INFLUENCING FACTORS AND MODEL CONSTRUCTION OF CHINA'S STEEL SUPPLY CHAIN ELASTICITY

Trabajo Final de Máster

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Abstract

This TFM first clarifies the concept and characteristics of steel supply chain elasticity. From the perspective of elasticity capabilities, it identifies the specific influencing factors of steel supply chain elasticity in the dimensions of absorptive capacity, adaptability, and recovery capacity. Next, based on the analysis of the impact mechanisms of the influencing factors and their combinations on steel supply chain elasticity in each dimension, research hypotheses are proposed, and theoretical models are constructed. Then, using survey data, in-depth insights into the actual impact patterns and specific degrees of influence of each influencing factor and factor combination on steel supply chain elasticity are revealed through hierarchical regression analysis. The results indicate that before an interruption in the steel supply chain, supply chain structural quality, forecasting ability, and supply chain collaboration in the absorptive capacity dimension positively affect elasticity, and the combination of these four factors has the greatest impact on elasticity forecasting ability. During an interruption, information sharing and flexibility in the adaptability dimension have a positive impact on elasticity, and the combination of these three factors also positively affects elasticity, with flexibility having the greatest influence. After an interruption, innovation in the recovery capacity dimension has a positive impact on elasticity, while enterprise risk management, supply chain integration, and the combination of these three factors have a negative impact on elasticity. Finally, practical guidance is provided based on the research findings to effectively formulate strategies for enhancing the elasticity of the steel supply chain in the new situation.

Key words: Steel supply chain; Supply chain elasticity; Absorptive capacity; Adaptability; Recovery capacity

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1. Introduction

In March 2021, data from the McKinsey Global Institute showed that on average, businesses experience a supply interruption lasting one to two months every 3.7 years, with various risk factors and interruptions increasing year by year. Especially in the post-pandemic era, the COVID-19 pandemic and other uncertain risk factors still exist, and enterprises continue to face the practical difficulties and challenges of production interruptions, logistics blockages, and declining demand.

Regarding the steel industry, on the supply chain side, in 2022, due to weak downstream demand, fluctuating steel prices, significant contraction and even loss of steel mill profits, steel mill production enthusiasm has declined, which leading to a downward trend in steel production.

According to data from the National Bureau of Statistics of China, from January to November, China's cumulative production of pig iron was 795.06 million tons, a year-on-year decrease of 0.4%, and crude steel production was 935.11 million tons, a year-on-year decrease of 1.4%.

Regarding imports and exports, in 2022, under the influence of the Russian-Ukrainian conflict and the resulting geopolitical situation, steel production in Russia, Ukraine, the European Union, and other European countries has been significantly restricted, and steel production outside of China has continued to decline. Coupled with the stable supply chain and relatively advantageous prices for Chinese steel exports, overseas order indices have temporarily improved.

However, on the demand side, in 2022, real estate investment has significantly decreased, and steel demand has weakened, leading to a downward trend in steel production, and crude steel consumption continues to decline year-on-year.

Lange Steel Research Center shows that the estimated apparent consumption of crude steel in China in 2022 will be 967 million tons, a year-on-year decrease of 2.4%. Furthermore, although costs have slightly decreased, steel prices have fallen more than costs, leading to a significant decline in per-ton steel profits, and the overall industry

profitability has significantly declined, reaching a new low in nearly 20 years, surpassing that of 2015.

On the other hand, the impact of the COVID-19 pandemic has caused multiple instabilities and interruptions in steel production and the supply chain, nowadays many companies hasn't recovered. It is clear that the steel supply chain is facing challenges in multiple aspects.

Based on the theoretical analysis and hypothesis formulation, this TFM will conduct an empirical study that takes into account the phased characteristics of elasticity capabilities and the relationships between elasticity capabilities at each phase. Through the use of hierarchical regression analysis, it aims to quantitatively reveal the specific mechanisms through which various influencing factors and their combinations impact the elasticity of the steel supply chain. This research seeks to further enrich the existing theoretical knowledge on steel supply chain elasticity and provide valuable insights for future related studies.

In conclusion, accurately identifying the influencing factors of the steel supply chain's elasticity, in-depth analysis of the complex relationships and interaction mechanisms between various factors, and further revealing the specific impact mechanisms of various influencing factors and different combinations of factors on the steel supply chain's elasticity, has important theoretical and practical significance for enterprise strategic decision-making. Research the elasticity of the steel supply chain is to help companies accurately identify the factors that are affected in their supply chain, and to analyze the complex relationships and interaction mechanisms between them in depth, thereby revealing the specific impact mechanisms of different combinations of influencing factors on the elasticity of the supply chain. This helps companies make better strategic decisions, reduce risks in the face of emergencies, and improve their ability to respond and adapt. In addition, studying supply chain elasticity can also promote cooperation and coordination among companies, thereby promoting the sustainable development of the entire industry.

