The transmission of disruptions in supply chains. Is there a snowball effect?

Abstract
Supply chains are now more than ever susceptible to many diverse risk factors and their negative effects, often referred to as disruptions. Such disruptions can be propagated and amplified alongside a supply chain, which constitutes the phenomenon of the “snowball effect”. The aim of the paper is to reveal the “snowball effect” in the transmission of disruptions depending on the level of supply chain integration. The first part of the paper highlights the general idea and characteristics of the “snowball effect” in the transmission of disruptions in a supply chain. The remainder of the paper has been devoted to the preliminary analysis of the “snowball effect” in the transmission of disruptions related to the supply chain integration.

Keywords: transmission of disruptions, amplification of disruptions, supply chain

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 [1]. 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.

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 [2]:

- limited range of disruptions, usually bilateral;
- widespread disruptions, generally holistic.

In the limited range of disruptions, the negative effects of risks are transmitted to a small number of links in a supply chain [2]. 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 [3]. 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.

**TYPES OF THE TRANSMISSION OF DISRUPTIONS IN SUPPLY CHAINS**

Depending on the direction of propagation, the transmission of supply chain disruptions can take the form of forward, backward and bidirectional (two-way) transmissions – Fig.2.

![Diagram showing the transmission of supply chain disruptions](image)

<table>
<thead>
<tr>
<th>Location of risk factors</th>
<th>Direction of propagation</th>
<th>Links on the level n-1</th>
<th>Relationships</th>
<th>Links on the level n</th>
<th>Relationships</th>
<th>Links on the level n+1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier</td>
<td>Forward propagation</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
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<tr>
<td>Manufacturer</td>
<td>Two-way propagation</td>
<td>![Image]</td>
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<tr>
<td>Customer</td>
<td>Backward propagation</td>
<td>![Image]</td>
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<tr>
<td>Link of the supply chain</td>
<td>Forward propagation</td>
<td>![Image]</td>
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<tr>
<td>Relationships of the supply chain</td>
<td>Backward propagation</td>
<td>![Image]</td>
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</tr>
</tbody>
</table>

Fig.2. The basic types of the transmission of supply chain disruptions

The forward propagation denotes that the disruptions caused by the exogenous or endogenous risk factors in the initial link are then transferred to the other echelons in a supply chain. The backward propagation is originated when the disruptions in the ultimate link of a supply chain are transferred to the initial echelons. The bidirectional transmission, in turn, is caused by the disruptions in the echelon located in the middle of a supply chain structure, which are then spread to the upstream and downstream links of a supply chain. Depending on the direction of
propagation, the transmission of disruptions arising from inter-organizational relationships may take the forms of both forward and backward transmissions.

It should be noted that the framework for analyzing the propagation of disruptions is illustrative. Depending on the structure of a supply chain, the propagation of disruptions may take more complex forms, which often makes it difficult to unambiguously analyze this phenomenon.

**CHARACTERISTICS OF THE “SNOWBALL EFFECT” IN THE TRANSMISSION OF DISRUPTIONS**

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 “snowball effect”.

The phenomenon of the “snowball effect” is illustrated in Figure 3.

![Fig.3. The “snowball effect” in a supply chain](image)

As depicted in Figure 3, 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 a 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 [4].

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 “snowball effect” was a result of European government’s response to the direct effects of the outbreak among livestock [5]. 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.

**IDENTIFICATION OF THE “SNOWBALL EFFECT” IN THE TRANSMISSION OF DISRUPTIONS**

The purpose of the identification of the “snowball effect” is to determine all disruptions that are likely to be transmitted in structures of supply chains [6]. In practice, one can use several methods for collecting information about the “snowball effect”. These include the experience of managers, the use of decision support systems, conducting surveys, "brainstorming" or recourse to the external consultants [7]. 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 “snowball 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
The key issue to resolve is to determine the scope of diagnosis outlining how many links are to be involved in the identification process [8].

The issue of the “snowball 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 “snowball effect”, namely the range of transmission and the amplification of disruptions. The confrontation of these two phenomena is presented in Figure 4, 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.

