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AN IDENTIFICATION OF THE "RIPPLING EFFECT" IN THE TRANSMISSION OF DISRUPTIONS IN SUPPLY CHAINS. THE DILEMMAS OF THEORETICAL STUDY AND EMPIRICAL RESEARCH

1. The transmission of disruptions in supply chains

The negative effects of risk, often referred to as disruptions, may directly or indirectly affect supply chains. The direct impact of disruptions can be triggered by exogenous or endogenous risk factors. Exogenous risk factors are external to a supply chain and located outside its boundaries. They fall into a wider macro-environment level or sector, whereas endogenous risk factors are embedded inside a supply chain, its participants or relationship between them(Rao, Goldsby, 2009, pp. 97-123; Tang, 2006, pp. 451-488; Peck, 2004, pp. 210-232; Cavinato, 2004, pp. 383-387).

In practice, the risk of adverse effects caused by certain factors is often transferred to other links in a supply chain. It means that the negative effects of risk are extended beyond the boundaries of individual firms and thus indirectly transferred to other companies. The propagation of negative effects of risk from one company to others as a result of an indirect impact of certain risk factors may be referred to as the transmission of disruptions.

The transmission of disruptions means that the negative effects of risk are extended to a larger number of participants in a supply chain. The primary source of these disruptions are exogenous and endogenous risk factors. Therefore, it may be assumed that the transmission of disruptions requires at least two companies of a supply chain to be involved in a process. One company is affected by a direct impact of these risk factors, and the other is affected by an indirect influence. The idea of the transmission of disruptions in a supply chain is depicted in Figure 1.

As illustrated in Figure 1, exogenous or endogenous factors affect a supplier directly, causing a certain disruption, which is then transmitted inside the structure of a supply chain to other participants. In this case, the supplier is the initial link, while the actors at other levels of material flow in the supply chain – producer and customer – are exposed to an indirect impact of risk factors. It is assumed that there ought to be an indirect impact of risk factors in the transmission of disruptions.

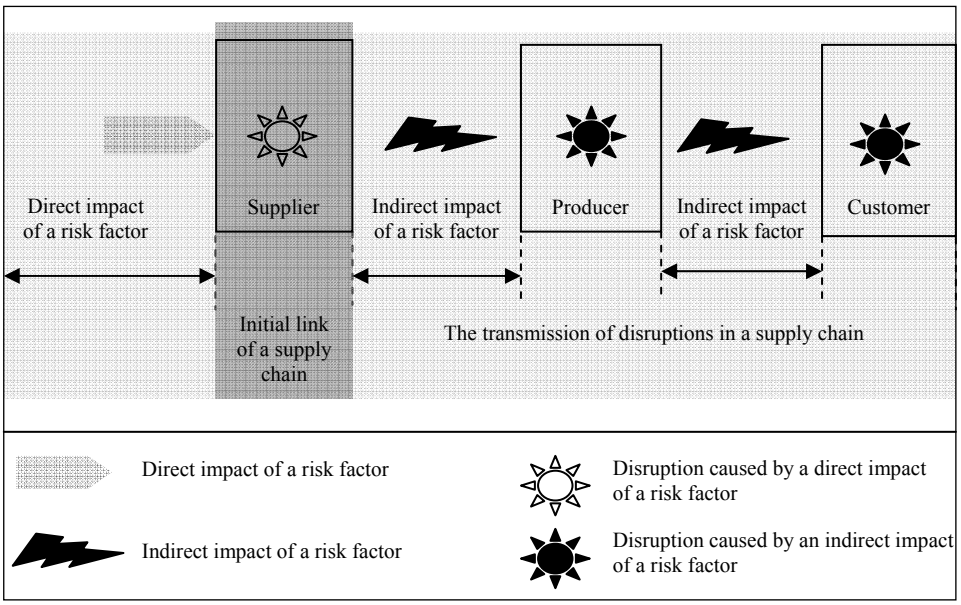

Figure 1. The schematic diagram of the transmission of disruption in a supply chain

The negative risk effects may spread to a larger number of participants in a supply chain. The range can be varied, but it generally falls within two types of disruptions located in the extreme positions of the continuum:

- limited range of disruptions, usually bilateral;
- widespread disruptions, generally holistic (Svensson, 2000, pp. 731-749).

