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Selecting the right supply chain based on risks

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Abstract

Purpose – The purpose of this paper is to propose a model that enables a company to select the supply chain strategy based on risk probability p (measure of how likely/often a detrimental event occurs) and risk impact i (expression of the significance of a loss when that event occurs).

Design/methodology/approach – This paper discusses four supply chain strategies: agility, robustness, resilience and rigidity. Mathematical models are used for the strategies' cost functions, which reveal optimal solutions and break-even points in dependence of p and i.

Findings – This paper proposes that resilience is appropriate in the case of high supply chain risk probability and impact, and rigidity if both values are low. When only risk impact is low, robustness is optimal, whereas agility is optimal when only risk probability is low.

Research limitations/implications – This research extends existing models for selecting the appropriate supply chain strategy.

Practical implications – Knowledge of the interplay between the strategies' cost functions and risk probability and risk impact is vital for companies. This may encourage managers to become more familiar with their strategy costs and supply chain risks.

Originality/value – To the author's knowledge, no corresponding model exists so far that links risk impact and risk probability to the four supply chain strategies.

Keywords Supply chain management, Strategy, Risk management, Agility, Robustness, Resilience

Paper type Research paper

1. Introduction

Due to the high-probability of risk occurrence, managers are usually aware of the everyday risks their supply chains are exposed to. Hence, measures are in place to mitigate these risks, e.g. by the use of multiple sources, safety stocks and flexible transportation. However, businesses that do not have a supply chain risk management (SCRM) in place may neglect specific risks – particularly if the frequency of occurrence is low or the nature of the risk is unique, as was the case when Ericsson experienced a major supply disruption after a fire at a key chip supplier's plant in 2000 (Norrman and Jansson, 2004). In addition, a financial crisis is indicative for less probable, but more destructive, risks that may hit a supply chain. The burst of the real estate bubble in 2007 led to a global economic downturn. In 2009 the global GDP was shrinking and the growth momentum was slow going into 2010. Global supply chains were directly affected by the crisis: traffic decreased across all transport modes and the volume of orders for logistics services and manufacturers was insufficient. The build-up of overcapacities in many companies also added to the difficulties. Everyday risks had to be managed in other ways than risks like financial crises, the loss of a key supplier, a volcanic eruption in Iceland or an earthquake in Japan. When concentrating on the

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strategic phase of supply chain management (SCM), the selection of the appropriate supply chain strategy is crucial to achieve a fit with the supply chain's risks. Supply chain strategies such as agility (Ramesh and Devadasan, 2007; Sharifi *et al.*, 2006; Yauch, 2011), robustness (Meepetchdee and Shah, 2007; Stonebraker *et al.*, 2009), and resilience (Ponomarov and Holcomb, 2009; Sheffi, 2005) have previously been discussed in the realm of manufacturing and SCM. The main purpose of this paper is to propose a model that enables a company to select the supply chain strategy based on the risk dimensions of "probability" and "impact". In a first step, based on a literature review, this article provides a conceptual overview of strategic SCM, and then defines the relevant supply chain strategies. Furthermore, relevant ideas of SCRM are outlined. In a second step, the costs of four supply chain strategies are illustrated and a framework to select the appropriate supply chain strategy is proposed by joining strategic SCM and SCRM.

2. Conceptual overview

According to a "unionist perspective" on logistics and SCM, presented by Larson *et al.* (2007), SCM can be seen both as "broad" and "deep". SCM is broad because it covers business functions such as manufacturing, marketing and logistics. SCM is deep because it covers strategic, tactical and operational management phases (de Kok and Graves, 2003, p. 1). The strategic phase of SCM relates to decisions made by a firm that have a long-lasting effect. These include decisions about outsourcing, supplier selection and warehouse/plant location (Simchi-Levi *et al.*, 2008, p. 12). The key element in this phase is the selection of the appropriate supply chain strategy in accordance with product and market requirements. To date, no final consensus has been obtained on how to define various strategies. Strategic SCM research is hampered as long as no conceptual clarity of the applied strategies exists. To help compensate for this lack, a literature overview is provided, which aims to clarify the understanding of four important supply chain strategies: agility, robustness, resilience and rigidity.