2. Theoretical Framework

2.1. Supply Chain elasticity

The concept of elasticity originates from the field of engineering (Recker, 1970), and was introduced to ecology by Holling in 1973, who proposed that elasticity is the ability to adapt to changes and cope with unforeseen situations. Horne (2013) first introduced this concept to organizational management, and stated that elasticity is a dynamic capacity of the organizational system to adapt to changes in the environment. Kamalahmadi et al. (2016) summarized the five fundamental traits of business elasticity from previous literature: dynamism, subject dependence, environment recognition ability, survival, adaptability and response, agility and innovation. Academics then applied the concept of elasticity to the level of the supply chain, and claimed that the elasticity of the supply chain is a passive reactive capacity that manifests when facing a disruption, and includes the capacity for resistance and recovery (Kamalahmadi et al., 2016). Christopher et al. (2004) proposed that the elasticity of the supply chain can allow the organizational system to return to the initial state after being disturbed, and even reach a more optimal and ideal state. Ponis et al. (2012) considered that supply chain elasticity is not only a reactive capability, but also a proactive capability. Due to the uncertainty of the external environment and the increasing potential risks, Ponomarov et al. (2009) believe that it is not enough to rely on the passive response ability of supply chain elasticity to solve the negative impact of supply chain disruption, but must take proactive measures.

Ponomarov et al. (2009) first suggested that the elasticity of the supply chain has proactive capacity, and the system can maintain control of the structure and function before facing a risk, to be prepared to face unforeseen events. For example, Ponis et al. (2012) proposed that supply chain elasticity can be improved through planning and designing the supply chain network, to avoid potential risks and disruptions. In the initial stage of the development of supply chain elasticity, most academics considered supply chain elasticity as a one-dimensional concept (Christopher et al., 2004). With further research, academics began to study supply chain elasticity from a two-dimensional perspective. On the one hand, some academics divided supply chain

elasticity into internal and external elasticity based on spatial distribution (Azevedo et al., 2016).

On the other hand, some scholars have divided supply chain elasticity into proactive elasticity and reactive elasticity based on temporal points (Ponomarov et al., 2009).

As research has deepened, supply chain elasticity had divided into more specific dimensions based on the types of skills required at each stage of development. Currently, most scholars agree to divide supply chain elasticity into three dimensions: preparedness, responsiveness, and recovery capability (Chowdhury et al., 2017). Preparedness refers to the ability to actively anticipate disruptive events and make proactive plans for them (Kamalahmadi et al., 2016). Responsiveness refers to the ability to ensure business continuity and maintain the functional integrity of the organization once a disruption occurs in the supply chain (Kamalahmadi et al., 2016). Recovery capability refers to the ability to take effective immediate response measures based on available resources after a disruption in the supply chain to minimize the negative impact on the supply chain (Kamalahmadi et al., 2016). On this basis, Bag et al. (2019) added a dimension of competence and suggested that companies could learn and develop new skills from disruptive events, thus improving their competitive advantage.

In addition, Zhuo et al. (2021) have divided the interruption time of the supply chain into three periods: preparatory elasticity of the supply chain before the interruption, including the ability to resist, avoid, and alert; responsiveness elasticity of the supply chain during the interruption, referring to the ability to respond and react; and recovery elasticity of the supply chain after the interruption, referring to the ability to survive and innovate.

Regarding the research on impact factors of supply chain elasticity, academics have conducted studies from different perspectives, such as supply chain relationships, business operational activities, dualism of the supply chain, supply chain vulnerability, among others. For example, Wieland et al. (2013) addressed and validated integration capability, close communication, and mutual cooperation from the perspective of supply chain relationships for their positive impact on supply chain elasticity. Carla et al. (2014), based on the perspective of business purchasing activities, analyzed the

effects of factors such as flexibility, visibility, and information sharing on eight key points of purchasing activities, such as transportation, supply chain design, and risks. The results demonstrated that promoting factors can improve purchasing efficiency, and that purchasing activities can enhance the elasticity of the supply chain.

Finally, in terms of research methods on supply chain elasticity, most academics have used planning models, explanatory structure models, simulation, among others. For example, Torabi et al. (2015) established a two-stage, two-objective planning model and empirically demonstrated that reserve suppliers and supplier excess capacity have a positive effect on supply chain elasticity. Liu Jiaguo (2015) used a supply chain elasticity system model constructed by an explanatory structure model to analyze the mutual influence models between impact factors and the process of forming supply chain elasticity.