![Matrix of the range of transmission and the strength of disruptions](image)

The most interesting situation of the “snowball 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.
THE SUPPLY CHAIN INTEGRATION AS A MAJOR DRIVER OF THE “SNOWBALL EFFECT” IN THE TRANSMISSION OF DISRUPTIONS

Integration determines the supply chain efficiency, and is often depicted as the essence or pillar of the concept. However, Copper et al. believe that, achieving true supply chain integration is “a lofty and difficult goal” [9].

The integrated supply chain approach uses a number of terms that indicate the need for closer and open relationships, including cooperation, coordination and collaboration between supply chain members to ensure the success of these arrangements [10, 11, 12]. Those terms may express the shift in the level of intensity of relationships between partners in supply chains [13]. Spekman et al. suggest that cooperative, coordinating and collaborative behaviours involve working together/jointly to bring resources into a required relationship to achieve effective operations in harmony with the strategies/objectives of the parties involved, thus resulting in mutual benefit [12]. Stevens points out that integration of this nature is more than a change of scope; it is more significantly a change in attitude away from the adversarial attitude of conflict to one of mutual support [14].

Cooperation, where firms exchanged essential information and engaged some suppliers/customers in longer-term contracts, is perceived as the “threshold” level of interaction [15]. Cooperating supply chain partners may provide automatic confirmations and share data on forecast, inventory availability, purchase orders [16]. The spectrum of coordinated functions is limited and the intensity of relationships between firms is rather low.

The next evolutional stage is coordination where both workflow and information were exchanged to make many of the traditional linkages between and among trading parties seamless [15]. In a coordinated relationship, supply chain partners act together more closely and rely on each other’s capabilities. Unlike cooperative relationships, coordination requires a high level of negotiation, compromise and long-term commitment [16]. Coordination often concerns a set of similar functions (e.g. logistic) to be performed jointly and smoothly. In this type of arrangements the relationships among supply chain partners are more intense and may be described as monitored business process links. It means that they are not as critical for the focal company in a supply chain, but at the same time, the company, as frequently as necessary, verifies and audits how the relationship is integrated and managed [17].

Collaborative behaviour engaged partners in joint planning and processes beyond levels reached in less intense trading relationships [15]. It has become a popular topic as an integral facet of supply chain management [18]. In general, collaboration denotes the greatest degree of integration. The partners are concentrated on a strategic vision of the future rather than on
near-term planning and tactical execution. The collaborative relationships move beyond supply chain operations to include other critical processes. In this type of integration, supply chain partners may invest in joint research and development projects [16]. Collaboration often concerns a set of different functions (e.g. logistic, marketing, production etc.) to be integrated. Therefore, this type of relationships may be described as managed business process links [17], giving the priority in allocating scarce resources to this type of critical links.

Empirical evidence suggests that close long-term relationships between customers and suppliers have a beneficial impact on performance [19]. However, integration may also lead to an excessive mutual dependence of companies in a supply chain [20], [17] being the major source of the transmission of disruptions. Consequently, over-dependence may cause amplification and propagation of disruptions in part of or in the whole supply chain [21]. Therefore, it seems to be interesting and inspiring in theoretical and empirical aspects to reveal the “snowball effect” in the transmission of disruptions from the perspective of supply chain integration.

**METHODOLOGY**

**Sample and data collection**

In order to reveal the “snowball effect” in the transmission of disruptions depending on the level of supply chain integration, a preliminary research has been conducted. It provides findings of a cross-sector empirical study conducted among practitioners dealing with the risk effects in their organizations.

The main research instrument used for this study was a questionnaire consisting of several sections examining the phenomenon of the propagation of disruptions. There is no single meta-theory for guiding the development of the survey. Instead, many aspects of general managerial practices were a subject of investigation. Data collected within the first release of the survey were gathered in 2011 in European companies.

For the purpose of the research presented in this paper, a number of 55 variables have been selected. The number of 43 items was gathered using 7-point Likert scale. They reflected respondents’ attitude towards the strength of transmitted disruptions.

The remaining portion of 12 items constituted the list of initial variables identified on the basis on literature review. They concerned the quality of established relationships among supply chain members. In particular, they investigated the level of trust and intensity of
commitment in achieving a goal, common investments and gathering necessary data on supply chain partners, the contribution of integration in the success of a supply chain [22].

The sample was compiled from the surveys of manufacturing and trading companies and originally consisted of 216 firms. As a result of initial data analysis, screening and elimination of observations with missing values, a group of 144 companies remained as the subject of further analysis. Those firms were leaders or major links in their supply chains consisting of at least three subsequent links.

