The adaptive capability of resilient supply chains. An empirical study

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Abstract
The paper aims to identify and examine the adaptive capability of resilient supply chains. The theoretical considerations concerning the issue of adaptation in supply chains, as an important facet of resiliency, are complemented with the findings of empirical study conducted in the sample of European supply chains.

Keywords: adaptation, resiliency, supply chain

INTRODUCTION

A 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. Consequently, the ability to adapt is one of the most crucial characteristics of resilient supply chains which considers the capability to self-organize, emerge and reconfigure the structure and behavior to satisfy new environmental conditions (Lee, 2004). In the literature one may encounter numerous theoretical considerations concerning the way the resilient supply chains should operate. However, they have mostly a conceptual character and they are usually based on the previous developments tracing the roots to the theory of complex adaptive systems (Choi *et al.*, 2001; Wildavsky, 1991, Mallak, 1998, Horne and Orr, 1998). Moreover, the issue of adaptation is a multifaceted concept itself, requiring profound study if transferred to the theory of resilient supply chains. The core component of adaptation is the organizational ability to learn. There are many levels of organizational learning, and thus the adaptation process may take different forms (Stacey, 1994; Jackson, 2003; Argyris and Schoen, 1978). In order to meet the aforementioned challenges, the paper aims to empirically explore the adaptive capability of resilient supply chains. The study posits that the process of adaptation is consistent with triple loop organizational learning, and thus composed of three subsequent stages including disruption discovery, recovery and pre-adaptation.

THE ISSUE OF ADAPTATION IN RESILIENT SUPPLY CHAINS

The most fundamental property of resilient supply chains is the capability to adopt to the uncertain environment. This issue has been also highlighted by Melnyk *et al*. (2010) who maintain that the resilient supply chains are prepared to recover quickly and effectively from disruptions caused by the natural disasters (such as earthquakes), social factors (employee strikes), medical emergencies (epidemics), economics setbacks (financial crisis) etc. However, the other authors posit that the resilient supply chains may be also exposed to the disruptions triggered by the internal factors, yet the probability of their occurrence, as well as severity of the consequences are usually much lower as compared to the factors eliciting from the external uncertainty. Consequently, the previous studies generally investigate external factors which may potentially (or actually) have an impact on the resilient supply chains (Juttner and Maklan, 2011; Chozick, 2007). One of the most important abilities of a resilient supply chain is its adaptive capability that generally consists of three subsequent stages, namely disruption discovery, recovery and pre-adaptation.

The resilient supply chains are characterized by the potential to discover a disruption in a reasonable period of time. Handfield (2007) argues that the management should be able to identify risk sources and types of disruptions, and thus to develop methods for discovering disruptions in a timely and responsive fashion – Fig. 1. Consequently, the phase of discovery requires to use forecasting methods and risk identification systems, monitor deviations and warning signals, implement the methods of contingency planning.