2.1 Agile supply chains

Much effort has been made to define supply chain agility. Christopher *et al.* (2006, p. 281) emphasize that supply chain agility is concerned "primarily with responsiveness". Likewise, many agility definitions share verbs that point at the ability of a system to answer to change, i.e. "react", "respond", "adapt" or "re-configure". Agility has been viewed as an ability "to adapt or respond in a speedy manner" (Braunscheidel and Suresh, 2009) and, very similarly, "to respond quickly and adequately" (Charles *et al.*, 2010). Very few authors consider agility to be proactive (Ismail *et al.*, 2011) rather than reactive. Agility has been understood both as a performance outcome and a structural or operational characteristic (Yauch, 2011). The capability of using resources in response to changes is important to the understanding of agility (Li *et al.*, 2008, p. 411). According to Ismail and Sharifi (2006), these changes are triggered by the demand side. They define agility as the ability to "rapidly align the network and its operations to the dynamic and turbulent requirements of the demand network". Jain *et al.* (2008) deem it as "the ability of a supply chain to rapidly respond to changes in market and customer demands". A similar view is expressed by Vinodh *et al.* (2010) and Khan *et al.* (2009). To Lee (2002), however, agility is a strategy that is appropriate in the case of both uncertain supply and uncertain demand. Others disregard the reasons for change: Bernardes and Hanna (2009) suggest that agility is an approach focused on "rapid system reconfiguration in the face of unforeseeable changes". This notion of an agile supply chain corresponds with the notion of an agile enterprise, which responds to unexpected change, whereas flexibility responds to expected change (Goranson, 1999, p. 68). Other authors consider flexibility a subset of agility (Swafford *et al.*, 2008, p. 289; Lummus *et al.*, 2005, p. 2688). In addition to flexibility, the concept of speed is inherent to agility (Prater *et al.*, 2001, p. 824) as reflected by the attribute "rapid" in several definitions. Taking the aforementioned attributes into account, the following definition is proposed.

Definition 1. A supply chain is agile if it uses resources that enable it to rapidly respond to change by adapting its initial situation.

2.2 Robust supply chains

In a broad sense, supply chain robustness may be seen as the ability to cope with both deviation and disruption (Dong, 2006). According to Meepetchdee and Shah (2007), it is defined as the extent to which the supply chain is able to carry out its functions despite some damage done to it, e.g. in the face of an attack (Dekker and Colbert, 2004). A robust supply chain retains the same stable situation as it had before changes occur (Asbjørnslett, 2008) and its processes are insensitive to noise factors (Mo and Harrison, 2005). Hence, a robust supply chain resists rather than responds to changes. In order to achieve that, the design of robust supply chains seeks to configure the supply chain infrastructure so that it performs well over a wide variety of possible demand scenarios (Harrison, 2005, p. 10). Tang (2006) suggests nine paradigms to achieve robust supply chains that aim to improve both the capability to manage supply or demand better under normal circumstances as well as the capability to sustain operations when a disruption hits. Many of these paradigms aim to integrate additional resources into the supply chain, i.e. additional modes, carriers and routes for transportation, additional stocks and additional suppliers. Thus, the robustness of a supply chain can often be rooted in its level of redundancy (Albert and Barabási, 2002). Redundancy is gained largely through investments in capital and capacity before the point of need (Rice and Caniato, 2003, p. 25 f). Not only redundant resources but also reliable resources contribute to robustness. It can therefore improve robustness by getting the right players involved early on in designing the supply chain (Handfield *et al.*, 2008, p. 42). The following definition is proposed.

Definition 2. A supply chain is robust if it uses resources that enable it to resist change without adapting its initial situation.

2.3 Resilient supply chains

According to Asbjørnslett (2008, p. 19), resilient systems have the ability to adapt and, therefore, resilience may be defined as a system's ability to return to a new stable situation after an accidental event. By the same token, Ponomarov and Holcomb (2009) describe it as the:

> [. . .] adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.

However, such definitions blur the boundaries between agility and resilience. A different view is held by Rice and Caniato (2003) and Sheffi and Rice (2005), who consider flexibility and redundancy as two ways to create resilience. This position is supported by Stewart *et al.* (2009, p. 351), who locate the ability to influence resilience in the balance of redundancy and flexibility. Flexibility is an integral part of agility, whereas redundancy is an integral part of robustness. Not surprisingly, several notions of resilience give the impression that resilience is a combination of agility and robustness. To Tang (2006), resilience is a strategy that enables operations to sustain during a major disruption and to recover quickly afterwards. Christopher and Rutherford (2004) state that a "resilient supply chain is certainly robust" and that a "resilient supply chain must also be adaptable". According to Christopher and Peck (2004), resilience is the "ability of a system to return to its original state or move to a new, more desirable state after being disturbed". Fiksel (2006) notes that resilience helps both to survive and to adapt. A supply chain can thus be resilient if its original stable situation is sustained or if a new stable situation is achieved as long as the supply chain is able to "bounce back from a disruption" (Sheffi and Rice, 2005). The following definition is proposed.

