibility and suggesting that firms should avoid close supplier relationships in uncertainty environments to gain flexibility in switching suppliers.

In this sense, the flexibility concept may be complemented by a range of inter organizational flexibility types. For example, in their literature reviews, Stevenson & Spring (2007) and Fatemi (2010) identify a number of flexibility types that are important on a SC level.

According to Stevenson & Spring (2007), these include re-configuration flexibility as the "potential to re-align or re-invent the SC", relationship flexibility as the "ability to build collaborative relationships both up and downstream", and logistics flexibility as the "potential to rapidly send and receive products cost efficiently". Fatemi (2010) proposes postponement flexibility as the "capability of keeping products in their generic form as long as possible downstream in the SC to incorporate the customer's product requirements in later stages" and sourcing flexibility as the "ability to find another supplier for each specific component or raw materials". Table 2 summarizes the key aspects of flexibility.

Types			Dimensions	Timeframe	Usage	Flexibility Reference
External	**Internal Firm**	**Internal Supply Chain**				
Product	Labour	Sourcing	Range-number	Operational	Proactive	Demonstrated
Mix	Routing	Re-configuration	Range-heterogeneity	Tactical	Reactive	Potential
Volume	Change-over	Relationship	Response	Strategic		
Delivery	Others	Postponement	Uniformity			
		Logistics				
		Others				

Table 2- Seven key aspects of flexibility

While internal SC flexibility types are relevant for the inter-organizational discussion within the SC, we argue that these types constitute internal types of flexibility because the end customer does not care how the SC manages to be flexible (e.g., by adding new partners when required or by linking existing partners by flexible logistics). The customer's concern is with the four external types, such as whether the SC can introduce novel products or change its product mix, volume or delivery arrangements output according to the customer's requirements. As previously highlighted, these external types have been considered in the manufacturing flexibility context (Slack, 1987). However, the debate should encompass the SC beyond a single manufacturing system. From this perspective, volume flexibility requires close coordination between a firm and its suppliers, especially in the face of increasing demand. This external flexibility type directly impacts SCs' performance by preventing out-of-stock conditions for products that are suddenly in high demand or by preventing high inventory levels (Fatemi, 2010). The ability to rapidly introduce new products and product variety and to adapt lead times to customers' requirements (delivery) are external flexibility types that require the integration of numerous value activities across the SC (Fatemi, 2010).

2.4.
Empirical Studies on Supply Chain Flexibility

In spite of the increasing importance of the topic, few empirical contributions investigate the structure of SCs from a flexibility viewpoint. Chang et al. (2006) extend the knowledge of manufacturing flexibility regarding its integration with SC activities, focusing on supplier involvement in the motherboard industry in Taiwan. They find that supplier involvement plays a major role in the development and performance of firm's manufacturing flexibility. However, though they do consider part of the SC, their focus is restricted to manufacturing flexibility. Sawhney (2006) investigates the interplay between uncertainty and flexibility in the SC and discusses how the processes in a SC interact to deliver flexibility. This author proposes a transformation framework that articulates how managers can configure flexibility simultaneously between the proactive and the reactive uses that coexist in a firm's day-to-day operations. However, a key shortcoming of Swahney's study, and one that is shared by most empirical studies on SCF (also see the studies by Vickery et al., 1999; Swafford et al., 2006; Hua et al., 2009; Merschmann & Thonemann, 2011; and the conclusions reached by Stevenson & Spring, 2007 on their literature review on SCF), is that it does not study the companies (tiers) in an interconnected way, as actually occurs, but treats the flexibility of SC partners as a secondary input. Sánchez & Pérez (2005) also do not consider connected firms, but they treat flexibility of SC partners as a primary input to explore the relationship between the dimensions of SCF and firm performance in Spanish automotive suppliers. They show that companies enhance more the basic flexibility capabilities (at the shop floor level) than aggregate flexibility capabilities (at the customer-supplier level).

More recently, Moon et al. (2012) develop a multifaceted scale for SCF through an empirical study among firms. These authors determine how an instrument with a set of multi-item measurement scales representing the SCF construct could be developed and validated. Although they have included many firms within the textile and clothing industry in China, they also do not focus on connected firms within a same SC.

The empirical study of Avittathur & Swamidass (2007) embrace connected

firms within the SC to investigate the effect of the match between the buyer and supplier flexibilities on the performance of U.S. manufacturing plants located in India. Nevertheless, their study is limited to multi-tier pairs (manufacturer / supplier).

Stevenson & Spring (2009) investigated the specific inter-firm practices that are used to achieve increased flexibility in multi-tier pairs and in the wider SC and how these practices and effects interact. To date, their study is the closest to the objectives of this current investigation. However, a key difference of their study, also shared by Avittathur & Swamidas (2007) and the other mentioned empirical studies on SCF presented, is that they did not examine the restrictions in a SC that limit its ability to demonstrate flexibility to end-customers.