In the limited range of disruptions, the negative effects of risks are transmitted to a small number of links in a supply chain (Svensson, 2000, pp. 731-749). For the purpose of this paper, this range consists of only two companies, which determines the transmission of disruptions from one company to the other (Kersten, Hohrath, Böger, 2007, p. 4). It is not important if a disruption in the first link is caused by endogenous or exogenous risk factors. At the other extreme continuum outlining the transmission of negative effects are widespread disruptions. The transmission of these disruptions affects all actors in a supply chain.

In general, the effects of risks are positioned between the two poles of limited range and widespread disruptions. As a result, a certain number of actors participating in a supply chain will be exposed to the negative effects of risk.

2. The characteristics of the "rippling effect" in the transmission of disruptions in a supply chain

The disruptions may be amplified during the transmission in a supply chain. It means that each successive link in a supply chain can be exposed to stronger effects of risks. The amplification of disruptions during the transmission may be referred to as the "rippling effect". This phenomenon is illustrated in Figure 2.

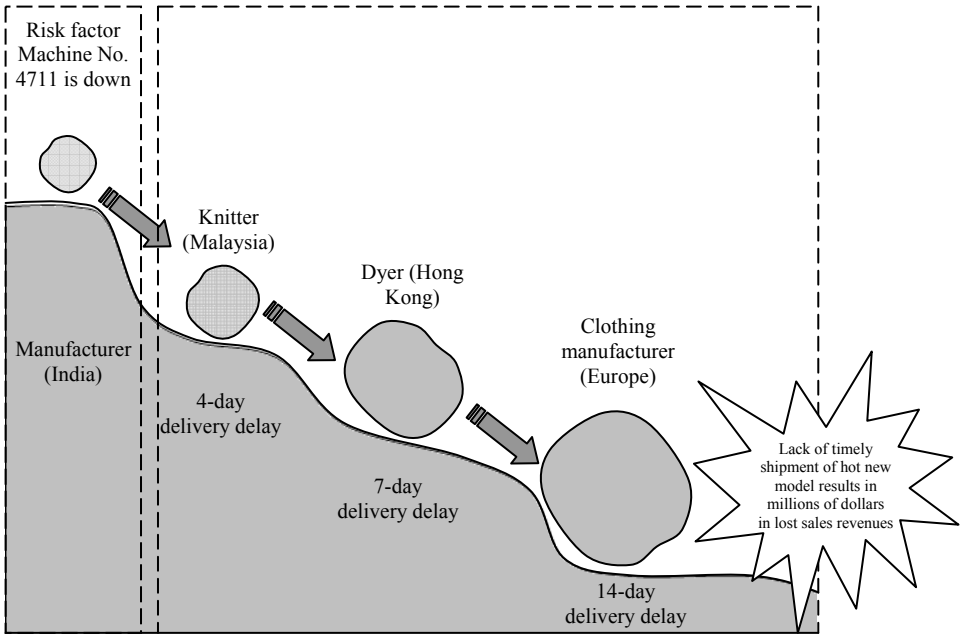

Figure 2. The "rippling effect" in a supply chain

Source: (Radjou, Orlov, Nakashima, 2002. p. 3).

As depicted in Figure 2, the malfunction of a machine at the manufacturer in India caused a delivery delay, which was then amplified during the transmission to subsequent links in the supply chain.

The transmission of amplified 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, 2001, pp. 1-11).

