Reinforcing feedback in resilient supply chains: 
Revealing the “snowball effect” 
in the transfer of disruptions

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Abstract
The paper attempts at investigating a reinforcing feedback in resilient supply chains in regard to the “snowball effect” in the transmission of disruptions. The theoretical considerations on the idea of reinforcing feedback in resilient supply chains are evidenced by cross-industrial findings of previous studies conducted worldwide.

Keywords: resiliency, systems theory, nonlinearity, cause-effect relationships

Introduction
Resilient supply chains as dynamic complex systems are capable to maintain, resume and restore operations after a disruption. However, the disruptions may often generate accelerating decline where initially small disruptions amplify themselves into larger and larger taking the form of the “snowball effect”.

The etymology of the term “resilience” is diverse. It was adopted from psychology and sociology for the purpose of supply chains and is directly related to the issue of social sensitivity, ecology, mental resistance (Ponomarov and Holcom 2009). Consequently, several definitions of resilient supply chain do exist and lend significant characteristics from resilience interpretations offered by the mentioned disciplines. The interdisciplinary character of the concept, as well as the difficulty of the research object, contribute to the fact that the problems of resilient supply chains, although interesting in their theoretical foundations and inspiring in respect of empirical research, have not been described and examined in a synthetic study yet.

Resilient supply chain is characterized by the ability to adapt to unforeseeable difficulties and return to its initial state (Coutu 2002). According to Christopher and Peck (2004), resilience in the context of supply chain refers to the ability of returning to the initial state or transition to another state, more desired after the occurrence of a specific disruption. In other words, resilience is the ability of a supply chain to adapt, regain lost strength and provide reactive response to the requirements of the environment.
In broad terms, constituting resilient supply chains requires to apply the practices of "good supply chains management" (Waters 2007). It is because supply chain acquires the feature of "being resilient" as a result of the regulatory impact (Christopher and Peck 2003). Consequently, there is a need to identify such properties, which allow for possibly most efficient supply chain management in a discontinuous environment. The correctness of this reasoning is confirmed by Christopher and Peck (2004), leading representatives of supply chain management in the UK, who argue that the possession of specific properties enables to operate in accordance with the idea of resilient supply chain. It shows a need to search for such ways of supply chain management that will take into consideration the properties making the supply chain truly resilient.

Resilient supply chains are open systems of interconnected elements, such as suppliers, third parties, customers, and that internally include other sub-systems (Gregory and Rawling 2003; Otto 2003). The openness of the system and the permanent interaction with its environment, leads to the conclusion that a resilient supply chain is induced by the system's environmental conditions. It suggests that resilient supply chains are mainly exposed to the factors triggered by external factors, located outside the supply chains. This issue has been also highlighted by Melnyk et al. (2010) who maintain that resilient supply chains are prepared to recover quickly and cost effectively from disruptions caused by natural disasters (such as earthquakes), social factors (employee strikes), medical emergencies (epidemics), economics setbacks (financial crisis), etc. However, it can be assumed that resilient supply chains may also be exposed to disruptions triggered by internal factors, yet their probability and severity of consequences is usually much lower to external uncertainty. Therefore, previous studies generally concern external factors which may potentially or actually have an impact on resilient supply chains (Juttner and Maklan 2011; Chozick 2007).

One of the most important abilities of resilient supply chains is to discover the disruption in a reasonable period of time. Handfield (2007) argues that executives must be able to identify risk sources and types of disruptions, and thus to develop methods for discovering disruptions in a timely and responsive fashion. Disruption discovery should then be followed by using appropriate methods to recover from negative risk effects quickly and prevent them from affecting further links of a supply chain.

There is a number of reasons determining an in-depth study on supply chain resiliency. One of them is noticed by Bakshi and Kleindorfer (2009) who posit that primary motivation for the increased research interest in resilient supply chains is the amplification of losses, either direct or indirect, resulting from disruptions. As depicted in Figure 1, late reaction on disruptions causes amplified effects which, in turn may be transmitted to other links in supply chain structure.