Definition 3. A supply chain is resilient if it uses resources that enable it to cope with change.

2.4 Rigid supply chains

Simply put, effectiveness is doing the right thing, while efficiency is doing things right (Chow *et al.*, 1994, p. 23). Efficiency has been considered as the antipode of responsiveness (Fisher, 1997) or of agility (Lee, 2002). However, efficiency is not the antipode of resilience because additional resist-or-respond resources may well be the "right things" to do in specific situations. Also leanness, which is an important term in manufacturing and SCM (Angelis *et al.*, 2011; Boyle *et al.*, 2011), has been considered the antipode of agility (Christopher and Towill, 2001). However, leanness is not the antipode of resilience: leanness is aimed to reduce lead times and material usage, but a lean supply chain must be able to respond quickly. Therefore, the term "rigidity" is proposed as the antipode of resilience.

Definition 4. A supply chain is rigid if it does not use resources that enable it to cope with change.

2.5 Strategy selection

Before presenting a model that helps to select the most appropriate strategy among the four supply chain strategies introduced previously, it is useful to give a short overview of strategy selection. An early proposition is based on the distinction between functional and innovative products. In contrast to innovative products, functional products have a long product life cycle, a low product variety and long-lead times. The demand of functional products is easier to predict than in the case of innovative products. Fisher (1997) observes that functional products require an efficient supply chain strategy, whereas innovative products require a responsive one. In essence, it is necessary to match supply chain strategies with products (Selldin and Olhager, 2007).

Managing demand and supply uncertainties is critical for all manufacturers (Liu *et al.*, 2010). Lee (2002) suggests that supply and demand uncertainties are decisive for the strategy: efficiency is appropriate for products with low demand uncertainty (functional products) in the case of low supply uncertainty (stable process). Risk hedging is appropriate for these products in the case of high supply uncertainty (evolving process). Responsiveness is appropriate for products with high demand uncertainty (innovative products) in the case of low supply uncertainty. Agility is appropriate for these products in the case of high supply uncertainty (Sun *et al.*, 2009).

The distinction has been made between lean, agile and "leagile" (hybrid) strategies. In their taxonomy, Christopher *et al.* (2006) have focused on replenishment lead times and predictability/variability of demand to guide the selection of appropriate supply chain strategies. Christopher and Towill (2001) propose three leagile approaches: the Pareto curve approach, the de-coupling point approach and the separation of "base" and "surge" demands.

In these models, different criteria are used for the selection of the appropriate strategy. Fisher (1997) focuses on the risk that arises from the uncertainty to predict demand in the case of innovative products. Lee (2002) also considers the risk that arises from the uncertainty on the supply side. Christopher *et al.* (2006) emphasize the importance of the risk that arises from short-lead times for the selection of the appropriate strategy. In essence, all models focus on supply and demand risks, but do not explicitly make contact with other types of risk discussed in SCRM.

3. Supply chain risk management

SCRM has been a hot topic in recent SCM research. It has been described as the identification and management of risks for the supply chain through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole (Jüttner *et al.*, 2003). There are two notions of a supply chain risk. In the first notion, the term has both positive and negative connotations, as the variation in the distribution of possible supply chain outcomes, their likelihood and their subjective values are the main focus (Jüttner *et al.*, 2003). In the second notion, the term "supply chain risk" has been construed only negatively with the chance of danger, damage, loss, injury or any other undesired consequences (Harland *et al.*, 2003). Approvingly, Wagner and Bode (2008) call a negative deviation from the expected value of a performance measure (resulting in negative consequences for the focal firm) a supply chain risk when this deviation is the result of a supply chain disruption. This negative-only view is supported in this article because it is consistent with an intuitive understanding of risk.

As described by Zsidisin *et al.* (2005, p. 3413), four processes exist to prevent discontinuities: risk identification is concerned with enumerating the causes/sources of potential supply chain disruptions; risk assessment comprises the evaluation of the probability of occurrence and the impact an event will have on the business for each cause or source of potential disruptions; risk treatment is about prioritizing the causes/sources of potential disruptions and developing strategies for reducing their probability and/or mitigating their impact on the business; and risk monitoring means to look at developments in the supply chain that may increase or decrease risks on an ongoing basis.

Several attempts have been made to categorize supply chain risk sources to be used in the risk identification process. For instance, Wagner and Bode (2008) distinguish five classes of supply chain risk sources: risks that result from disruptions emerging from downstream supply chain operations; risks that result from disruptions emerging from upstream supply chain operations; risks that result from legal enforceability and execution of supply chain – relevant laws and policies as well as the degree and frequency of changes in these laws and policies; infrastructure risks, which include disruptions that materialize from the infrastructure a firm maintains for its supply chain operations; and catastrophic risks, such as epidemics or natural hazards, socio-political instability, civil unrest and terrorist attacks.