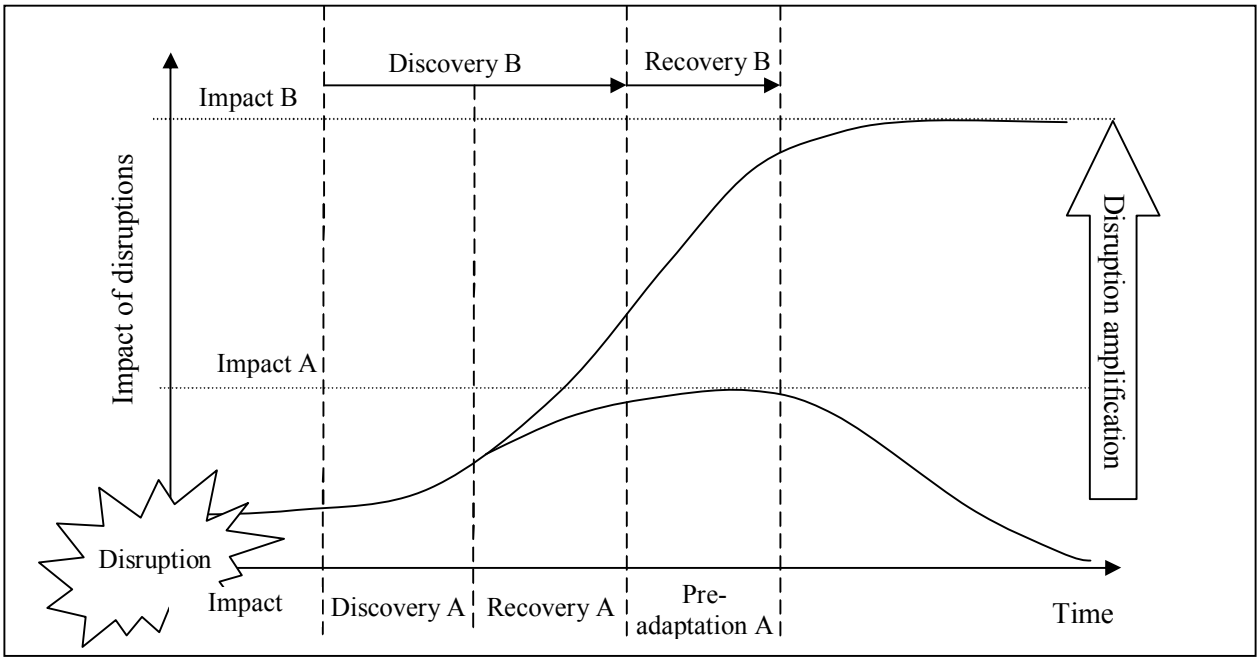

Figure 1 – The adaptive capability of resilient supply chains

Adopted from R. Handfield: *Reducing the impact of disruptions to the supply chain*, SAScom Magazine, April, 2007, pp. 33-41.

Disruption discovery should be then followed by using appropriate methods to recover from the negative risk effects quickly and prevent them from affecting further links of a supply chain. In other words, recovery denotes that the resilient supply chains are able to quickly organize a formal response team of the employees that reacts to the crisis, establish efficient communication strategy in a variety of extraordinary situations and undertake necessary steps in order to mitigate the disruptions, regardless of the costs. The management of resilient supply chains ought to be experienced in successful dealing with the negative effects of uncertainty.

Pre-adaptation denotes increasing the fullness and deepness of learning about the diversity of issues and faced dilemmas (Flood and Romm, 1996). Following the opinion of Stacey (2011), we posit that the pre-adaptation phase is manifested in the form of 'collective mindfulness'. It means that facilitated or inhibited pre-adaptation is capable to produce new structures and strategies. Following the view of Batesson (1981), pre-adaptation may be referred to as a process learning that denotes 'learning to learn'. On this level of learning, the resilient supply chain learns to improve its learning process. This leads to a modification of the values of the theories-in-use as well as the strategies and expectations (Argyris and Schön, 2006).

During the pre-adaptation process, the organization is capable to transform because its internal relationships are more visible and obvious. The patterns of relationships between the resilient supply chains and environment are becoming more recognizable. An in-depth understanding these patterns and possible consequences of actions may lead to changes of organizational structure. Pre-adaptation has a direct nature as it enables to identify the role and significance of organizations (Morgan, 1996). From the perspective of organizational learning, the development of learning ability of the organization is a prerequisite to survive and succeed in increasingly dynamic and complex environments (Georges *et al.*, 1999). Pre-adaptation is characterized by the capability to relocate the employees between the organizational departments, exchange the orders placed at the suppliers, use of strategic gaming and simulation models to perform the adaption processes, seizing advantages from changes in the market, developing innovative technologies to improve operations, creative problem solving, individual accountability for performance. The resilient supply chains also train the employees in a wide variety of skills, fill in leadership voids very quickly and regularly use feedback and benchmarking tools. Pre-adaptation requires a strong culture of caring for employees, further reduction of lead-times for the products and effective employment of the continuous improvement programs.

METHODOLOGY

Sample and measures

The main research instrument used for this study was a questionnaire consisting of several sections examining the stages of the adaptation process. The set of data was collected in 2015. The study had a non-exhaustive character. The target sample were companies representing the manufacturing and trading sector in Poland. This approach excluded the companies from the

service industry, as they do not necessarily perform logistics services, and thus do not participate in material flows in the supply chains (e.g. hospitals, banks, marketing agencies, insurance companies). Consequently, triads comprised of three subsequent echelons as the units of supply chains have been investigated (Choi and Wu, 2009). The companies solicited for this study were formal leaders or major links with a strong position in their triads and expertise concerning the adaptation and resiliency in the supply chains. The sample finally consisted of 122 accepted organizations that had at least one supplier and one customer. The main research instrument used for this study was a questionnaire consisting of several sections examining the adaptive capability and environmental conditions. Firstly, the number of 12 variables on the environmental conditions were captured by a 5-point Likert scale and manifested the level of certainty/ uncertainty of the environment. These variables particularly concerned the activity of competitors, government regulations, price pressures from the competitors, changes in the social and cultural environments, as well as the natural and man-made disasters. Next, the adaptive capability of supply chains was investigated. The number of 6 items measured the phase of disruption discovery, the group of 4 variables captured the recovery process. Finally, the last group of 19 variables measured pre-adaptation. All three groups of variables were formed by the 5-point Likert scale items, and thus the level of intensity of each phase of adaptation might be calculated.