The majority of the surveyed firms (65 percent) are trade companies, remainder of the research sample includes manufacturers. The prevailing share of the companies operate in wholesale and retail grocery sector (13 percent), fabricated metal products, industrial and commercial machinery sector and manufacturing of motor vehicles (a total of 12.5 percent), followed by the companies from a mining industry (8 percent), trading companies (selling cross-industry products, mainly household goods – 6 percent, clothes – 5 percent, chemicals – 4 percent, electronic equipment – 3%).

The prevailing share of 68 percent of the sample employed up to 9 people, followed by 17 percent of the companies employing from 10 to 49 persons. Much smaller share of 9 and 7 percent of the sample belonged to the companies employing from 50 to 249 and above 250 people respectively.

Research methods

In order to reveal the “snowball effect” in the transmission of disruptions depending on the level of supply chain integration a two-step statistical analysis was employed.

The first step was the reduction of the many variables available through Principal Component Analysis (PCA) with Varimax Rotation in order to highlight the main underlying multi-item constructs reflecting the issues of integration in supply chains. In stage two, a cluster analysis was conducted. It enabled to observe the “snowball effect” in the extracted classes of companies grouped by the level of integration.

Principal Component Analysis was performed on 48 variables. The number of 12 variables reflected multidimensional aspects of supply chain integration. Each item was used separately for four groups of partners in supply chains, namely: primary members, including upstream (i.e. suppliers and manufacturers) and downstream structure (i.e. customers) of a supply chain, supporting members, performing the logistics activities (i.e. logistics service providers) and supporting members, performing the non-logistics activities (i.e. banks, financial providers,
market research firms etc.). In the result, the overall number of 48 variables was employed in a study. In order to develop a strong structure of constructs a group of 10 variables was dropped for low correlation indices with other variables. The Principal Component Analysis conducted in a space of the remaining variables showed a clean factor-loading pattern with minimal cross-loadings and high loading on the one construct factor. The value of some factor loadings is below a nominal cut off point of 0.65, but better than 0.5 on all factors. Therefore, the original variables were kept in a model [23]. PCA conducted finally on 38 items revealed a solution consisting of 10 factors (Table 1) which explain 68.5 percent of total variance. The number of factors was determined by the analysis of the percentage of variance explained and the Kaiser criterion [24].

The PCA resulted in producing the total number of 10 factors, used for the further research:

- Factor 1: quality of the relationships established with supporting members, performing the non-logistics activities (degree of trust to supporting members, their knowledge of the specificity of other supply chain partners, integration with service providers generating a synergistic effect, involvement of providers in the integration, improvement of the competitive position as a result of interaction with non-logistics service providers, additional efforts offered by service providers to improve links with supply chain partners, contribution of the supporting members to achieve common goals, the process of communication with non-logistics service providers);

- Factor 2: quality of the relationships established with supporting members, performing the logistics activities (knowledge of the specificity of other supply chain partners, integration with service providers generating a synergistic effect, involvement of providers in the integration, improvement of the competitive position as a result of interaction with logistics service providers, contribution of the supporting members to achieve common goals);

- Factor 3: Frequency of evaluation of the relationships among supply chain partners (suppliers, customers, supporting members performing the logistics and non-logistics activities);

- Factor 4: Use of ICT in establishing the relationships among supply chain partners (suppliers, customers, supporting members performing the logistics and non-logistics activities);

- Factor 5: The level of investment in the development of relations among companies in the supply chain (suppliers, customers, supporting members performing the logistics and non-logistics activities);
### Table 1.
The structure of the constructs obtained through the Principal Component Analysis