Another good example are the epidemics which provoked national crises, affecting many organizations involved in supply chains. The extent and severity of the consequences caused by the risk of foot and mouth disease or BSE particularly affected the European supply chains. The "rippling effect" was a result of European governmental response to the direct effects of the outbreak among livestock (Peck, 2005, pp. 210-232). The infection of cattle as a consequence of the direct impact of epidemic led to the imposition of additional formal restrictions on manufacturing and distributing meat products. It caused several disruptions in the supply chains operating in the food industry. On the other hand, the fuel supply chains experienced additional disruptions associated with road transportation. They were caused by the authorities' decision to place disinfectant mats at roadside checkpoints.

The issue of the "rippling effect" in supply chains is complex and multifaceted, so the empirical study may pose many difficulties. There are two closely related phenomena employed in the "rippling effect", namely the range of transmission and the amplification of disruptions. The confrontation of these two phenomena is presented in Figure 3, which enables us to identify the following situations:

- mitigation of disruptions in the transmission to a smaller number of firms in a supply chain;
- mitigation of disruptions in the transmission to a larger number of firms in a supply chain;
- amplification of disruptions in the transmission to a smaller number of firms in a supply chain;
- amplification of disruptions in the transmission to a larger number of firms in a supply chain.

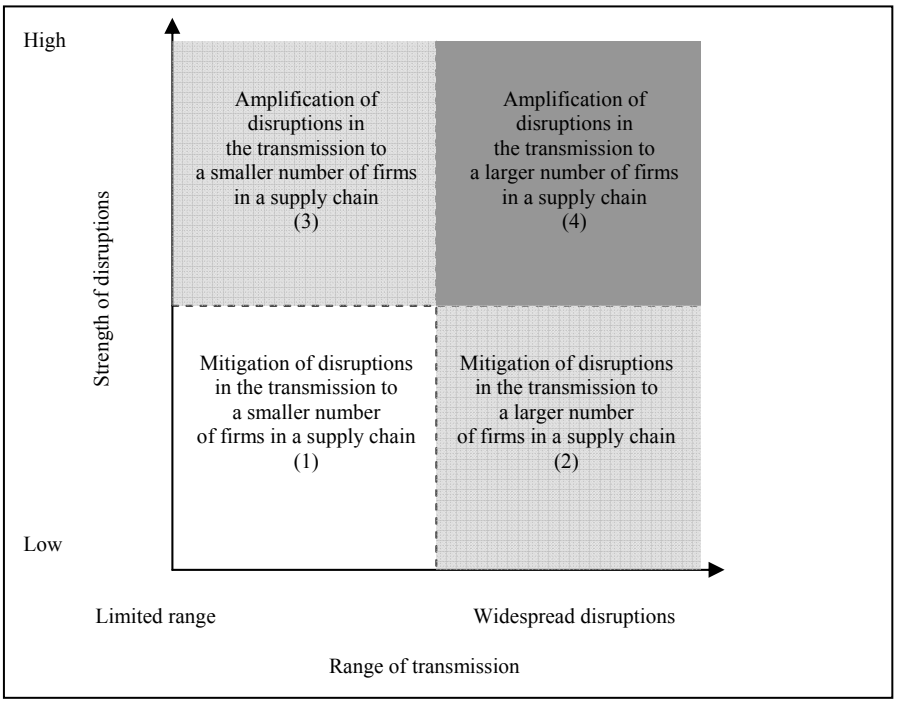

Figure 3. Matrix of the range of transmission and the strength of disruptions

The most interesting situation of the "rippling effect" are the disruptions which were amplified and transmitted to a larger number of firms in a supply chain. However, the relationships between the range of transmission and the strength of disruptions are only illustrative. It is rather uncommon that the effects of risk are transmitted to all companies in a supply chain, having a holistic impact. On the other hand, the disruptions are not only amplified in the transmission, but they may also be mitigated.