Research model and methods

In order to conduct the study, the research sample consisting of 122 organizations was split into two groups regarding the level of certainty/uncertainty surrounding the examined supply chains. The classification criteria were 12 variables measuring the level of environmental certainty/ uncertainty. In order to conduct the study, the *K-means* cluster analysis was employed and produced two clusters. One of them embraced a group of 57 supply chains operating in the uncertain environment. The results of *K-means* cluster analysis were compared with the class assignment obtained from the hierarchical cluster analysis. Based on the results of two partition methods, the contingency table was constructed and *Rand index* calculated. The measure of agreement showed that 79% pairs of objects are placed in the same class. It means a high level of agreement and confirms the correct choice of *K-means* cluster analysis as the leading clustering method (Krieger and Green, 1999).

This group of companies were recognized to gather resilient supply chains as operating in such environmental conditions requires them to obtain a higher degree of resiliency. The further analysis was conducted in this group. In the second step of the study, the Partial Least Squares model (PLS model) was developed. In the opinion of Ainuddin *et al*. (2007) the use of PLS is especially suited to exploratory studies, where the measures are new and the relationships have not been previously tested. Furthermore, as a rule of thumb for PLS, the sample size should be ten times larger than the largest number of structural paths directed at a particular construct in the inner path model (Barclay *et al.*, 1995; Chin, 1998; Birkinshaw *et. al.*, 1995). The sample size used in the study is 57 and the largest number of structural paths directed at a particular construct

in the proposed path model is 1. Therefore, the study meets the criterion of sample size. PLS requires to specify dependent and independent variables before carrying out any analysis. In the study, disruption discovery will have an impact on organizational recovery, and the latter one has, in turn, the effect on pre-adaptation.

The PLS Path Model in this study consists of the inner (structural) model, which is comprised of the constructs and their hypothesized relationships and the outer (measurement) model describing the relationship between latent (unobserved) and manifest (observed) items (Tenenhaus *et al.,* 2005). First, the reliability and validity of the measurement model was assessed, followed by the assessment of the structural model (Hulland, 1999). The proposed measurement model has reflective items from the latent variable to the manifest variables in their blocks. The application of the reflective outer model posits that changes in the constructs are expected to be manifested in changes in all of their indicators. In the model, observed items ought to be highly correlated, as they explain the same construct (Jarvis *et al*., 2003; Diamantopoulos and Winklhofer, 2001). Consequently, removing any item from the block of variables should not have a significant effect on the latent variable. In other words, the observed items constituting a reflective block do not need to represent all the aspects that form the concept (McDonald, 1996). In fact, the items are interchangeable and share the same construct.

In order to check the hypothetical structure of constructs in the model, the Exploratory Factor Analysis (*EFA*) with the Principal Component Analysis (PCA) and Varimax Rotation were conducted. The number of 3 factors have been chosen for the analysis. The inspection of anti-image correlation matrix has led to the elimination of several variables as their measure of individual sampling adequacy (*MSA*) was below a nominal cut-off point of .5. In addition, in the result of factor analysis a number of variables were excluded from the model, as they indicated insufficient factor loadings below .5. Finally, the model presented in Figure 2, has been obtained and used in the further PLS analysis.

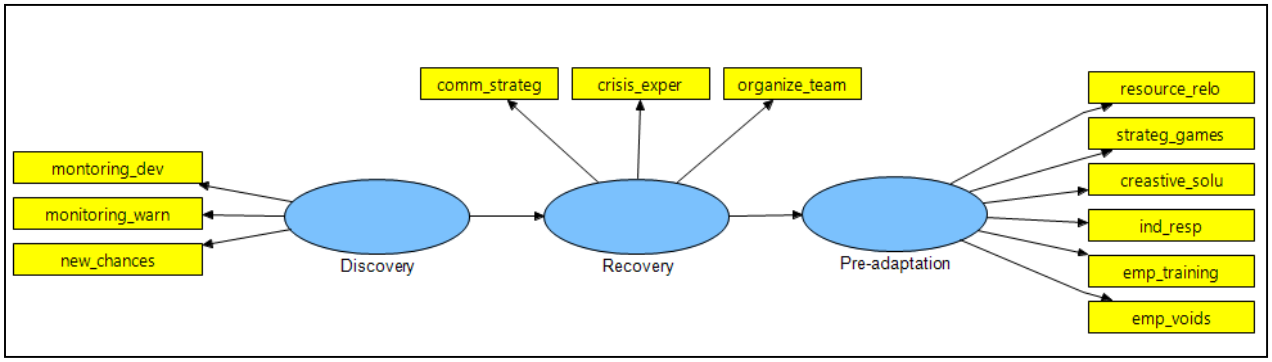

Figure 2 – The PLS model

The first construct in the model, manifesting the adaptation phase of discovery was composed of three variables: monitoring deviations in the environment (monitoring_dev), identifying and monitoring warning signals that may indicate upcoming disruptions (monitoring_warn), and recognizing new business opportunities (new_chances). The second construct that demonstrates