<table>
<thead>
<tr>
<th>Constructs</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of the relationships established with non-logistics service providers</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Quality of the relationships established with logistics service providers</td>
<td></td>
<td>.769</td>
<td>.721</td>
<td>.668</td>
<td>.668</td>
<td>.576</td>
<td></td>
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</tr>
<tr>
<td>Frequency of evaluation of the relationships among supply chain partners</td>
<td></td>
<td>.816</td>
<td>.752</td>
<td>.670</td>
<td>.652</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of ICT in establishing the relationships among supply chain partners</td>
<td></td>
<td>.841</td>
<td>.819</td>
<td>.674</td>
<td>.589</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>The level of investment in the development of relations among companies in the supply chain</td>
<td></td>
<td>.799</td>
<td>.752</td>
<td>.713</td>
<td>.571</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commitment and frequency of the communication with the suppliers</td>
<td></td>
<td>.777</td>
<td>.742</td>
<td>.567</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Contribution of the companies to achieve the competitive goals of a supply chain</td>
<td></td>
<td>.802</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Similar value system shared among supply chain partners</td>
<td></td>
<td></td>
<td>.750</td>
<td>.715</td>
<td>.520</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Synergistic effect generated as a result of interaction with suppliers and customers in a supply chain</td>
<td></td>
<td></td>
<td>.657</td>
<td>.616</td>
<td></td>
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<tr>
<td>Undertaking additional efforts in order to improve the relationships in a supply chain</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.726</td>
<td>.661</td>
</tr>
</tbody>
</table>
- Factor 6: Commitment and frequency of the communication with the suppliers;
- Factor 7: Contribution of the companies to achieve the competitive goals of a supply chain;
- Factor 8: Similar value system shared among supply chain partners;
- Factor 9: Synergistic effect generated as a result of interaction with suppliers and customers in a supply chain;
- Factor 10: Undertaking additional efforts in order to improve the relationships in a supply chain.

The second step of the study was the classification of the sample into homogenous groups through cluster analysis. The criteria for classifying the sample into clusters were the ten factors extracted in previous step of the study and reflecting the major aspects of supply chain integration.

In the opinion of Humphries et al., cluster analysis is an unusual method to classify a large sample of dyadic, highly interdependent, supply chain relationships based upon the quality of their interactions [25]. The goal of a cluster analysis is to group the companies into classes containing the similar organizations in terms of the level of supply chain integration.

At first in order to determine the number of clusters a hierarchical cluster analysis with Ward’s partitioning method and squared Euclidean distance was performed [26]. In the result of the analysis four clusters were formed. The number of groups was obtained through the greatest increase in the agglomeration coefficient while minimizing a number of clusters [27]. The greatest increase corresponds to the grouping of all cases from four to three clusters.

The number of four clusters was then used to perform K-Means Cluster Analysis to assign each case to the appropriate cluster. The criterion of the cluster membership was the minimal Euclidean distance between each case and classification center represented by centroid (cluster center). Additionally, the results of K-means cluster analysis were compared with a class assignment obtained from the hierarchical cluster analysis. On the basis of the results of two partition methods the contingency table was constructed and Rand index calculated. The measure of agreement showed that 74 percent pairs of objects are placed in the same class. It means a high level of agreement and confirmed a correct choice of K-means cluster analysis as the leading clustering method [28]. The method enabled to draw the conclusions of cluster analysis [27].

Figure 5 depicts the breakdown of the data set by the level of integration expressed by cooperative, coordinative and collaborative relationships.
The comparison of the level of integration gained by the examined clusters suggests that the first group constituting 33 percent of the sample contains the companies establishing cooperative relationships, the second class including 24 percent of the data set is formed by the firms coordinating their relationships. Finally, the last group with the prevailing share of 43 percent of the sample consists of the companies establishing collaborative links. As the number of observations in one of the four groups is very low (share of 0.5 percent of companies in a sample) its in-depth analysis was dropped. Consequently, the three clusters were a subject of further detailed investigation.

**PRELIMINARY RESULTS**

**Disclosure of the “snowball effect” in the transmission of disruptions**

The aim of the study is to identify the “snowball effect” in the transmission of disruptions and to reveal the role of supply chain integration in that phenomenon. The results of the analysis are presented in two major dimensions, namely from the perspective of the direction of transmission concerning the forward, backward and two-way propagation of the “snowball effect” and from the standpoint of the type of flow in supply chains i.e. material, information and finance.

The preliminary study suggests that the propagation of the “snowball effect” exists in a physical flow of products in supply chains. The risk factors located in the subsequent links of the supply chains generate the disruptions which are then transmitted with a greater strength.
to the other companies. The increase in the strength of propagated disruptions is clearly observed in the forward and backward transmission in the material flow of the examined companies establishing collaborative relationships in their supply chains. It may indicate the phenomenon of the “snowball effect” – Table 2 and 3. For instance, the disruptions caused by the risk located in the company at the layer ‘n-1’ in a supply chain are propagated forwardly and amplified in the firms at the layers ‘n’ and ‘n+1’ in the structure of a supply chain.