2.2. Steel Supply Chain

A complete steel supply chain is a network consisting of steel enterprises at the core, with mines (including beneficiation plants), steel enterprises, distributors, and end users, providing products to customers through this network and realizing value chain enhancement. The products in the steel supply chain include various steel products such as structural steel, strip steel, wire rod, and tube products. The main raw materials are ores, such as iron ore, manganese ore, limestone, and dolomite. In this supply chain, mines are suppliers and directly affect nature, so there are no suppliers (referring only to raw material suppliers, as mines still have suppliers of fuel, tools, equipment, etc.), while in general supply chains, suppliers usually have suppliers. The steel enterprise, as a manufacturer, consists of multiple relatively independent production units. The adjacent units have a supply and demand relationship, so the internal structure of the steel enterprise also shows an obvious supply chain structure.

Currently, research methods for the steel supply chain mainly include planning models, simulation models, statistical analysis, and empirical research. Planning models can model decision-making problems in the supply chain and obtain optimal decision-making solutions. Statistical analysis can extract laws and trends of the supply chain from a large amount of data. Empirical research can observe and analyze the actual operation of the supply chain to obtain the characteristics and problems of the supply

chain. Maqsood Sandhu (2013) used a simulation model to study the impact of information sharing on the inventory level of the steel supply chain. Simulation models can simulate various situations in the supply chain and evaluate the stability and feasibility of decision-making solutions.

3. Objectives and hypotheses

3.1. Definition of Related Concepts

The steel supply chain elasticity is adaptive, stage-specific and dynamic.

a.Self-adaptability

In the process of steel supply chain operation, facing the disturbance of external uncertainty, the steel supply chain elasticity will change in the direction of adapting to the environment under the active strategic adjustment and coordination of each node enterprise, showing a certain degree of self-adaptability. For example, when the steel supply chain is initially faced with disturbance, it will exist in the form of supply chain structure quality, inventory control, etc. When the steel supply chain fails to absorb the disturbance and is forced to interrupt, the steel supply chain elasticity will exist in the form of supply chain restructuring, node enterprises close contact, etc. After the supply chain is interrupted, the steel supply chain elasticity will exist in the form of resource integration, etc. to restore the supply chain.

b.Stages

Steel supply chain elasticity is a kind of anti-risk capability that has always existed since the steel supply chain was built, but this anti-risk capability is only expressed during the actual occurrence of the disturbance and accompanies the whole disturbance process. The actual trajectory of steel supply chain elasticity can be divided into three

stages: absorption, adaptation and recovery. Absorption stage shows that the steel supply chain uses its own advantages (e.g. structure, inventory) to reduce the probability of disruption before the disruption. The adaptation stage is when the steel supply chain fails to absorb the disturbance and is forced to interrupt by reconfiguring the supply chain, closely connecting with enterprises and other emergency methods to minimize the loss of interruption and prepare for subsequent recovery. The recovery stage shows that after the disruption of the steel supply chain, the supply chain performance is quickly restored to normal or higher than normal by using the financial advantages of the company to integrate the recovery resources and promoting the collaboration among employees through the advantages of corporate culture to quickly eliminate the existing risks. Accordingly, elasticity can be divided into three dimensions: absorptive capacity, elasticity and adaptability.

Absorptive capacity is the ability of the steel supply chain to absorb or resist the impact of external disturbances through proactive preparation of risk measures and to minimize the probability of disruption at a relatively low cost or effort level. Therefore, absorptive capacity is the direct risk tolerance of the steel supply chain at the stage when it faces disturbances and disruptions have not yet occurred, and can be considered as the first line of defense of the steel supply chain against external risks. Adaptive capacity is the ability of the steel supply chain to quickly adapt itself and attempt to mitigate disruptions by implementing non-standardized operational practices without any recovery activities, where non-standardized operational practices are a series of contingency measures that are taken passively when the steel supply chain is affected by adverse external factors. Therefore, adaptive capacity is the risk adaptation capability presented by the steel supply chain when it fails to absorb disturbances and is forced to undergo disruptions, which can be regarded as the second line of defense of the steel supply chain against external risks. elasticity is the ability of the steel supply chain to quickly return to a normal or above normal state through a series of recovery measures and guidance activities when it is unable to maintain an acceptable level of performance even after taking a series of actions to absorb disturbances and adapt to disruptions. Thus, elasticity is the ability of the steel supply chain to present risk exclusion after a disruption occurs, and can be considered as the third line of defense of the steel supply chain against external risks.