Both the range of possible outcomes and the distribution of probabilities for each of the outcomes are reflected by risk (Norrman and Jansson, 2004, p. 436). Hence, for the risk assessment process, two elements of a risk are decisive: probability and impact. The former is a measure of how often a detrimental event occurs, whereas the latter expresses the significance of that loss (Zsidisin *et al.*, 2004). When assessing the probability, both the extent of the exposure to risk and the probability of a trigger that will release the risk must be examined (Harland *et al.*, 2003, p. 54). It can be assumed that severe regulatory/legal/bureaucratic, infrastructure and catastrophic risks that lead to the release of *ad-hoc* announcements are less probable than quotidian demand side and supply side risks (Wagner and Bode, 2008, p. 317). When assessing the impact, intangible, nonregulated consequences and losses as well as clearly identifiable financial, tangible implications need to be considered (Harland *et al.*, 2003, p. 54). It may be critical for a supply chain if a sole key supplier suddenly goes bankrupt or a monopsonistic customer suddenly does not order any more, but it may also be critical for the supply chain if an OEM loses its reputation. Although the distinction between risk probability and risk impact is common in risk assessment practice and theory, to the author's knowledge, no explicit attempt has been made to link these two risk elements to the four supply chain strategies discussed previously.

Tomlin (2006, p. 640) finds that the nature of a disruption, e.g. frequent but short vs rare but long, is a key determinant of the optimal strategy when studying mitigation and contingency strategies. Tang and Tomlin (2008, p. 14) discuss different strategies that are either intended to reduce the likelihood of the occurrence of certain undesirable events or designed to reduce the negative implications of these events. Risk probability and risk impact are therefore suggested to be used as decision criteria (= input) to select the strategy for a given supply chain (= output).

During a 1999 Taiwanese earthquake disruption, the supply of essential computer components was affected. Dell responded rapidly by offering special price incentives to entice its online customers to buy computers that utilized components from other countries (Tang, 2006). Although the probability of an earthquake affecting the supply of a specific component is low, Dell's supply chain was agile enough to avoid a high risk impact by switching to a new stable situation. On the demand side, the probability of an unexpected bankruptcy of a main customer may not be high; however, such an event could have a tremendous impact on a supply chain. Management resources that allow the rapid re-invention of a supply chain to adapt to the needs of new customers enable the supply chain to adapt to a new stable situation.

A typical example for multiple sourcing can be found in the food industry, which is susceptible to frequent, but minor, supply fluctuations. Although the supply volume of a single supplier of grain or milk may vary, the volume variations of different suppliers may be equalized from the food processor's perspective. Although the impact of minor supply fluctuations is low, food supply chains are robust enough to resist frequent risk occurrences by retaining a stable situation. Not only the supply, but also the demand is subject to fluctuations. The ordering behaviour may vary on a day-to-day basis for incalculable reasons, such as mood or even the weather; however, preparations for sudden peak demand may be made if safety stocks are used. This brings additional resources into the supply chain, allowing for a cushioning of unexpected demand changes without leaving the path of stability.

4. Supply chain strategy cost models

Before developing propositions that link supply chain risks and supply chain strategies, the costs that exist in rigid, agile, robust and resilient supply chains are illustrated for the risk "destruction of a plant by a storm", which was chosen as an example. The overall costs of each supply chain strategy can be further divided into costs that result from negative consequences (risk occurrence costs) and costs that result from investing in risk mitigation capabilities (risk mitigation costs). The more that is invested in mitigating risks, the lower the costs resulting from a risk occurred would be. This goes hand in hand with a mathematical model used by Kleindorfer and Saad (2005), who suppose a company is interested in the tradeoff between the cost of risk mitigation investments, including the cost of management systems, and the expected costs of disruptions. A mathematical model is thus used to compare the suitability of such supply chain strategies for different degrees of risk impact and risk probability. The use of mathematical models is well accepted in the social sciences (Frankel *et al.*, 2005, p. 189).

