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Supply Chain Agility: Achieving Robustness and Logistics Performance

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Abstract

Purpose: This study aims to empirically analyze the influence of supply chain agility and flexibility on supply chain robustness and logistics performance, addressing a research gap in the context of dynamic business environments. **Research design, data and methodology:** The study examines causal relationships between supply chain agility, flexibility, robustness, and logistics performance among businesses in South Korea. Data were collected through a survey of 300 workers in supply chain-related departments. A structural equation model was employed for hypothesis testing. **Results:** The empirical analysis shows that supply chain agility and flexibility positively and significantly influence supply chain robustness, which in turn has a significant positive impact on logistics performance. **Conclusions:** This study contributes by providing empirical evidence on the importance of supply chain agility, flexibility, and robustness in enhancing logistics performance. The findings suggest prioritizing the development of these capabilities for competitive advantage. Further research on the interrelationships between various supply chain capabilities and their impact on performance outcomes is highlighted.

Keywords: Supply Chain Agility, Supply Chain Flexibility, Supply Chain Robustness, Logistics Performance

JEL Classification Code: I19, M19, M39

1. Introduction

In recent years, uncertainties in global politics, economy, and diplomacy have impacted numerous areas, dramatically changing business management. Changes in business management can be explained with theories from various disciplines, but in a broad context, such changes may be categorized into supply chain diversification and restructuring. Supply chain diversification and restructuring have been taking place at an unprecedented scale and pace (Grossman et al., 2023). Hence, it is essential for businesses that pursue the goal of long-term survival to consider how they would restructure internal organizations and where they could make external investments (Stevens & Teal, 2024).

Meanwhile, new studies have consistently appeared that explain changes observed in the supply chain management method. For instance, the method of supply chain management in the automobile industry has been traditionally represented by the concept of "Just In Time (JIT)," which has been widely used in supply chain and logistics research. However, recently, the "Just In Case (JIC)" concept has appeared to emphasize that businesses need to respond to every case, and this term stresses the importance of supply chain flexibility and agility (Y. K. Ha, 2022). In addition, "Global Value Chain (GVC)," which refers to supply chain management focused on costs and efficiency,

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is sometimes replaced with "Trusted Value Chain (TVC)," which insists on trust among supply chain participants (Orlanyuk-Malitskaya et al., 2024).

The focus of supply chain management has shifted from costs and efficiency toward building and operating a supply chain centered on resilience and responsiveness to unexpected situations. Cost-centered supply chain operations are likely to lead to significant losses. In this regard, investment in supply chain agility and flexibility to respond to every type of uncertainty in the market, production, logistics, and others, rather than operating cost-centered supply chain management, could prevent future losses, enhancing performance.

Previous studies have significant meaning in that they have expanded research related to supply chains by introducing changes in supply chain operation methods and new concepts (Choi & Shim, 2015; Kang & Lee, 2018). Moreover, these studies have presented alternatives for performance improvement along with implications by presenting phenomena and concepts. However, despite the need for follow-up studies to prevent unexpected losses while preparing for global uncertainties and to derive sustainable performance, research presenting new measures in this regard is somewhat insufficient. In other words, at the current point where the supply chain operation method needs to be fundamentally changed, it is necessary to prove the qualitative research through quantitative research via empirical analysis targeting supply chain participants.

This study sets supply chain agility and flexibility as independent variables and examines the influence of these variables on supply chain robustness and logistics performance. Doing so, it presents unique and valuable academic implications, departing from previous studies, in that it conducts an effective empirical analysis of previous methods that have been merely defined conceptually. Moreover, this study shows that investment in the supply chain, which was considered unnecessary in the past, may prevent losses and enhance performance. It also suggests practical implications for those in the field.