The phenomenon of the transmission and amplification of disruptions may be described as the “snowball effect” which means that each successive link in a supply chain can be exposed to stronger effects of risks. This problem has also been raised by U. Juttner et al. (2003) who mention about the “network effect” which is linked to the negative consequences of risks arising from relationships among the parties in supply chains while Kersten et al. (2012) refer to supply chain risks which are those risks that affect at least two companies of a supply chain, and it is irrelevant whether a company is affected directly or indirectly by a supply chain risk.
The phases of lifecycle of resilient supply chains
Adopted from R. Handfield: Reducing the impact of disruptions to the supply chain, SAScom magazine, April, 2007, pp. 33-41.

The problem has also been addressed by Cheng and Kam (2008) who suggest that risk may arise at the node or link and affect other links and nodes in a networked structure of supply chains. Consequently, van Dorp and Duffey (1999) advocate to treat the risk effects as simultaneous and interdependent elements rather than sequential and statistically independent. This entails the possibility to depict the “snowball effect” in the transmission of disruptions as reinforcing feedback in resilient supply chains.

**The idea of a reinforcing feedback in resilient supply chains**

The concept of feedback in resilient supply chains draws on systems thinking and provides several implications for breaking out of reactive mindset that comes inevitably from a simple linear thinking.

First of all, the concept of feedback means any reciprocal flow of influence. In other words it posits that each influence is both cause and effect and nothing is ever influenced in just one direction. Instead of direct cause and effect relationship one should see relationships in a particular indirect sequence. Consequently, it is important to see reality systematically as circles of influence rather than straight lines (Senge 2004). Every circle tells a story showing how the structure creates a particular pattern of behavior or, in case of a complex structure such as resilient supply chains, several patterns of behavior, and how that pattern might be influenced. The feedbacks may be graphically depicted as a feedback circle diagram which shows system wide interrelationships (Senge 2004).
It is important in resolving resilient supply chains as dynamic complex system, in which strategic choices on the forces that shape change and organizational disruptions are made. In order to describe cause - effect nature of disruptions in resilient supply chains, a language of interrelationships, made up of circles is needed. Therefore, a feedback circle diagram may be very instrumental when the transmission of disruptions is considered.

In practice, the risk of adverse effects caused by the certain factors, are often transferred to the other links in the supply chain. It means the negative effects of risk are extended beyond the boundaries of individual firms and thus, indirectly transferred to the other companies. The propagation of the negative effects of risk from one company to the other firms as a result of indirect impact of certain risk factors may be called as the transmission of disruptions. For instance, improper unloading of the product by a customer may cause a damage to the manufacturer’s transportation infrastructure, which may result in accumulation of stock at a supplier caused by an unavailability of transportation means due to the damage. The sequence of different disruptions observed in succeeding links in resilient supply chains may affect on the improvement and greater caution of unloading process at the customer in future. Figure 2 shows the example illustrated with a feedback circle diagram.

One of the types of feedback process is reinforcing, which is the engine of growth or accelerating decline. A pattern of decline exists where small drops amplify themselves into larger and larger drops, such as the decline in bank assets when there is a financial panic (Senge 2004). The example of accelerating decline is also the amplification of disruptions during the transmission from one company to the others. The amplification of disruptions may be illustrated with the “snowball effect”.

In reinforcing processes such as the “snowball effect” in the transmission of disruptions, a small change builds on itself. In other words, a small disruption snowballs, with more and more and still more of the same, resembling compounding interest. Some reinforcing (amplifying) processes are vicious cycles, in which things start off badly and grow worse.
The “snowball effect” in the transmission of disruptions as a reinforcing feedback in resilient supply chains

The disruptions may be amplified during the propagation in the supply chain. It means that each successive link in the supply chain can be exposed to the stronger effects of risks. The transmission of amplified disruptions means that the negative effects of risk are intensified and expanded on a larger number of participants in the supply chain. The amplification of disruptions during the transmission may be referred to as the “snowball effect”. For instance, the malfunction of a machine at the manufacturer in India caused a delivery delay, which was then amplified from 4-day delivery delay at the knitter to 14-day delivery delay at the clothing manufacturer. Finally, this results in lack of timely shipment of hot new models leading to the loss of sales revenues estimated in millions of dollars (Radjou and Orlov 2002).