4.1 Rigidity costs

It is common risk management practice to make the risk probability and the risk impact i comparable and to use the same scale for all risk types. This can be achieved by normalizing i. That is, a low impact is indicated by a value close to zero, whereas a high impact is indicated by a value close to 1:

$$0 \leq p, i \leq 1$$

In accordance with Zsidisin *et al.* (2004), risk probability measures how often a detrimental event occurs (0 – never, to 1 – very often) and risk impact expresses the significance of that loss (0 – no loss, to 1 – catastrophic loss). In the case of a rigid supply chain, no investment exists in risk mitigation capabilities. That is, on average, the overall costs c_{rig} of a rigid supply chain consist of the occurrence costs only and these costs are equal to the quantified risk (= probability p impact i):

$$c_{rig}(p, i) = p \cdot i$$

4.2 Agility costs

The following example indicates the character of agile supply chains. Let us assume that a company possesses five plants, each of which produces different products. Every year one of the plants is destroyed by a storm ($p = 0.2$). However, it is unknown whether an expensive or an inexpensive plant will be destroyed next year (unknown impact). The company's supply chain is agile if additional capacities are accumulated in each of the plants, which then enable them to rapidly respond to the unexpected destruction of a plant by standing in for each other. Whatever the impact will be (either an expensive or an inexpensive plant will be destroyed), the investment in agility is the same before such an event occurs. In sum, overall agility costs are composed as follows.

First, it is assumed that, in reality, 100 percent risk mitigation is impossible to achieve. Therefore, part of the initial occurrence costs (indicated by a factor $\gamma_{agi}, 0 < \gamma_{agi} < 1$) still exist.

Second, costs to mitigate risks using agility do not depend on the realized risk impact. The more that plants are destroyed by a storm every year (and thus the higher the risk probability would be), the more expensive it is to invest in agility because more capacities are needed. Hence, costs to mitigate risks using agility depend on the risk probability. Costs to mitigate risks using agility are calculated as a percentage (indicated by a factor α, $0 < \alpha < 1$) of p in this research.

In conclusion, overall agility costs c_{agi} are composed of two elements: a part of the initial occurrence costs ($\gamma_{agi} \cdot p \cdot i$) and risk mitigation costs ($\alpha \cdot p$). Only the former part depends on the realized risk impact:

$$c_{agi}(p, i) = \gamma_{agi} \cdot p \cdot i + \alpha \cdot p$$

In Figure 1, the overall costs of rigid vs agile supply chains are depicted in dependence on i. If we consider a constant p then it is more efficient to choose a rigid supply chain in the case of a small i and an agile supply chain in the case of a large i. A high fixed-cost element $\alpha \cdot p$, however, could shift the c_{agi} curve entirely above the c_{rig} curve. This happens when it is expensive to invest in agility (high α) or when the risk probability is high (high p). To summarize, provided that risk mitigation costs are not too high, an agile supply chain is more efficient than a rigid one if the risk probability is low and the risk impact is high. This is supported by Verstraete's (2008) observation that flexibility needs to be built in if the risk probability is low and the risk impact is high.

4.3 Robustness costs

The following example indicates the character of robust supply chains. Let us assume that a company possesses a plant in the USA. The supply chain would be severely impacted if this plant would be destroyed by a storm next year (e.g. $i = 0.8$). However, it is unknown whether this destruction will occur. The company's supply chain is robust if additional capacities in the form of a second plant in Europe are built, which would enable it to resist the unexpected destruction of the US plant. Whatever the probability of the destruction of the US plant, the investment in robustness is the same before the event occurs. Hence, costs to mitigate risks using robustness do not depend on the risk probability. The more important the plant in the USA is (and thus the higher the risk impact would be), the more expensive it is to invest in robustness

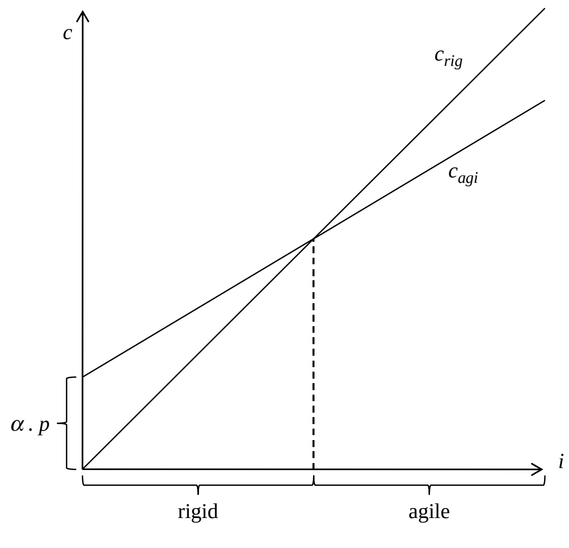

Figure 1.
Comparison of the overall costs of rigid vs agile supply chains

because the more expensive the additional plant in Europe would be. Hence, costs to mitigate risks using robustness depend on the risk impact. Costs to mitigate risks using robustness are calculated as a percentage (indicated by a factor β, $0 < \beta < 1$) of i in this research. Again, it is assumed that a part of the initial occurrence costs still exist. This is indicated by a factor γ_{rob}. In conclusion, the overall costs c_{rob} of a robust supply chain are composed as follows:

$$c_{rob}(p, i) = \gamma_{rob} \cdot p \cdot i + \beta \cdot i$$

As shown in Figure 2, the overall costs of rigid vs robust supply chains are depicted in dependence on p. If we consider a constant i, then it is more efficient to choose a rigid supply chain in the case of a small and a robust supply chain in the case of a large p. A high fixed-cost element $\beta \cdot i$, however, could shift the c_{rob} curve above the c_{rig} curve. This happens when it is expensive to invest in robustness (high β) or when the risk impact is high (high i). To summarize, provided that risk mitigation costs are not too high, a robust supply chain is more efficient than a rigid one if the risk probability is high and the risk impact is low. This is supported by Tang (2006), who observes that multiple suppliers enable a firm to handle regular demand fluctuations and maintain continuous supply – and, thus, enable a firm to handle low-impact risks. Multiple sources reduce the risk in case of disruptions (Tullous and Utrecht, 1992).

4.4 Resilience costs

As discussed previously, a resilient supply chain is both agile and robust. Therefore, it is necessary to invest in risk mitigation capabilities to achieve both agility (costs: $\alpha \cdot p$) and robustness (costs: $\beta \cdot i$). In comparison with an agility-only or a robustness-only strategy, the risk occurrence costs are further reduced. This is indicated by a factor γ_{res} ($\gamma_{res} < \gamma_{agi}, \gamma_{rob}$). In conclusion, the overall costs c_{res} of a resilient supply chain are composed as follows:

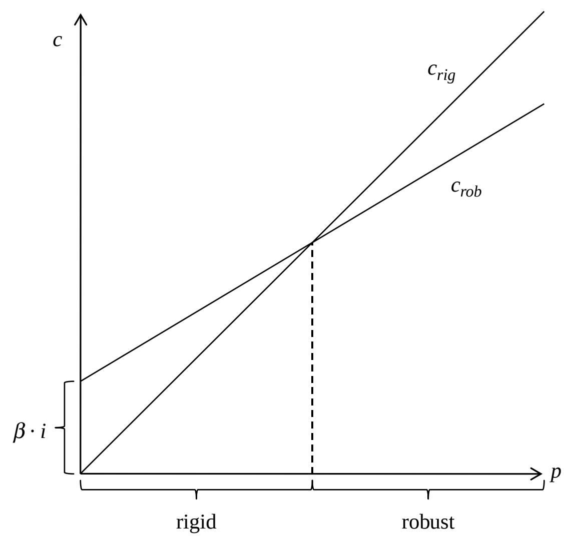

Figure 2.
Comparison of the overall costs of rigid vs robust supply chain

$$c_{res}(p, 1) = \gamma_{res} \cdot p \cdot i + \alpha \cdot p + \beta \cdot i$$

Figure 3 shows the overall costs of rigid vs resilient supply chains, which are depicted in dependence on i and p, respectively. In the graph on the left (constant p), the slope of the c_{res} curve is $\gamma_{res} \cdot p + \beta$ and the c-intercept is $\alpha \cdot p$. In the graph on the right (constant i), the slope of the c_{res} curve is $\gamma_{res} \cdot i + \alpha$ and the c-intercept is $\beta \cdot i$. Hence, the two curves have an intersection in both graphs if it is inexpensive to invest in agility (low α) and robustness (low β), this leads to a low slope, and if i and p are high, this leads to high c-intercepts. Provided that risk mitigation costs are not too high, a resilient supply chain is more efficient than a rigid one if the risk probability is high and the risk impact is high. For example, using inventory to achieve robustness may only be reasonable if the company is also agile by being able to rapidly adapt these products to new market requirements because many products can become obsolete while they are stored (Sheffi, 2005, p. 172). Therefore, resilience should be selected if the probability that new, better, and less expensive products are introduced by competitors is high and the corresponding risk impact is also high.

However, in this case it is also more efficient than an agile and a robust supply chain if:

$$c_{res}(1, 1) = \gamma_{res} + \alpha + \beta < \gamma_{agi} + \alpha = c_{agi}(1, 1)$$

and:

$$c_{res}(1, 1) = \gamma_{res} + \alpha + \beta < \gamma_{rob} + \beta = c_{rob}(1, 1)$$

This is the case when the joint implementation of agile and robust measures leads to a substantially lower part of the initial occurrence costs to bear (indicated by γ_{res}) and, again, if the risk mitigation costs (α and β, respectively) are not too high. The former condition is usually true because, when departing from a robust towards a resilient strategy, additional investments in agile measures will reduce the proportion of initial occurrence costs to bear (and vice versa).