It is also important to identify the risk factors which are sources of disruptions amplified during the transmission. The most difficult to identify is the transmission of disruptions caused by the risk factor which directly affects a larger number of companies in a supply chain (Cheng, Kam, 2008, pp. 345-360). Risk factors such as natural disasters or financial crises often simultaneously and directly affect a larger number of links in a supply chain (van Dorp, 2004, pp. 240-255). The disruptions caused by this group of risk factors are not sequential in their nature and are often interdependent (van Dorp, Duffey, 1999, pp. 17-29). The particular risk factor which affects a larger number of companies in a supply chain may be referred to as "common risk factor". In practice, it is very often an exogenous risk factor.

3. The identification of the "rippling effect" caused by a "common risk factor"

The purpose of the identification of the "rippling effect" is to determine all disruptions that are likely to be transmitted in structures of supply chains (Khan, Burns, 2007, pp. 197-216). In practice, one can use several methods for collecting information about the "rippling effect". These include the experience of managers, the use of decision support systems, conducting surveys, "brainstorming" or recourse to the external consultants (Hillson, 2002, pp. 1-11). However, from the institutional point of view, the use of such methods should be complemented with a definition of the scope of diagnosis. In other words, it is important to identify the specific characteristics of links relevant from the perspective of the "rippling effect". Gilbert and Gips argue that while it makes sense to consider potential disruptions at the supplier's suppliers, it is less understandable and may be more costly to read the effects of risk at further stages of a supply chain structure. Hence, the key issue to resolve is to determine the scope of diagnosis outlining how many links are to be involved in the identification process (Gilbert, Gips, 2000, pp. 70-74).

The problem is that the "rippling effect" may not even be observable in particular situations. It means that the disruptions occurring in a specific link of a supply chain are not necessarily amplified during the transmission. In this case, time and financial expenditures incurred in relation to the identification of such disruptions are not justified, because they do not lead to a higher level of efficiency in the entire supply chain.

It is rather difficult to identify the transmitted disruptions caused by a risk factor which directly affects a larger number of companies. In particular, there are three situations significant for the identification of the "rippling effect", namely:

- the effects of the direct impact of a risk factor differ from the disruptions in the "rippling effect" (transmitted indirectly from other firms);
- the "rippling effect" occurred among companies in a supply chain operating in different parts of the world;
- the strength of disruptions in the "rippling effect" is noticeably higher than the same effects caused by the direct impact of a risk factor.

The effects of the direct impact of a risk factor in individual companies may differ from the disruptions caused by this factor transmitted to other firms in a supply chain. The ability to identify the "rippling effect" in this situation is illustrated in Figure 4.

As depicted in Figure 4, the risk of a flood, which negatively affects a supply chain operating in a particular region, may be a good example. The

direct impact of this factor resulted in a damage to the infrastructure, so that the supplier failed to fulfill the previously agreed date of the contract for a supply of raw material to the manufacturer. Although the latter one was also affected by the negative effects of a direct exposure to the risk, the failure to meet the date of delivery was more destructive for the manufacturer. The indirect impact of disruptions caused by an exogenous risk factor at the supplier stopped the production process, which in turn may lead to disruptions with the customers of the manufacturer. Thus, it is easier to distinguish between the direct and indirect impacts of disruptions, if the disruption transmitted from one company to another is different compared to the effect caused by the direct impact of a risk factor.