2. Theoretical Background

2.1. Supply Chain Agility

For business management, agility refers to the ability to swiftly respond to changes and uncertainties in the business environment. Recently, many companies have tried to respond to various consumer needs by building supply chains. Then, one question arises: What does agility mean within the supply chain? Swafford et al. (2008) defined agility as the ability to perform operational activities with the partners in the supply chain to respond and adapt to the rapidly changing market. In other words, agility is closely related to the effects of strategic supply chain management in the competition among supply chains (Li et al., 2008); hence, it is a prerequisite for building an efficient supply chain.

Meanwhile, regarding agility, Panigrahi et al. (2023) claimed that companies that have developed agility along the supply chain could better respond to unexpected situations than those that have not, as such companies could more accurately match supply and demand. Lin et al. (2006) stressed that if businesses do not co-manage fluctuations in the market with supply chain partners, the entire supply chain may collapse. Enhancing flexibility may bring about cost reduction, product innovation, quality improvement, and shortened delivery time, based on which businesses may improve their competitive advantage (Tse et al., 2016). In this study, flexibility is considered an antecedent of robustness as it is hard to copy agility, which helps improve the performance of the entire supply chain (Fayezi et al., 2017).

2.2. Supply Chain Flexibility

With the changes in the business landscape and ecosystem, the concept of flexibility is widely discussed in diverse topics, such as chief executive officers of companies and supply chains. According to the definition by Wadhwa et al. (2008), a company's flexibility refers to its attitude to arrange or modify a contract that the company executed with its trading partner, depending on the market environment, situation, and exchange relationship. In other words, it can be referred to as the ability to adapt to environmental changes, and in terms of production management, it can be understood as the amount of costs required to shift from producing a certain product to producing a different product and the range of products which can be produced (Arawati, 2011).

Vickery et al. (1999) explored supply chain flexibility by categorizing the concept into more detailed items, including volume, launch, and product. Specifically, volume flexibility implies the ability to respond to the market's demand by increasing or decreasing production volume, while launch flexibility involves the ability to perform an expedited launching of new products. Product flexibility refers to the ability to produce differentiated products to adapt to changes in the market. Similarly, Singh et al. (2020) classified the concept of supply chain flexibility into three categories: product flexibility, volume flexibility, and new product flexibility. Based on previous research, this study defines supply chain flexibility as a company's ability to respond to the changes and demands of the market correctly and effectively. Then, the concept is thoroughly analyzed.

2.3. Supply Chain Robustness

A robust supply chain works well even when damaged by risk. Then, one question arises: What does robustness mean within the supply chain? The concept of robustness can be explained as the ability to be prepared to take necessary action. In particular, Swafford et al. (2006) defined robustness as the ability or strategy to prevent any influence from a specific event. In other words, robustness implies the ability to perform a strategy established prior, and it requires accurately predicting changes. Braunscheidel and Suresh (2009) explained robustness as the capability of the supply chain to perform its functions well, even if the supply chain was partly damaged due to risk. In addition, Wallace and Choi (2011) argued that robustness implied the ability to maintain a stable situation without suffering shocks although negative changes occurred. Based on the results of previous studies, supply chain robustness can be defined as the capability to resist the various changes encountered in the business environment.

Robustness is a critical and essential concept for those who work in the supply chain, as, for many reasons, unexpected events may occur along the supply chain. Wang and Webster (2007) argued that internal risks related to logistics and funding, as well as external risks in relation to policy, economy, and culture, always existed in the supply chain. Tanuputri and Bai (2023) also contended that risks related to supply, operation, demand, control, and the environment always existed. Hence, if robustness is not considered, preventing the collapse resulting from events or incidents may be challenging, and properly controlling the existing structures and functions may become impossible (Madzimure, 2020). A supply chain needs to exhibit robustness to achieve the ultimate goal of the entire supply chain and consistently operate it.