The aforementioned example illustrates the need to distinguish between everyday risks and exceptional risks. Similar examples could be proposed for demand risks, supply risks as well for internal risks of a supply chain, which lead to similar observations. Using such examples as a starting point, propositions will now be

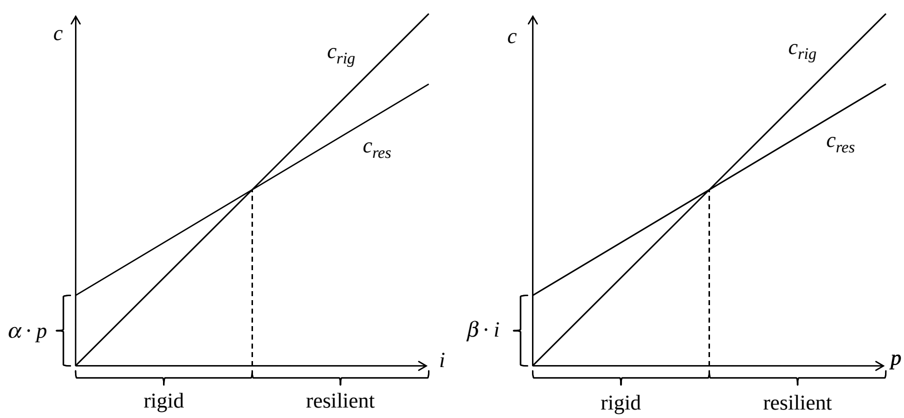

Figure 3.
Comparison of the overall costs of rigid vs resilient supply chains

developed that explain the link between probability and impact of a supply chain risk and the efficiency of a certain strategy.

5. Propositions

Researchers have argued that "[p]revention is better than cure" (Kleindorfer and Saad, 2005, p. 55). This holds true for everyday risks: a supply chain risk with a high probability and a low impact is an everyday risk and should already be considered when designing the supply chain, i.e. proactively. Because of the high frequency of occurrence of an everyday risk, the supply chain must be able to routinely resist the risk. Additional resources must therefore be provided to integrate redundancy and reliability into the supply chain. Hence, robustness is an appropriate supply chain strategy for such risks. It is not appropriate, however, to respond to frequent risk occurrences by redesigning the supply chain frequently. Therefore, agility is a possible strategy, but in comparison with robustness, it is inefficient to handle such risks:

P1. Robustness is the most efficient strategy when the probability of a supply chain risk is high and its impact is low.

On the other hand, predictability is needed to proactively mitigate risks based on a robust strategy, but change is often hard to predict (Dess and Beard, 1984). This holds true for exceptional risks: a supply chain risk with a low probability and a high impact is an exceptional risk and should therefore be handled reactively in case of its occurrence. Because of the high impact of an exceptional risk, the supply chain must be able to rapidly respond to such a risk. In order to integrate fast management capabilities and good responsiveness into the supply chain, additional resources must be provided. Hence, agility is an appropriate supply chain strategy for these kinds of risks. It is not appropriate, however, to integrate a huge amount of redundancy into the supply chain design to enable it to resist all possible risks, however rarely they may occur. Therefore, robustness is a possible strategy, but in comparison to agility, it is inefficient to handle such risks:

P2. Agility is the most efficient strategy when the probability of a supply chain risk is low and its impact is high.

In the case of risks that have a low probability and a low impact, it may be efficient to avoid the use of agility and robustness resources:

P3. Rigidity is the most efficient strategy when the probability of a supply chain risk is low and its impact is also low.

Both resources may simultaneously be used to join forces against risks that have a high probability and a high impact:

P4. Resilience is the most efficient strategy when the probability of a supply chain risk is high and its impact is also high.

These propositions are summarized in Figure 4.

6. Discussion and conclusion

6.1 Further research

Great progress has been made from observing individual risks in order to select the right supply chain strategy. Particularly notable is Lee's (2002) model, which integrates