c.Dynamicity

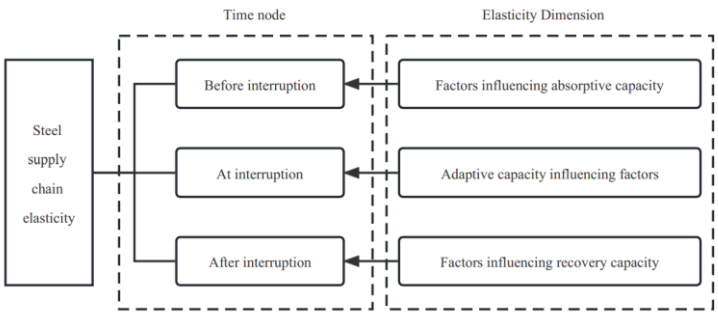
The main expression is that the elasticity of the steel supply chain and the way it is characterized are continuously changing. During the whole disturbance process, the steel supply chain needs to take various measures in time to resist, adapt to and eventually recover itself from the disturbance, and the implementation of different measures makes the steel supply chain have different anti-risk capabilities at different stages, so that the elasticity size can be continuously changed. At the same time, as the disturbance time goes on, the characterization form of elasticity will produce a dynamic transformation from absorption capacity to adaptation capacity to recovery capacity.

3.2. Identification of Factors Affecting the elasticity of the Steel Supply Chain

3.2.1. Identification Approach

Based on the adaptive, phased, and dynamic characteristics of the elasticity of the steel supply chain, disruptions are divided into three stages before, during, and after the interruption, with the interruption as the time node. From the perspective of the corresponding elasticity capabilities, this study explores the factors affecting the elasticity of the steel supply chain in terms of absorptive capacity, adaptive capacity, and restorative capacity dimensions.

Figure 3-1: Identification Approach



3.2.2. Absorption Capacity Dimension

Absorption capacity is a characterization of the elasticity of the steel supply chain before interruption. It is the ability of the steel supply chain to proactively prepare for

disturbances and avoid interruption risks through structural design, resource reserves, and other pre-preparations. Based on the characteristics of absorption capacity and the structure of the steel supply chain, four influencing factors have been identified through the combing and summarizing of existing literature, as shown in Table 3-1.

Table 3-1: Four influencing factors of the elasticity of supply chain before interruption

Influencing Factors	**Related literature**
Predictive power	Bai, Yuanlong (2018); Liu, Jiaguo et al. (2012)
Visibility	Dubey et al. (2020)
Supply Chain Collaboration	Yu et al. (2019)
Quality of supply chain structure	Liu, Jinling (2018); Kamalahmadi (2016); Kim et al. (2015)

Dubey's (2020) study found that the greater the visibility, the clearer the supply chain operational situation is for a company, allowing for optimized inventory, production, and purchasing planning, increasing the ability to absorb disruption events in the supply chain. Yu et al. (2019) found that supply chain collaboration can foster joint planning among partners, achieving seamless communication of information and establishing collaborative work mechanisms to rapidly increase the ability to absorb supply chain disruptions. Predictive capability refers to the ability of the steel supply chain to accurately predict and analyze potential risks in raw material procurement, transportation, production and other aspects, and take targeted preventive measures in advance. In a disruptive environment, the stronger the predictive capability of the steel supply chain, the more detailed the consideration in coordinated decision-making, resource planning, risk prevention and supply chain structure design, and the lower the probability of steel supply chain disruption. Therefore, the predictive capability affects the absorptive capacity of the steel supply chain to some extent. The quality of the supply chain structure is mainly reflected in three aspects: the complexity of the structure, the density of nodes and key nodes. In a disruptive environment, a high-quality steel supply chain can not only effectively disperse risk through structure complexity and reduce the fragility of the steel supply chain, but also reduce the probability of simultaneous disruption of enterprises at nodes by geographically distributing enterprises. In addition, the high stability steel supply chain structure can

also improve the ability to resist disturbances of the whole steel supply chain by elastic pre-incorporation of key nodes, reducing the probability of disruption of the steel supply chain. In summary, the quality of the supply chain structure affects the absorptive capacity of the steel supply chain.

3.2.3. Adaptive capacity dimension

Adaptive capacity is a way to represent the elasticity of the steel supply chain during disruption and is the ability of the steel supply chain to adapt to the disruption environment and reduce disruption losses through emergency measures such as reconstruction and resource replacement. Based on the characteristics of adaptability and the structure of the steel supply chain, four influential factors are identified based on a review and summary of existing literature, as shown in Table 3-2.