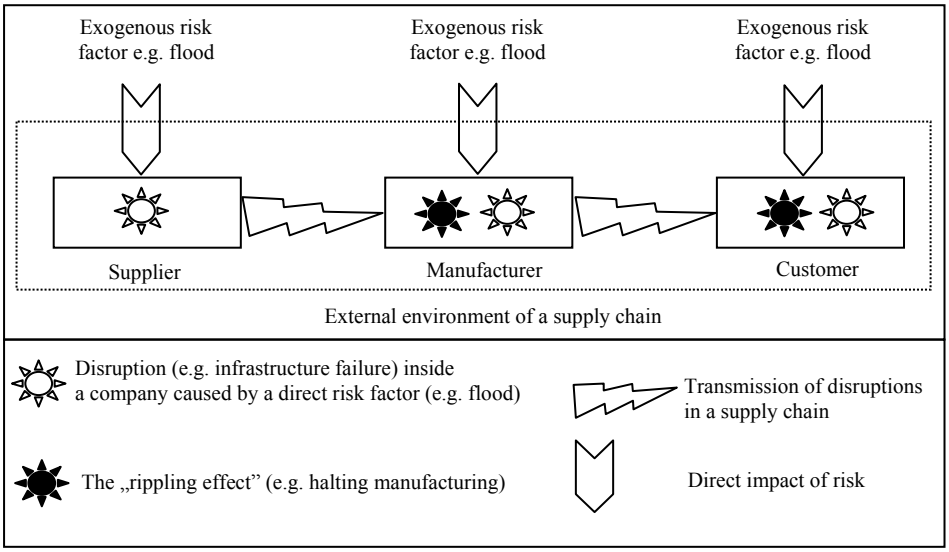

Figure 4. Identification of the effects caused by the direct impact of a risk factor and disruptions in the "rippling effect"

As depicted in Figure 5, amplified disruptions caused by risk factors may be transmitted from one company to another in a 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.

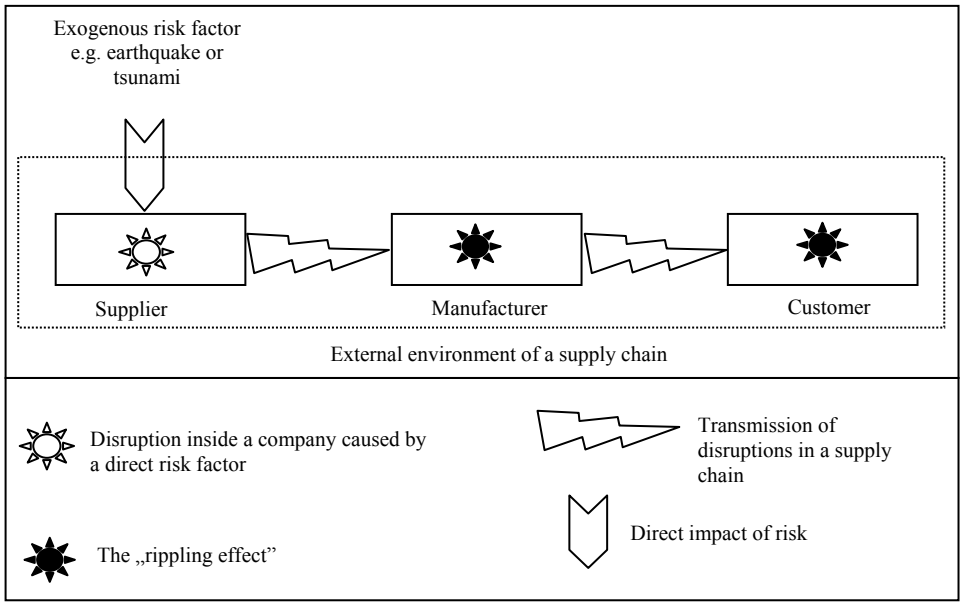

Figure 5. Identification of the "rippling effect" occurring among companies in a supply chain operating in different parts of the world

The "rippling 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 (Wyborcza.biz, 2011).

Table 1 presents the ability to identify the "rippling effect" caused by a specific risk factor in terms of its range of impact and the similarity of disruptions caused by the direct and indirect effects of risk.

As Table 1 shows, it might be impossible to identify the "rippling effect" caused by a global risk factor, affecting all companies in a supply chain, and when the similarity of the disruptions caused by the direct and indirect effects is high.