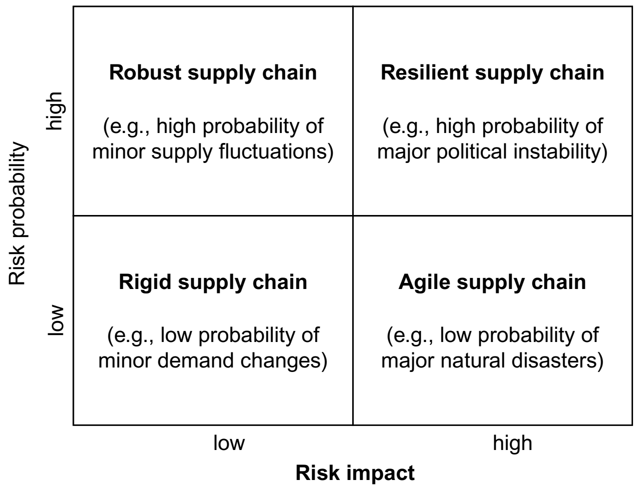

Figure 4. Using the risk matrix to select the appropriate supply chain strategy

both supply and demand risks. The model presented in this research is not restricted to supply or demand risks but can be applied generically for every kind of supply chain risk. This may lead to various risk matrices similar to that shown in Figure 4 for a single supply chain risk. These matrices may lead to different suggestions for the right strategy for different parts of the supply chain. For example, the supply side may be confronted with everyday risks and therefore a robust supply-side strategy would be selected (e.g. high inventory), whereas the demand side might be confronted with exceptional risks leading to an agile demand-side strategy (e.g. quick response). Finding a way to consolidate these individual risk matrices in order to derive a strategy that combines all risk types would be a worthwhile goal.

Some opportunities exist for future research to make the model presented in this article more robust and complete. Particularly, the propositions presented in this study can be a starting point both for empirical research that is aimed at hypothesis testing and for conceptual articles to refine strategy selection. Researchers are encouraged to present models for strategy selection that extend and refine previous models as well as the model presented here, and that include other factors in managing supply chains.

6.2 Theoretical implications

The main theoretical contribution of this research stems from the combination of two literature streams: strategic SCM and SCRM. On the one hand, the research builds on well-established models that help to select the appropriate supply chain strategy on the basis of market-related factors. Most notably, Fisher (1997) uses demand-side uncertainty to select the right strategy, a model that was later expanded by Lee (2002), who also considers supply-side uncertainty. On the other hand, SCRM literature suggests the need to identify risks related to the supply side, demand side and infrastructure of a supply chain, and to assess these risks on the basis of their probabilities and impacts. This research suggests a generalization of all strategy selection models by taking additional types of risks into consideration when selecting the right strategy.

6.3 Managerial implications

High probability/low-impact events are part of the scope of daily management operations, tending to the relatively small random variations in demand, quality problems or absenteeism, whereas low-probability/high-impact events call for planning and a response that is outside the realm of daily activity (Sheffi, 2005, p. 21). In this research, propositions that link risk impact and risk probability to rigid, agile, robust and resilient supply chain strategies were developed. Decision makers can use the model to select a supply chain strategy that fits the supply chain's risk characteristics.

As the initial examples demonstrate, important in practice is that efficient risk-mitigation capabilities are created in order to benefit from an agile and/or robust strategy. Long-term decisions, like the selection of the right strategy, may affect the supply chain tremendously. It may therefore be even more important to know the cost functions. Lack of this knowledge may lead to a wrong decision, which could lead to substantial extra costs. Both the risks that are affecting a company and the selected supply chain strategy influence the costs that a firm faces. Companies can benefit from this research because it helps to achieve strategic fit.

There may be different cost functions in every supply chain that a company is involved in. As long as the cost functions are unknown and selecting the appropriate strategy also depends on dimensions like "risk probability" and "risk impact", no general statement can be made on how to find the right strategy for a supply chain. The findings indicate that robustness is the right strategy in cases in which the probability of a risk is high and the risk impact is low. For example, McDonald's restaurants have a prominent public profile that represents American-style fast food and may therefore be a potential terrorist target. But an attack on a single or even several McDonald's assets may not be severe enough for the entire company because of the highly distributed – and hence robust – structure (Sheffi, 2005, p. 22). Conversely, the findings indicate that agility is the right strategy when the probability of a risk is low and the risk impact is high. Nokia, for instance, rapidly responded to the fire at the chip supplier's plant in 2000 and gained a sustained competitive advantage from these agility capabilities. It can also be concluded that resilience is the right strategy in the presence of both high probability and high-impact risks, and that rigidity is the right strategy if both values are low.

The relationships between the two risk dimensions and the four supply chain strategies fit well when costs to build up robustness or agility are below a certain value. Knowledge that these costs, as well as risk probability and risk impact, have an influence on the selection of the supply chain strategy offers new insights and may force supply chain managers to become familiar with their robustness/agility cost functions. Other strategy selection models focus on supply and demand risks, but companies can use the model presented in this paper as a blueprint to be applied to any supply chain risk type. SCRM has often been neglected in the area of selecting the right strategy. The amalgamation of strategic SCM and SCRM hence represents progress in SCM.

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