Table 2.

The relationships between the strength of the „snowball effect” in a forward transmission of disruptions and the level of supply chain integration
(Median scores: 1,00 - the lowest impact, 7,00 – the highest impact)

<table>
<thead>
<tr>
<th>Type of the flows in supply chains</th>
<th>Links on the level n-1</th>
<th>Links on the level n</th>
<th>Links on the level n+1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaboration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>3.00</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>Information</td>
<td>3.00</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>Finance</td>
<td>2.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Coordination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>5.00</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>Information</td>
<td>5.00</td>
<td>5.25</td>
<td></td>
</tr>
<tr>
<td>Finance</td>
<td>4.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Cooperation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>4.00</td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>Information</td>
<td>4.00</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Finance</td>
<td>3.00</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

However, the “snowball effect” seems to decline in the physical flow of products when the level of supply chain integration decreases. It may explicitly be observed in the forward and
backward transmission of disruptions. The preliminary analysis may provide that there is a phenomenon of the “snowball effect” in the transmission of disruptions in the physical flow of products which is determined by the level of supply chain integration.

Table 3.

The relationships between the strength of the „snowball effect” in a backward transmission of disruptions and the level of supply chain integration
(Median scores: 1,00 - the lowest impact, 7,00 – the highest impact)

<table>
<thead>
<tr>
<th>Type of the flows in supply chains</th>
<th>Links on the level $n-1$</th>
<th>Links on the level $n$</th>
<th>Links on the level $n+1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>4.50</td>
<td>3.00</td>
<td>2.50</td>
</tr>
<tr>
<td>Information</td>
<td>1.00</td>
<td>2.50</td>
<td>3.00</td>
</tr>
<tr>
<td>Finance</td>
<td>1.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Material</td>
<td>3.50</td>
<td>3.50</td>
<td>3.00</td>
</tr>
<tr>
<td>Information</td>
<td>1.00</td>
<td>2.75</td>
<td>3.25</td>
</tr>
<tr>
<td>Finance</td>
<td>1.00</td>
<td>2.00</td>
<td>3.75</td>
</tr>
<tr>
<td>Material</td>
<td>1.50</td>
<td>2.50</td>
<td>3.00</td>
</tr>
<tr>
<td>Information</td>
<td>1.50</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Finance</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

The similar tendency may be observed when analyzing the “snowball effect” in the forward transmission of disruptions in the information flow. The level of supply chain integration seems to play more important role in increasing the “snowball effect” in the transmission of disruptions. When the examined companies establish coordinative and collaborative relationships the strength of the “snowball effect” in the forward transmission of disruptions

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increases in the information flow. On the other hand, the strength of the “snowball effect” decreases when the companies cooperate in their supply chains. Interestingly, the strength of disruptions in the backward transmission in the information flow decreases. This may mean that the transmitted disruptions are not amplified in the information flow, suggesting there is no “snowball effect”, but simultaneously may spread to the other links involved in the material and finance flow in the supply chains.

Table 4.

The relationships between the strength of the „snowball effect” in a two-way transmission of disruptions and the level of supply chain integration
(Median scores: 1,00 - the lowest impact, 7,00 – the highest impact)

<table>
<thead>
<tr>
<th>Type of the flows in supply chains</th>
<th>Links on the level (n-1)</th>
<th>Links on the level (n)</th>
<th>Links on the level (n+1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaboration</td>
<td>Material 1.00</td>
<td>4.50</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>Information 2.00</td>
<td>5.00</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Finance 2.00</td>
<td>4.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Coordination</td>
<td>Material 1.00</td>
<td>4.75</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>Information 1.00</td>
<td>4.25</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>Finance 2.00</td>
<td>5.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Cooperation</td>
<td>Material 1.50</td>
<td>3.50</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>Information 1.00</td>
<td>5.00</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Finance 1.00</td>
<td>4.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The results also revealed a clearly delineated tendency in the decrease of disruptions in the forward and backward transmission in the finance flow. This may suggest that although the problems of cash settlements are not transferred to the financial sphere in the supply chain,
but they may cause increased disruptions in the material flow. This represents probably one of the major reasons of the “snowball effect” in the physical flow of products. In addition, it should be noted that the disruptions in the finance flow are not only propagated to the companies participating in the flow of products. They can also come from the traders and providers of non-logistical services (e.g., banks, investment funds, insurance companies, etc.). The propagation of negative effects caused by the risks located in those links may be one of the factors contributing to the “snowball effect” propagated forwardly and backwardly in a material flow of products in the supply chains.