Table 1

Identification of the "rippling effect" in terms of the range of impact and similarity of disruptions caused by the direct and indirect effects of risk

Range of the impact in a supply chain	**Similarity of disruptions caused by the direct and indirect effects**	
	High	**Low**
Global	Impossible	Difficult
Local	Difficult	Relatively easy

As depicted in Table 1, the ability to identify the "rippling effect" might be difficult in two situations, namely:

- if the similarity of disruptions caused by the direct and indirect impacts of a risk factor is small, while the extent of its impact on a supply chain is global;
- if the similarity of disruptions caused by the direct and indirect impacts of a risk factor is high, while the extent of its impact on a supply chain is local.

It is relatively easy to identify the "rippling effect' when the extent of disruption is local, and while there is little similarity between the effects caused by direct and indirect risk factors. Additionally, there is a higher probability to identify the "rippling effect" caused by a specific risk factor when the strength of transmitted disruption from one company to another is noticeably higher than the same effects caused by the direct impact of this risk factor.

4. Dilemmas to identify "the rippling effect" in terms of exogenous and endogenous risk factors

The determinants of identification of the "rippling effect" have been illustrated in Figure 6. The arrow in Figure 6 begins at the corner of the rectangular, which indicates the global impact of disruptions (affecting all supply chain members), high similarity of the effects caused by direct and indirect impacts and low strength of disruptions in the "rippling effect". On the other hand, the arrowhead goes to the opposite corner of the rectangular, which indicates the local effect of disruptions (affecting only selected supply chain members), high differentiation of the effects caused by direct and indirect impacts and high strength of disruptions in the "rippling effect". Under such circumstances the identification of the "rippling effect" is relatively the easiest.

The above considerations show that the ability to read the "rippling effect" may differ depending on the exogenous and endogenous nature of risk factors.

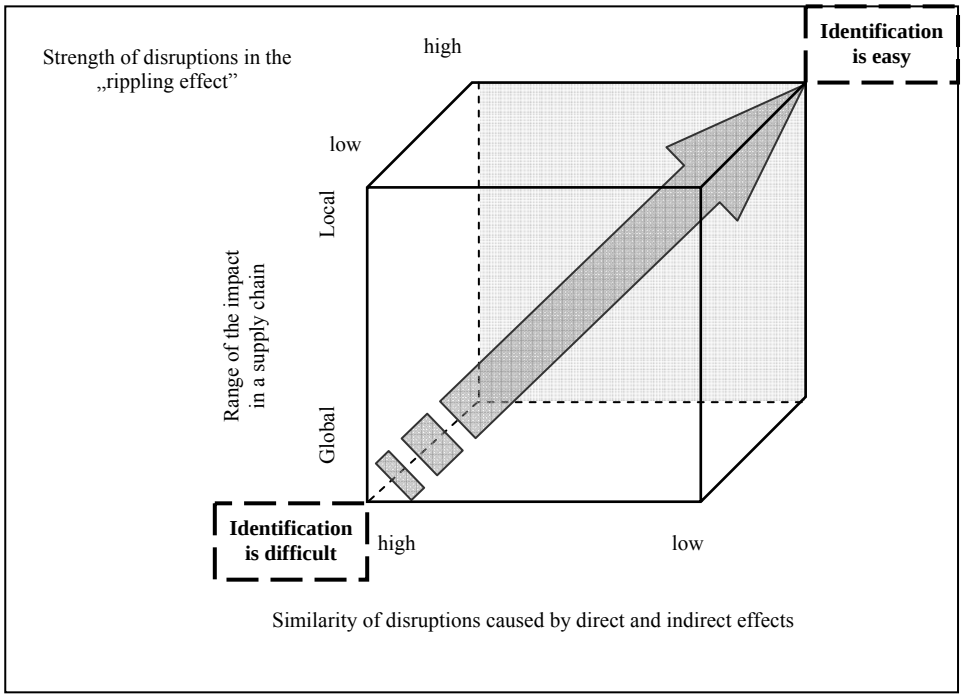

Figure 6. Determinants of identification of the "rippling effect" in the transmission of disruptions in a supply chain