the adaptive activity of resilient supply chains is the recovery process which consists of the following components: ability to quickly organize the formal response team that aims to deal with the problems (organize_team), effective communication strategy in the extraordinary situations (comm_strate), and experience in successful dealing with the crisis occurring in the environment (crisis_exp). Ultimately, the third construct – the adaptive phase of pre-adaptation includes organizational capability to relocate the employees between the organizational departments (resource_relo), strategic gaming and simulation models to perform the adaption processes (strateg_games), creative problem solving (creative_solu), individual accountability for performance (ind_respo), training the employees in a wide variety of skills (emp_training), filling leadership voids very quickly and regularly (emp_voids).

The outer path model

The reflective outer model was assessed with respect to their reliability and construct validity – Table 1. Reliability testing usually includes internal consistency and composite reliability (*CR*). Each of three constructs indicates Cronbach's alpha coefficient exceeding .7. The coefficients of *CR* estimated for the underlying constructs in a measurement model are above value of .7. The results of reliability are satisfactory regarding an early stage of the study (Nunnally & Bernstein, 1994). The indicator reliability for all constructs, as measured by the square of factor loadings, should be above .4 for the explorative study (Hulland, 1999).

Table 1 - The results summary for the outer model

Latent variables	Indicators	Loadings	Indicator reliability	Composite reliability	AVE
Discovery	monitoring_dev	.831	.690	.77	.54
	monitoring_warn	.632	.400		
	new_chances	.780	.609		
Recovery	organize_team	.656	.430	.80	.58
	comm_strateg	.885	.784		
	crisis_exp	.719	.517		
Pre-adaptation	resource_relo	.715	.512	.86	.50
	strateg_games	.806	.650		
	creative_solu	.640	.410		
	ind_respo	.691	.478		
	emp_training	.667	.445		
	emp_voids	.746	.557		

The convergent validity, as measured by the coefficients of average variance extracted (*AVE*), is equal or above a nominal cut-off point of .5 across all constructs. It indicates that all latent

variables in the model are able to explain more than half of the variance of its indicators on average (Chin, 1998), which is acceptable for the exploratory study. The discriminant validity has been assessed to explore if the appropriate items load substantially on their hypothesized constructs and load no larger than .3 on any other component (Hair *et al.*, 2006). Although, the outcome of analysis demonstrates that the observed items, used to measure the specified constructs highly loads (above .6) on their assigned components, the threshold of .3 is not met for all cross-loadings. It may suggest that some variables load substantially on more constructs. It may stem from the fact that in the practical study, it is difficult to clearly devise a delineated pattern of behavior of resilient supply chains in the subsequent phases of the adaptation process.

The discriminant validity also meets the *Fornell–Larcker* criterion that posits that the *AVE* coefficient of one construct is larger than the highest square of its correlation with the other constructs (Fornell and Larcker, 1981). Table 2 shows the *AVEs* in italics in the diagonal of the correlation matrix and the values off-diagonal are the squared correlations between the constructs.

The square of correlations is less than the corresponding *AVE* which indicates discriminant validity of the measures. Employing the *Fornell-Larcker* criterion (Fornell and Larcker, 1981), each construct in the outer model share more variance with its assigned indicators than with any other latent variable.

Table 2 – Correlation matrix

Constructs	Discovery	Recovery	Pre-adaptation
Discovery	*.53*		
Recovery	.14	*.58*	
Pre-adaptation	.12	.36	*.50*

Note: The AVE is provided in italics in the diagonal; the squared correlations between the constructs are given off-diagonal

Overall, as the criteria for reliability and construct validity are met, the obtained measurement results in the outer model are satisfactory and appropriate for proceeding with an estimation of the structural model.

Inner model

The reliable and valid outer model estimations allowed to evaluate the inner (structural) path model. In order to assess the structural model, the coefficients of determination (R^2) of the constructs, standardized path coefficients and prediction relevance of the model have been determined.