The interesting conclusions may be drawn regarding the analysis of two-way propagation of disruptions in the product, information and finance flows – Table 4. In general, the companies positioned close to the market and ultimate customers are exposed to the “snowball effect” transmitted from the preceding links. The companies located more upstream in the supply chains report relatively small impact of disruptions transmitted from the subsequent echelons. Summing up, the “snowball effect” may generally be observed in the material and information flows in supply chains. It is a very important result as both flows play a vital role in effective supply chain management. Additionally, based on the results of the preliminary study, it may be concluded that the strength of the “snowball effect” is dependent on the level of supply chain integration. The more intense relationships established among supply chain partners, the strength of the “snowball effect” increases.

**Difficulties in identifying the “snowball effect” in the light of empirical study**

The preliminary analysis of the results revealed that the “snowball effect” may not 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 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 [29]. Risk factors such as natural disasters or financial crises often simultaneously and directly affect a larger number of links in a supply chain [30]. The disruptions caused by this group of risk factors are not sequential in their nature and are often interdependent [31]. 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. The conducted research reveal that, there are three situations significant for the identification of the “snowball effect”, namely:

− the effects of the direct impact of a risk factor differ from the disruptions in the “snowball effect” (transmitted indirectly from other firms);
− the “snowball effect” occurred among companies in a supply chain operating in different parts of the world;
− the strength of disruptions in the “snowball 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 “snowball effect” in this situation is illustrated in Figure 6.

As depicted in Figure 6, 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.

As depicted in Figure 7, 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.

Fig.7. Identification of the “snowball effect” occurring among companies in a supply chain operating in different parts of the world
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 [32].

Table 5 presents the “snowball 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 5 shows, it might be impossible to identify the “snowball 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 5.
The “snowball effect” in terms of the range of impact and similarity of disruptions caused by the direct and indirect effects of risk

<table>
<thead>
<tr>
<th>Range of the impact in a supply chain</th>
<th>Similarity of disruptions caused by the direct and indirect effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Global</td>
<td>Impossible</td>
</tr>
<tr>
<td>Local</td>
<td>Difficult</td>
</tr>
</tbody>
</table>

As depicted in Table 5, the ability to identify the “snowball 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 “snowball 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 “snowball 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. The proposed framework for analyzing the propagation of amplified disruptions should be positively verified as it serves a crucial role for identification of the phenomenon. Therefore, it is worth noting that the “snowball effect” seems to be a vital ingredient of the contemporary supply chains. However, its extent and strength differ considering the type and direction of flow in the supply chain which should be definitely considered by practitioners and managers while making a decision process. The conducted study also indicates that the propagation of amplified disruptions in the supply chains requires further in-depth and extensive analysis. It is a very interesting issue but still unexplored and unexplained.

PROPOSALS, FUTURE DIRECTIONS AND FURTHER RESEARCH
Apart from providing some insights into the contribution of identification of the “snowball effect” in a supply chain, the paper also highlights the potential areas of future research. The natural continuation of the issues considered in the paper is to define the ways of identification and measurement of the “snowball effect” enabling to make cross-sectoral and international comparisons of disruptions amplified in the transmission. The determinants of identification of the “snowball effect” have been illustrated in Figure 6. The arrow in Figure 8 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 “snowball 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 “snowball effect”. Under such circumstances the identification of the “snowball effect” is relatively the easiest. The above considerations show that the ability to read the “snowball effect” may differ depending on the exogenous and endogenous nature of risk factors.
The observation of the “snowball 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 “snowball effect”. The tendency is sustained when the strength of disruptions in the “snowball effect” caused by the factor is low. This may partially explain why managers often have problems with the identification of the “snowball 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.

The above mentioned argumentation allows to conclude that the “snowball 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. 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 “snowball effect” 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 “snowball effect” and indicate exemplary strategies preventing from the negative effects of disruptions transmitted along a supply chain.

REFERENCES