The observation of the "rippling effect" caused by an exogenous risk factor might be relatively difficult as it requires considering environmental conditions and the specificity of a supply chain. It is worth noting that all companies operating in a particular region are exposed to the direct effect of a risk factor. Therefore, similar effects caused by the direct and indirect impacts of these risk factors can often obscure the phenomenon of the "rippling effect". The tendency is sustained when the strength of disruptions in the "rippling effect" caused by the factor is low. This may partially explain why managers often have problems with the identification of the "rippling effect" caused by exogenous risk factors.

On the other hand, endogenous risk factors are rooted in a specific company or the relationship between them, hence the direct impact of their negative effects is generally not applicable to all firms in a supply chain. The disruptions caused by endogenous risk factors are not common for a greater number of companies operating in a particular supply chain.

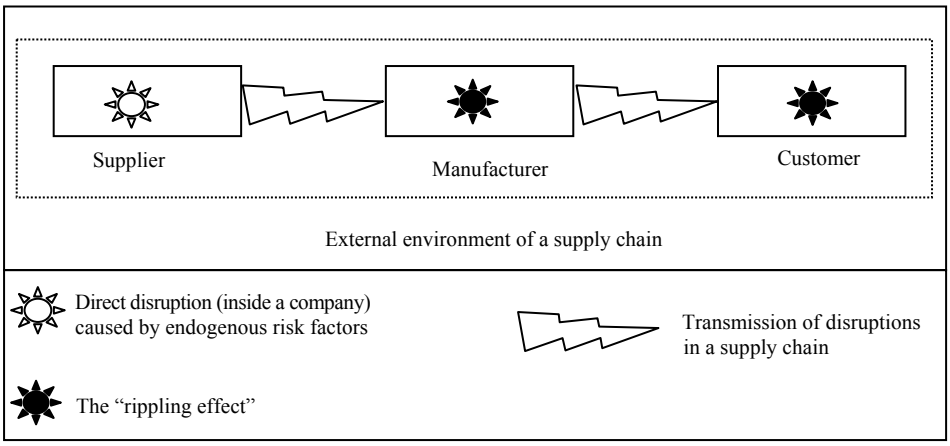

Figure 7. Identification of the "rippling effect" occurring among companies in a supply chain caused by an endogenous risk factor

The above mentioned argumentation allows to conclude that the "rippling effect" caused by endogenous risk factors is generally easier to identify than if it is originated from exogenous risk factors. The disruptions caused by endogenous factors are in fact characteristic for a particular group of companies in a supply chain, or result from the relationships between these firms – Figure 7. However, one ought to remember that sometimes it is difficult to distinguish the risk factors which cause particular disruptions. In general, at the same time there might be many different and interrelated risk factors, which are collectively perceived as the primary source of the "rippling effect" in a supply chain.

5. Future directions and further research

Apart from providing some insights into the contribution of identification of the "rippling effect" in a supply chain, the article also highlights the potential areas of future research.

The natural continuation of the issues considered in the article is to define the ways of measurement of the "rippling effect" enabling to make cross-sectoral and international comparisons of disruptions amplified in the transmission.

Another important element requiring investigation is the analysis of major determinants of the "rippling effect" in supply chains. Collaboration between companies seems to be the one of the most important bases for a transmission of amplified disruptions in supply chains. It may be assumed that the more intense relationships among the supply chain partners, the larger chance for the "rippling effect". Therefore, it would be interesting to investigate how collaboration

between companies contributes to the transmission of amplified disruptions in a supply chain. This analysis might also reveal the managerial methods and instruments mitigating the strength of transmitted disruptions. The study should define the appropriate attitude of companies towards the phenomenon of the "rippling effect" and indicate exemplary strategies preventing from the negative effects of disruptions transmitted along a supply chain.

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