As resilient supply chains are usually exposed to external uncertainty, the magnified disruptions may cause new effects, different from the original ones. For example, the terrorist attack in the United States on September 11th, 2001 caused the government’s response to the attack: closing borders, shutting down air traffic and evacuating buildings throughout the country. These additional effects affected supply chains operating in Europe and USA. For example, as a result of transportation restrictions, the supply chains in the automotive industry – Toyota and Ford - experienced several days of disruption in the continuity of supply of components to the factories located in the north of the country (Sheffi 2002). This induced temporary halting of assembly lines, which in turn, made the manufactured cars unavailable at the selling sites.

*Fig. 3. The example the “snowball effect” in the transmission of disruptions illustrated with a reinforcing feedback circle diagram*
As the companies in resilient supply chains suffer more acutely from disruptions, the US government may change its previous decision and mitigate the transportation restrictions. It is important to highlight that each subsequent link in supply chain structure is exposed to the stronger effect of a particular disruption, even though the disruptions may differ while transmission from one link to the other. Figure 3 depicts exemplary “snowball effect” in the transmission of disruptions in resilient supply chains. In order to illustrate the phenomenon of the “snowball effect”, the amplification of the strength of transmitted disruptions is highlighted with a positive sign (‘+’) at each circle of causality in a reinforcing feedback circle diagram.

It is worth noting that supply chain resilience is not a one-time process, achieved once and for all in the result of linear and static events. Accordingly, the resilience cannot be described as linear cause-effect relationships which provide with the similar consequences in a short and long time. On the contrary, resilient supply chains may be depicted as a non-deterministic model (Jackson 2003), in which cause and effect are not close in time and space. It means that the interaction of the underlying system that is the most responsible for generating the symptoms effects, which in turn, could lead to changes producing disruptions (Senge 2004).

The cause and effect is not close in space when, for instance the amplified disruptions caused by risk factors may be transmitted from one company to another in a resilient supply chain operating in different parts of the world. In such a situation, only a certain number of firms in this supply chain are exposed to the direct impact of the same risk factor. The disruption caused by a risk factor in a company operating in a particular region is transmitted to other firms in other parts of the world. The premise of such a situation is generally the local extent of the impact of such risk factors. It refers primarily to natural disasters, political factors, etc. For example, the earthquake and tsunami which struck the northern part of Japan in the first half of 2011, led to a deterioration of production in the plants located in that specific part of the country. The disruptions (halting production) induced by exogenous risk factors (earthquake and tsunami) in the chain companies operating in Japan were transmitted to companies in other parts of the world, primarily in the United States and Europe.

The “snowball effect” caused by the earthquake and tsunami in Japan might be observed in the supply chains of automotive, electronics and aviation industries. For example, the Peugeot-Citroen supply chain reported difficulties in production of some types of diesel engine, due to the lack of electronic components that had been produced by Japanese plants located in the affected areas. Similarly, the American division of the General Motors supply chain was forced to stop the production of cars in one of its factories located in the United States. GM Assembly plants in South Korea withdrew from the production of vehicles in overtime, as they were impacted by the shortage of car parts from Japan (Swierczek 2013).

To sum up, the discussion shows that phenomenon of the “snowball effect” in the transmission of disruptions may be illustrated with a reinforcing feedback circle diagram. Among the major determinants of treating the “snowball effect” in the transmission of disruptions as reinforcing process one may enumerate reciprocal character of the flow of influence, non-linear, wide cause-effect relationships, distance between causes and effects in terms of space and time, vicious cycles which sometimes characterize the “snowball effect”.

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Investigating a reinforcing feedback in resilient supply chains – a critical review of previous studies

Although the “snowball effect” in the transmission of disruptions may be explained with a language of systems theory through the reference to a reinforcing feedback circle diagram, the empirical investigation of this phenomenon is still in its infancy. Therefore, the articles and empirical studies involving multidimensional aspects of the transmission and amplification of disruptions are very scarce, and thus not well-documented. Furthermore, even though the authors are aware of the significance of the “snowball effect” in the transmission of disruptions in supply chains, they usually do not attempt to investigate this phenomenon.