In general, the subsequent stages of adaptation explain a diverse amount of variance in the constructs, with R^2 values of .339 for the recovery phase of adaptation and .570 for the pre-adaptation process. The findings suggest that the coefficients of determination for the following

phases of adaptation are moderate. In the opinion of Chin (1998) if any endogenous latent variable (recovery and pre-adaptation in the proposed model) is explained by only a few (e.g., one or two) exogenous latent variables, moderate value of R^2 may be accepted. Therefore, the R^2 values for the following two phases of adaptation: recovery and pre-adaptation provided an indication of the predictive ability of the independent variables (Cohen and Cohen, 1975).

Table 3. Structural (inner) model results

	Proposed effect	Stand. path coefficient	*t*-value	Significance (*p*-values)
Effects on the recovery process (R^2 = 0.339)				
Discovery of disruptions	+	+ .373	4.855	p < .00
Effects on the pre-adaptation process (R^2 = 0.570)				
Recovery process	+	+ .598	9.804	p < .00

In order to determine the standardized path coefficients of the model and their statistical significance, a bootstrapping re-sampling technique was employed (Davison and Hinkley, 2003). Results from 500 re-samples revealed that all links in the model are significant at *p-level* < .000 – Table 3. The PLS findings show there is a positive and significant effect of the adaptation phase of discovery on the recovery process of resilient supply chains (path coefficient is +.373, p <.000) and recovery on the pre-adaptation process (path coefficient is +.598, p <.00). To assess collinearity of the inner model, the tolerance and Variance Inflation Factor (*VIF)* were calculated. The obtained values meet a rule of thumb with the value of *VIF* below 5 and the tolerance above .2 for two regression models (the first model with discovery as an independent variable and recovery as a dependent variable, and the second model with recovery as an independent variables and pre-adaptation as a dependent variable). In addition, in order to assess, if the exogenous latent variables contribute to the endogenous latent variables in both regression models, Cohen's f^2 was evaluated. For the recovery model and pre-adaptation model, Cohen's f^2 is .513 and 1.32, respectively which demonstrates the large effects of independent variables on dependent variables in both models. In order to evaluate the model fit in the PLS analysis, the Stone-Geisser test of predictive relevance was calculated (Geisser, 1975). The level of Q^2 show that the observed values are reproduced by the model and its parameter estimates. It implies that the inner model has a predictive relevance, as $Q^2 > 0$ for the constructs in both models (the recovery model $Q^2 = .06$ and the pre-adaptation model $Q^2 = .14$).

PRELIMINARY FINDINGS OF THE STUDY AND CONTRIBUTION

An estimation of the PLS Path Model provides the results concerning the adaptive capability of resilient supply chains. The findings evidence that there are three subsequent phases of operation of the resilient supply chains discovery of disruptions, recovery process and pre-adaptation. The preliminary analysis revealed that not all of the initially-employed variables, sufficiently explain the variance of the constructs manifesting certain steps in the adaption process. The findings of

the study demonstrate that among variables, significantly contributing to discovery of disruptions one may enumerate monitoring the deviations in the environment, identifying and monitoring the warning signals that may indicate upcoming disruptions, and recognizing new business opportunities. The second adaptive activity of resilient supply chains is the recovery process which consists of the following components: ability to quickly organize the formal response team that aims to deal with the problems, effective communication in the extraordinary situations, and experience in successful dealing with the crisis occurring in the environment. Ultimately, the adaptive phase of pre-adaptation includes capability to relocate the employees between the organizational departments, use of strategic gaming and simulation models to perform the adaption processes, creative problem solving, individual accountability for performance, training the employees in a wide variety of skills, filling leadership voids very quickly.

The coefficients of determination for the recovery process and pre-adaptation are moderate whilst the standardized path coefficients are positive and significant. These results demonstrate that discovery of disruptions should precede the recovery process, while the recovery should be then followed by the pre-adaptation phase. Interestingly, the standardized path coefficients between discovery and pre-adaptation is significant, however its value is noticeably lower than the value of other path coefficients. It may suggest the necessity to maintain the appropriate sequence of adaptation activities performed in resilient supply chains.

The major contribution of the study is providing the empirical evidence that the adaptive capability of resilient supply chains requires to undertake certain steps to make the organization capable to operate in a dynamic and nonlinear environment. This issue is particularly important for managers of contemporary supply chains that need to maintain a satisfying level of resiliency in order to deal with the increasing environmental turbulence.

On the other side, the analysis revealed that some of the indicators do not sufficiently and significantly contribute to the constructs manifesting the adaptive capability of organizations. Therefore, there is a need of further developments of certain solutions and components constituting the subsequent steps of the adaptation process of the resilient supply chains. It would be also interesting to analyze the findings of the PLS study with the control variables constituted by the size of the solicited companies and the level of uncertainty of the operating environment.

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