2.4. Logistics Performance

The supply chain is a comprehensive and integrated process through which supplied raw materials are produced and converted into final products, which are then delivered to consumers through distributors and other channels (Cox, 1999). The objective of supply chain management is to satisfy consumers and increase sales volume at a minimum cost throughout every process on the supply chain. The supply chain sometimes shows complexity depending on the company's capabilities, equipment, and facilities. Therefore, using the right tools to measure the performance of the supply chain is necessary.

As a supply chain can be considered a network of independent enterprise entities, the efficiency of individual companies is typically considered for measuring the performance of the entire supply chain. This study utilizes logistics performance as an indicator because it can be measured relatively objectively and provides a tangible measurement of the efficiency of the supply chain (Ha et al., 2011). Meanwhile, logistics performance is a logistics-related indicator, which implies that logistics management may enhance work effectiveness and efficiency, increasing cost advantages and services (Lambert & Pohlen, 2002). In other words, logistics performance involves efficiency improvement in the inflow, outflow, and conversion along the supply chain, and representative measurement indicators include inventory turnover, total logistics cost, lead time, and production flexibility (Andersson et al., 1989).

3. Hypothesis Setting and Research Model

3.1. Supply Chain Agility and Robustness

Supply chain agility is the ease of cooperation and coordination among all activities performed along the supply chain. Domains for coordination are categorized into market, customers, logistics responsiveness, and collaboration with supply chain partners. To explain supply chain agility from the perspectives of the market and customers, it can be considered how promptly a supply chain responds to the needs of the market and customers when rapid changes occur in the internal and external environments of the supply chain. These considerations are directly related to the market share and sales performance, which correspond to supply chain risk management (Jajja et al., 2018).

To improve supply chain agility, it is also necessary to build consumer trust in delivery by diversifying logistics routes or means of transportation when faced with logistics issues. Such processes may be counted as expenditures, but ultimately, they may positively influence supply chain robustness. Finally, achieving supply chain agility generally requires active communication and cooperation with supply chain partners. This achievement may also contribute to enhancing supply chain robustness (Woo et al., 2018).

Supply chain agility can be explained as the appropriate and correct response to uncertainties, and all these factors may directly influence supply chain robustness. Hence, this study proposes the following hypothesis:

H1: Supply chain agility has a significant positive influence on supply chain robustness.

3.2. Supply Chain Flexibility and Robustness

Supply chain flexibility refers to the ease of adjusting plans along the supply chain, and such a feature is distinguished from that of prompt responses. While supply

chain agility involves conducting prompt adjustments in response to a specific situation, supply chain flexibility is related to the adjustment of mid- or long-term plans (Tang, 2006).

Supply chain flexibility primarily involves the adjustment of plans to meet customers' demands and the adjustment of production plans. From the perspective of customers, it may be explained as adjusting production volume in response to customer orders, as well as adjusting order lead time and the overall schedule. Uncertainties inside and outside the supply chain affect not only direct participants of the supply chain but also customers who are at the end stage of consumption. Depending on the market or economic situation, the volume of orders may dramatically decrease or increase, or sometimes, the product needs to be delivered earlier or later than expected. In response to those situations, diverse actions are taken for responding to market situations and maintaining the existing customer base, and consequently, those actions may enhance supply chain robustness and business performance (Namdar et al., 2018; Y. Wang et al., 2010).

As explained above, flexibility for customers also means flexibility in terms of production. This is because customers and the market are factors that can be responded to by adjusting production. In summary, supply chain flexibility means adjusting plans to be prepared for uncertainties, and these factors lead to supply chain robustness. Hence, this study proposes the following hypothesis:

H2: Supply chain flexibility has a significant positive influence on supply chain robustness.

3.3. Supply Chain Robustness and Logistics Performance

This study assumes that supply chain agility and flexibility influence supply chain robustness. Supply chain robustness implies resilience to risks or stability. It relates to how appropriately a company can respond to the market and customer demands, logistics issues, and the necessity of adjusting supply chain-related plans in cooperation with supply chain partners, thereby overcoming crises and maintaining the business as usual.