Table 3-2: Three influencing factors of the elasticity of supply chain at interruption

Influencing Factors	**Related literature**
Information Sharing	Bai, Yuanlong (2018); Liu, J. et al. (2012); Cao et al. (2010)
Flexibility	Dubey et al. (2020)
Reconfigurability	Wieland and Wallenburg (2013); Mandal (2012)

A flexible supply chain can respond quickly to unforeseen external situations and take timely management plans according to the characteristics of the turbulent environment, which helps to effectively cope with supply chain disruption. Information sharing can share key information with supply chain partners in real time and enrich mutual perspective, and make timely response to the event disruption. Reconstruction capability refers to the ability of the steel supply chain to take urgent and flexible emergency measures in rebuilding the structure and process flow when a serious disruption occurs due to disturbances. The greater the change in the external environment, the more complex the disruption of the steel supply chain, so efficient reconstruction is necessary to maintain the overall operation of the steel supply chain and the competitive advantage of enterprises in the nodes of the steel supply chain and

reduce disruption losses. Therefore, reconstruction capability is an influential factor of the adaptive capacity of the steel supply chain.

3.2.4. Recovery capacity dimension

Recovery is how the elasticity of the steel supply chain after a disruption is represented. It is the ability of the steel supply chain to quickly stabilize and improve its operation through financial advantages, resource integration, business culture, and other favorable conditions after a disruption. Combining the characteristics of elasticity and steel supply chain structure, the following three influencing factors are identified, as shown in Table 3-3, based on the review and summary of existing literature.

Table 3-3: Three influencing factors of the elasticity of supply chain at interruption

Influencing Factors	**Related literature**
Supply Chain Integration	Bai, Yuanlong (2018); Liu, Jiaguo et al. (2012); Recker et al. (1970)
Supply Chain Risk Management	Chowdhury et al. (2017)
Enterprise Innovation	Sabahi et al. (2020)

Supply chain integration can provide strategic guidance between different departments within the company after a supply chain disruption, which can aid in rapid recovery and stabilization. Supply chain risk management considers that managers have extensive knowledge and experience in risk management, which enables them to quickly adapt to changes after a disruption and make supply chain operational processes recover more effectively. Business innovation is divided into two dimensions: product innovation and management innovation. Product innovation can quickly adjust products according to external changes after a supply chain disruption, while management innovation can apply unique management skills to the enterprise after a disruption. Both can help the rapid recovery of the enterprise, improve the elasticity of the supply chain, and accumulate valuable experience for the future development of the enterprise.

3.3. Hypothesis

In the process of analyzing the mechanism of elasticity in the steel supply chain, the research will be conducted in two parts based on the progressive relationship of three dimensions of elasticity capabilities (absorption capacity - adaptive capacity - recovery capacity). Firstly, studying the individual impact mechanisms of various factors on the elasticity of the steel supply chain, and secondly, studying the combined impact mechanisms of different factor combinations on the elasticity of the steel supply chain. Based on the above analysis, the theoretical model for the mechanism of influence factors on the elasticity of the steel supply chain is constructed as shown in Figure 3-2.

Figure 3-2: The construction idea of theoretical model

3.3.1. Research hypothesis of absorption capacity

a. Predictive power

Supply chain forecasting ability refers to the ability of an enterprise to accurately predict market demand, supply situation and other related factors in the future. If companies can accurately forecast market demand and steel supply, they will be better able to adjust production plans, purchase raw materials and allocate resources to adapt to changes in market demand. Such predictive capabilities can help companies react quickly when demand rises or falls, avoid shortages or excesses in the supply chain, and ensure that products are delivered on time. When the supply chain is faced with external shocks or changes, such as weather disasters, policy changes, or actions of competitors, companies with strong predictive capabilities can take actions in advance, such as finding alternative supply sources, adjusting production plans or inventory management, to mitigate potential risks and ensure the stability of the supply chain. Based on the above analysis, a research hypothesis is put forward:

Ha1: Predictive power has a significant positive impact on the elasticity of steel supply chain.

b. Visibility

Supply chain visibility refers to the transparency and real-time information of all links in the supply chain, including data sharing and traceability in raw material procurement, production, transportation, warehousing and distribution. A supply chain with high visibility can provide accurate and real-time data and information, enabling enterprises to better understand market demand and supply conditions in order to make more timely and accurate decisions. This helps iron and steel enterprises adjust resource allocation, optimize production planning and inventory management in the supply chain to meet market demand and respond to emergencies or changing challenges. In addition, supply chain visibility can also help companies better communicate and collaborate with supply chain partners, share information and coordinate actions. When problems or changes occur in any part of the supply chain, a supply chain with visibility can detect and respond to them faster, thereby reducing the impact of supply

chain disruptions and risks. Based on the above analysis, a research hypothesis is put forward:

Ha2: Visibility has a significant positive impact on the elasticity of steel supply chain.