So far, one of the most coherent empirical study on the “snowball effect” in the transmission of disruptions has probably been conducted by Juttner (2005). The respondents participating in the study were asked to rate the extent to which each of prominent events (such as Y2K millennium bag, fuel protests in 2000, foot and mouth outbreak, transportation infrastructure failure, terrorist attacks of 11th September) affected supply chains consisting of three subsequent tiers, namely suppliers, own organizations and customers (Juttner 2005).

The transmission of disruptions reflected in feedback circles was indicated when no differences between the scores at three tiers was observed. It meant that disruptions had spread across the supply chain and affected all its member organizations equally. Accordingly, the findings indicated that the three scores were significantly correlated for each of the events, providing support for the phenomenon of the transmission of disruptions. On the other hand, the exploration of the “snowball effect” in the paper is very limited. Only the scores for the impact of the terrorist attacks of 11th September were compared across the three groups of supply chains which operate globally, internationally and in the UK. The findings confirm that supply chains operating globally were significantly more seriously affected than supply chains operating internationally or within the UK (Juttner 2005).

The issue of the “snowball effect” in the transmission of disruptions has also been empirically addressed by Cheng and Kam (2008) who suggest that risk may arise at the node or link and affect other links and nodes in a networked structure of supply chains. Instead of systems theory, the authors employed agency theory as a research perspective in their paper. Drawing on the tenets of agency theory, the paper outlines a conceptual framework for analyzing supply chain risks based on the precepts of inter-organizational transactional relationships in a network environment and network collaborations. As a supply chain is considered to be hierarchically structured, the risk impacts are felt at several levels affecting the entire network, sub-network or one individual node or link. As depicted in the paper, the nature of network relationships within and between these levels defines how risk impacts propagate and, in turn, how effective any recovery action in resilient supply chains will be (Cheng and Kam 2008). Although the paper has not a strictly quantitative character, its strength lies in the side-by-side comparisons of risks in the different principal-agent structures, showing how inter-dependencies and inter-relationships affect, how risks affect individual parts of the network or even the whole network.

The findings of previous studies evidence that the issue of the “snowball effect” as a reinforcing feedback circle is the problem of crucial importance both in the theoretical
and practical frameworks, and thus requires an in-depth identification, profound analysis and reliable discussion. Moreover, the previous studies show that the “snowball effect” in the transmission of disruptions is a vital problem for managerial practice, faced by executives of supply chains operating either locally and globally. Yet, this phenomenon still lacks of comprehensive investigation and thorough study within the context of resilient supply chains.

**Recommendation for the further study**

The investigation of the “snowball effect” in the transmission of disruptions in resilient supply chains is challenging but lofty task. Therefore, in order to investigate this phenomenon, several issues should be considered.

One of the theoretical perspectives which may be used in investigation of the “snowball effect” is systems thinking. This research approach may particularly provide a significant support for investigating the “snowball effect” in the transmission of disruptions in resilient supply chains. Employing systems thinking enables to study resilient supply chains as a dynamic and complex system, and thus to analyze its transition from one state to the other. There is an infinite number of different states of resilient supply chains which are usually achieved in accordance with the second learning cycle. Accordingly, the cycle is partially dependent on the extend and strength of transmitted, and amplified disruptions.

One should be aware that the “snowball effect” in the transmission of disruptions may sometimes take a form of vicious cycle, which denotes that the negative disruptions start off badly and grow worse over time during the transmission. However, it should be noted that pure accelerating decline rarely continues unchecked in nature, because reinforcing processes rarely occur in isolation. Eventually, stimulators and limits are encountered. The first ones may increase and even accelerate the “snowball effect” in the transmission of disruptions while the latter ones can slow growth, stop it, divert it, or even reverse it.

This is a very important observation as the risk sources and their consequences are usually inextricably linked. It suggests that, in practice, there are several risk events occurring at one time in supply chains which result in a number of negative effects with a diverse strength and, to a different extent, exposed to the transmission. Therefore, the “snowball effect” should not be considered in isolation, as relationships between different risks or their consequences may be of a synergistic nature. Accordingly, the managers are usually trying to mitigate the negative effects of particular risk factors, and thus balancing the transmitted and amplified disruptions.

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