To put it differently, a company equipped with a robust supply chain can stably operate its business through optimal responses to various situations and diverse scenarios, even when faced with internal and external uncertainties and changes. Such companies may perform well in many areas, particularly logistics performance (Braunscheidel & Suresh, 2009; Valikangas, 2010). Hence, this study proposes the following hypothesis.

H3: Supply chain robustness has a significant positive influence on logistics performance.

This study's hypotheses are summarized in Figure 1.

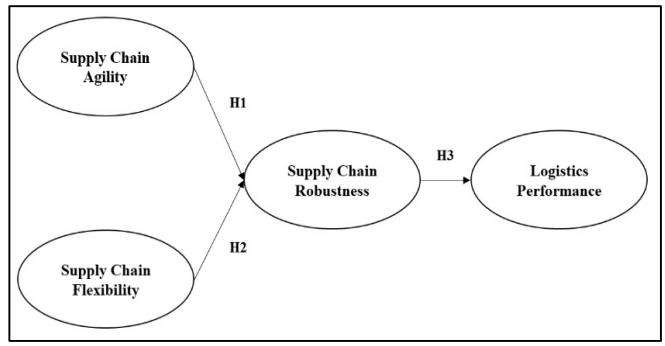

Figure 1: Research Model

4. Research Methodology and Empirical Analysis

4.1. Data Collection and Sample Characteristics

This study surveyed Korea's supply chain sector workers to empirically analyze the relationships among agility, flexibility, robustness, and logistics performance involving companies along the supply chain. Entrust Survey, an online survey firm, was hired for this study, and 1,000 copies of the questionnaire were distributed throughout March 2024. A total of 343 copies of the questionnaire were collected, and among them, 300 copies were analyzed after excluding those with non-responses or incorrect answers. Table 1 presents the characteristics of the sample.

Table 1: Sample Classification

Characteristic	Classification	Frequency	Rate(%)
Industry	Manufacturing	187	62.33
	Wholesale and Retail	54	18.00
	Mining	32	10.67
	IT/Information Services	18	6.00
	Financial Services	3	1.00
	Others	6	2.00
No. of Employees (No. of Employed Persons)	< 250	20	6.67
	250-499	49	16.33
	500-749	47	15.67
	750-999	43	14.33
	> 1000	141	47.00
Sales Volume	Less than KRW 50 billion	54	18.00
	Less than KRW 100 billion	107	35.67
	Less than KRW 500 billion	99	33.00
	Less than KRW 1 trillion	33	11.00
	KRW 1 trillion or more	7	2.33

4.2. Measurement of Variables

The survey questionnaire used in this study comprised the four domains of "agility," "flexibility," "robustness," and "logistics performance," with demographic factors included to understand the characteristics of the sample. Based on the results of the previous studies, all variables were analyzed using four measurement items. For the measurement of respondents' perceptions, this study used a 5-point Likert scale, with one point referring to "highly negative," three points for "not positive nor negative," and five points for "highly positive." Table 2 presents the operational definitions of the variables.

Table 2: Operational Definitions

Variable	Operational Definition	Reference
Supply Chain Agility	Adjusting the level of customer services	Panigrahi et al. (2023); Tse et al. (2016)
	Adjusting the reliability of delivery	
	Adjusting the responsiveness to the changing needs of the market	
	Active cooperation with supply chain partners for sales activities in overseas markets	
Supply Chain Flexibility	Adjusting volume to customer orders	Arawati (2011); Singh et al. (2020)
	Adjusting lead time to customer orders	
	Adjusting schedules to customer demands	
	Adjusting production volume	
Supply Chain Robustness	When damage is caused by a risk, maintaining the business in a stable condition as before the occurrence of such damage	Srimarut and Mekhum (2020); Madzimure (2020)
	When damage is caused by a risk, earning a sufficient amount of time to respond to the situation by accepting and adapting to changes resulting from there	
	When damage is caused by a risk, successfully taking action under various scenarios is available	
	Even when damage is caused by a risk, appropriately performing original functions	
Logistics Performance	Total logistics cost (logistics-related costs including transportation, storage, and inventory management costs)	Aharonovitz et al. (2018); Munim and Schramm (2018)
	Lead time (time required for producing and delivering the ordered product)	
	Order fill rate (the ability to deliver the ordered product to a designated place within the given period under the given condition)	
	Inventory Turnover (annual turnover rate of inventory)	