c. Supply chain collaboration

La colaboración en la cadena de suministro se refiere a la cooperación y coordinación entre los participantes de la cadena de suministro en diferentes eslabones para lograr objetivos comunes. En la cadena de suministro de acero, involucra múltiples eslabones y participantes desde la adquisición, producción y procesamiento de materias primas, logística y transporte hasta la distribución del producto final. La implementación efectiva de la colaboración en la cadena de suministro puede fortalecer la cooperación entre todos los participantes, mejorar la eficiencia del intercambio de información y la comunicación, reducir el desperdicio y los retrasos innecesarios y, por lo tanto, mejorar la eficiencia operativa y la flexibilidad de toda la cadena de suministro. Esta colaboración puede fortalecer la sensibilidad a la demanda y los cambios del mercado, haciendo que la cadena de suministro sea más flexible y adaptable, mejorando así la resiliencia general de la cadena de suministro. Based on the above analysis, a research hypothesis is put forward:

Ha3: Supply chain collaboration has a significant positive impact on the elasticity of steel supply chain.

d. Supply chain structure quality

From two aspects of supply chain complexity and node density, the necessity of supply chain structure quality to improve the absorptive capacity of steel supply chain is expounded. First, the complexity of the supply chain includes the number of supply chain nodes, the number of transportation routes and the diversity of transportation methods. Under the condition of the same amount of raw material procurement, the more supply sources, the number of transportation routes, and the transportation methods, the more complex the supply chain structure will be. The probability of interference is greater. Secondly, node density is also called node concentration, which specifically refers to the geographical distance between supply chain node enterprises. The smaller the node density, the more dispersed the node enterprises of the steel

supply chain, and the smaller the probability of the supply chain nodes being disturbed at the same time. The high-quality steel supply chain structure has the characteristics of high complexity and low node density. Therefore, the quality of the supply chain structure positively affects the elasticity of the steel supply chain. Based on the above analysis, the research hypotheses are put forward:

Ha4: Supply chain structure quality has a significant positive impact on the elasticity of steel supply chain.

When a disturbance occurs, the elasticity of the steel supply chain is initially characterized in the form of absorptive capacity. Forecasting ability, supply chain visibility, supply chain collaboration, and supply chain structural quality are all key influencing factors before the interruption. The combination configuration and interaction of each other Impacts can have a combined effect on steel supply chain elasticity. Based on this, analyzing the interaction terms of the four is more conducive to in-depth exploration of the actual relationship between the dimension of absorptive capacity and supply chain elasticity. For this, the following hypothesis is put forward:

Ha5: 4 interaction items of absorptive ability have a significant positive impact on the elasticity of steel supply chain.

3.3.2. Research hypothesis of adaptive capacity

a. Information sharing

Information sharing can provide real-time and reliable information flow among all links in the supply chain. By sharing information on market demand, supply status, logistics, and more, various parties can more accurately understand current supply chain disruptions. This kind of information sharing helps reduce information lag. Through information sharing, supply chain participants can jointly analyze the current situation, quickly adapt to the current situation in the event of supply chain disruption, and better deal with risks and uncertainties. For this, the following hypothesis is put forward:

Hb1: Information sharing has a significant positive impact on the elasticity of steel supply chain.

b. Flexibility

Through flexibility, the supply chain can quickly respond to changes in market demand, adjust production capacity and delivery time, and reduce inventory backlog and slow-moving risks. At the same time, flexibility can also help the supply chain find alternative sources, adjust transportation plans, and maintain production continuity in the event of raw material supply interruptions and transportation problems. In addition, working with a flexible partner can provide more options and resources to jointly respond to changes and challenges.

For this, the following hypothesis is put forward:

Hb2: Flexibility has a significant positive impact on the elasticity of steel supply chain.

c. Reconfigurability

A steel supply chain with high reconfiguration capability not only has the spare resources needed to restructure the supply chain, but also can quickly process interruption information and use spare resources to adapt to the interruption environment, reduce the interruption loss and scope of influence, and maintain the functions of the steel supply chain and nodes on the chain enterprise's competitive advantage. Therefore, the ability to restructure directly and positively affects the elasticity of the steel supply chain, and ultimately helps to improve the competitiveness of the supply chain. For this, the following hypothesis is put forward:

Hb3: Reconfigurability has a significant positive impact on the elasticity of steel supply chain.