4.3. Reliability and Validity Tests

This study verified the proposed hypotheses using a structural equation model. Before hypothesis testing, reliability and validity were tested using the SPSS 18.0 and AMOS 18.0 programs. The survey questionnaire consisted of 16 items, and Cronbach's alpha was used to test the reliability of these items. In the social sciences, reliability is obtained when Cronbach's alpha is 0.7 or higher (Hair et al., 2010). For the items used in this study, Cronbach's alpha is 0.7 or higher, indicating no reliability issues.

Next, confirmatory factor analysis was conducted to test convergent validity and discriminant validity. Various indices were used to review the goodness-of-fit of the structural equation model, including confirmatory factor analysis. The analysis results of the goodness-of-fit of the measurement model are CMIN/DF=2.602, CFI=0.938, TLI=0.927, RMSEA=0.049, GFI=0.914, revealing that the model fits the recommended values suggested by Hair et al. (2010). The construct reliability and AVE values were calculated for the convergent validity test. Convergent validity is obtained when the construct reliability value is 0.7 or higher while the AVE value is 0.5 or higher (Hair et al., 2010). In this study, the test results show no issues in relation to convergent validity. Table 3 presents the results of reliability and convergent validity tests.

Table 3: Results of Reliability and Convergent Validity Tests

Factor	Cronbach's alpha	Construct reliability	AVE
Supply Chain Agility	0.776	0.792	0.572
Supply Chain Flexibility	0.792	0.867	0.620
Supply Chain Robustness	0.725	0.813	0.611
Logistics Performance	0.757	0.746	0.599

Table 4: Results of the Discriminant Validity Test

	Supply Chain Agility	Supply Chain Flexibility	Supply Chain Robustness	Logistics Performance
Supply Chain Agility	0.572	-	-	-
Supply Chain Flexibility	0.551	0.620	-	-
Supply Chain Robustness	0.473	0.523	0.611	-
Logistics Performance	0.410	0.386	0.487	0.599

[a] The numbers in the table indicate the squared value of the correlation coefficient, excluding those presented on the diagonal line.

4.4. Empirical Analysis

In this study, hypothesis testing was performed for agility, flexibility, robustness, and logistics performance. Through data analysis, reliability and various categories of reliability were obtained, based on which path analysis was conducted for the suggested research model. According to the path analysis results, the goodness-of-fit of the model analysis for hypothesis testing are CMIN/DF=2.843, CFI=0.922, TLI=0.914, RMSEA=0.051, and GFI=0.899. Hence, the results fit the values recommended by previous studies (Hair et al., 2010). Then, a structural equation model was used for estimation. The path analysis results are presented in Table 5.

Table 5: Hypothesis Testing Results

	Standardized Coefficient	S.E.	C.R.	p	Accepted or Not
Hypothesis 1	0.415	0.036	7.588***	0.000	Accepted
Hypothesis 2	0.374	0.048	5.624***	0.000	Accepted
Hypothesis 3	0.397	0.124	3.026***	0.000	Accepted

[a]* p<0.05, ** p<0.01, *** p<0.001

5. Conclusions

5.1. Discussion

In summary, this study contributes to the theoretical understanding of supply chain capabilities and their interrelationships while providing actionable insights for practitioners. The knowledge gained from this research can guide supply chain managers in developing effective strategies and making informed decisions to optimize their supply chain performance.