When the supply chain fails to absorb disturbances and is interrupted, the steel supply chain elasticity is mainly characterized by the ability to adapt to the interruption. Under the adaptability dimension, the combination of reconfiguration capability, flexibility and information sharing can have a joint effect on steel supply chain elasticity. Specifically, on the one hand, partners in the supply chain with a high degree of information sharing are more willing to actively send the latest environmental dynamics and market change signals, making all kinds of information in the supply chain more visible, thus helping enterprises in the supply chain. More flexibility to

carry out adaptive refactoring activities when the chain is interrupted. On the other hand, as a complex system engineering, supply chain reconstruction requires a large amount of supply chain member information, which will prompt enterprises to communicate and contact more frequently, further expand and deepen the cooperative relationship between steel supply chain nodes, thereby improving flexibility to a certain extent to increase the elasticity of the steel supply chain. For this, the following hypothesis is put forward:

Hb4: 3 interaction items of adaptive ability have a significant positive impact on the elasticity of steel supply chain.

3.3.3. Research hypothesis of recovery capacity

a. Supply chain intergration

Supply chain integration encourages cooperation and coordination between different parties. In the steel supply chain, cooperation and coordination between various links can speed up the response time and improve the elasticity of the supply chain. At the same time, supply chain integration encourages a diversified supply chain strategy, that is, reduces dependence on a single supplier by establishing a cooperative relationship with multiple suppliers. This diversified supply chain strategy can improve supply chain elasticity and reduce risk. In the steel supply chain, a diversified supply chain can reduce dependence on a certain region or a certain type of raw material, and make it easier to find alternative suppliers when there is a supply disruption or price fluctuation. For this, the following hypothesis is put forward:

Hc1: Supply chain integration have a significant positive impact on the elasticity of steel supply chain.

b. Supply chain risk management

The steel supply chain is a complex system involving multiple links such as raw material procurement, production and processing, logistics and transportation, and sales. In this process, various risk factors may adversely affect the normal operation of the supply chain, such as natural disasters, supplier bankruptcy, policy changes, etc. The goal of supply chain risk management is to identify, assess and reduce risks that may

threaten the stability and operation of the supply chain. By taking appropriate risk management measures, the elasticity of the steel supply chain can be enhanced, allowing it to quickly adjust and recover in the face of risk shocks. For this, the following hypothesis is put forward:

Hc2: Supply chain risk management have a significant positive impact on the elasticity of steel supply chain

c. Enterprise innovation

When a supply chain is disrupted, corporate innovation can help restore the stability and reliability of the supply chain so that normal operations can resume as quickly as possible. Through innovative approaches and strategies, companies can quickly evaluate alternative options in the market and establish partnerships with new suppliers. This type of innovation can help companies maintain business operations during disruptions and remain flexible when supply chains resume. Innovative data analytics and predictive models can help companies better predict and plan for recovery after supply chain disruptions. By collecting and analyzing relevant data, companies can better understand the weaknesses and vulnerabilities in the supply chain, and develop corresponding plans to reduce the impact of disruptions, and quickly adjust and restore supply chains after disruptions.

For this, the following hypothesis is put forward:

Hc3: Enterprise innovation have a significant positive impact on the elasticity of steel supply chain.

The innovation capability of enterprises can help enterprises discover and respond to potential supply chain disruption risks. Through innovation, companies can develop new supply channels, adopt new technologies and production processes, thereby reducing the probability of supply chain disruption. It can also promote the process of supply chain integration. Innovation can help companies develop new supply chain models and strategies, thereby improving supply chain synergy and efficiency. At the same time, enterprise risk management measures can also support innovation. By assessing and managing potential risks, enterprises can make better decisions and invest in innovative measures to improve the elasticity of the supply chain. Through risk

management, enterprises can assess and monitor various risks in the supply chain, and take corresponding measures to reduce these risks. This includes building the elasticity and elasticity of the supply chain network, building close partnerships with suppliers, and establishing alternate supply channels and inventory management strategies, among others. These risk management measures can promote mutual trust and cooperation among supply chain partners and strengthen the effect of supply chain integration. Effective supply chain integration can speed up the transfer of information flow and logistics, improve response speed and flexibility, and restore the normal operation of the supply chain faster.

Based on the above analysis, a research hypothesis is put forward:

Hc4: 3 interaction items of recovery ability have a significant positive impact on the elasticity of steel supply chain.

3.3.4. Summary of Research Hypotheses

All assumptions are summarized and summarized as shown in Table 3-4.