The hypothesis testing results are as follows. First, supply chain agility has a significant positive influence on supply chain robustness. The analysis results confirm the importance of internal and external customers, explicitly showing that it is also essential to swiftly respond to and accept external customers' demands while managing the supply chain. Cooperation with supply chain partners is another crucial factor (Kim et al., 2015). In other words, meeting the needs of internal and external customers leads to building a supply chain that works stably when faced with global uncertainties, resulting in good performance.

Second, supply chain flexibility has a significantly positive influence on supply chain robustness. Supply chain flexibility involves the overall adjustment of plans. Adjusting plans does not mean a one-time adjustment of plans but implies adjusting the internal systems and processes of the supply chain. This aspect is as critical as producing quality products or diversifying the supply chain. When the internal and external environments of the supply chain experience dramatic changes, taking ad-hoc actions to adapt to change is crucial. However, swiftly and accurately adjusting mid- and long-term plans through well-established and rightly organized work processes directly results in good performance and supply chain robustness.

Third, supply chain robustness has a significant positive influence on logistics performance. Supply chain robustness is also explained with concepts such as stability and resilience. In other words, with supply chain robustness, companies may adequately respond to global uncertainties or risk factors and quickly overcome temporary challenges without suffering severe damage. This capability helps overcome crises or prevent damage and produces direct results. Moreover, it may contribute to indirect and direct results, proving to be a critical factor in the operating supply chain.

5.2. Implications

This study provides academic, practical and policy complications. First, it suggests supply chain agility as an antecedent of supply chain robustness. This result has been sufficiently reviewed in previous studies on supply chain management. Specifically, many previous studies argued that resilience comprises agility and robustness and then analyzed those factors in a parallel relationship (Durach et al., 2015; Mackay et al., 2020). This study proves that agility and robustness have a causal relationship, not a correlation. In other words, this study suggests that a review of these factors needs to be performed based on a mutually complementary relationship rather than from a macroscopic or a microscopic perspective, depending on the surrounding environment. This has great academic significance not only in presenting a new model in supply chain operation but also in that it can serve as a major independent variable or mediating variable in follow-up studies.

Second, this study suggests a conceptual model for the proposed structural causal relationship based on supply chain agility, flexibility, robustness, and logistics performance. Unlike previous studies that focused on the success factors for building a supply chain and the relationship between effective management methods and performance, this study examines the structural relationship needed for building an efficient supply chain by

concentrating on its capabilities. Doing so, this study confirms the need to achieve supply chain agility and flexibility. It suggests which capabilities supply chain designers require to maintain their competitiveness or gain a comparative advantage.

Third, as the business environment has become increasingly globalized along with the swift changes in today's world, uncertainties along the supply chain have been gradually increasing. This study recommends that to prepare for and respond to such risks, the management of companies should recognize the importance of supply chain agility, flexibility, and robustness and develop those capabilities. In particular, these three concepts have different characteristics as they refer to the ability to respond to and recover from crises, help resist shocks through prevention, and respond flexibly to environmental changes, respectively. Consequently, businesses that have built supply chains should try to respond to and overcome supply chain risks by reinforcing those capabilities. However, in the current situation where uncertainty is increasing, the efforts of a single company are insufficient, and it is thought that the government's policy support will also be necessary.

5.3. Limitations and Future Recommendations

Despite its contributions, this study has some limitations. First, this study explained that intangible factors inside and outside the supply chain could generate various results and proved that those factors might lead to good logistics performance. However, as this study merely focused on logistics performance, whether those factors led to good performance in all areas of supply chain management was not sufficiently explained. In this regard, further analysis of additional factors, including financial and non-financial performance, would validate a broader range of research questions and contribute to expanding research into these topics for interdisciplinary research. Second, this study did not examine the antecedents of agility and flexibility. It stated that one of the factors leading to agility and flexibility was the cooperation among supply chain participants. Further research to quantify the cooperative relationship among supply chain participants and search for the factors generating good performance would provide meaningful implications.

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