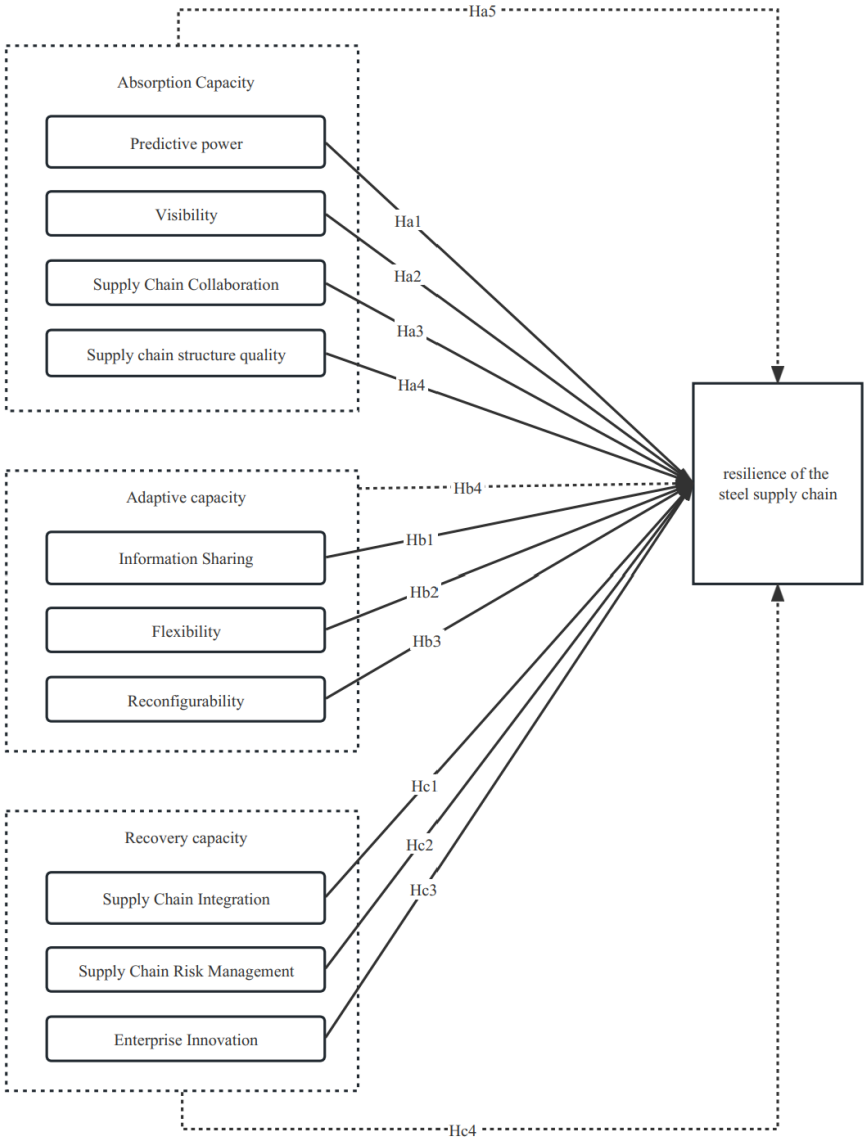
Table 3-4: Summary of Research Hypotheses

No.	Context
Ha1	Predictive power has a significant positive impact on the elasticity of steel supply chain
Ha2	Visibility has a significant positive impact on the elasticity of steel supply chain
Ha3	Supply chain collaboration has a significant positive impact on the elasticity of steel supply chain
Ha4	Supply chain structure quality has a significant positive impact on the elasticity of steel supply chain
Ha5	4 interaction items have a significant positive impact on the elasticity of steel supply chain
Hb1	Information sharing has a significant positive impact on the elasticity of steel supply chain
Hb2	Flexibility has a significant positive impact on the elasticity of steel supply chain
Hb3	Reconfigurability has a significant positive impact on the elasticity of steel supply chain
Hb4	3 interaction items have a significant positive impact on the elasticity of steel supply chain
Hc1	Supply chain integration have a significant positive impact on the elasticity of steel supply chain

Hc2	Supply chain risk management have a significant positive impact on the elasticity of steel supply chain
Hc3	Enterprise innovation have a significant positive impact on the elasticity of steel supply chain
Hc4	3 interaction items have a significant positive impact on the elasticity of steel supply chain

Based on the analysis of the impact mechanism of the above steel supply chain elasticity factors on elasticity and the proposed assumptions, combined with the theoretical model to construct the following combination diagram.

Figure 3-3:Hypotheses combined with models



4. Methods and Data

4.1. Questionnaire design and data collection

The sample selection of this TFM includes three aspects: the selection of research objects, the selection of respondents, and the selection of research areas.

a. Selection of research objects. The core of this study is to explore the complex mechanism of factors affecting the elasticity of the steel supply chain. As the designer and foundation of the steel supply chain structure, steel manufacturing enterprises play a leading role in all operational activities of the steel supply chain to which they belong, and are also the initiators and coordinators of partnerships on the chain. Stakeholders are the most connected and interacted, and therefore most familiar with the overall picture of the steel supply chain. Based on this, this paper focuses on the steel manufacturing industry. At the same time, in order to further improve the universality of the research results, it is decided to select enterprises of different sizes, years of establishment and ownership structures as the research objects of this study.

b. Research area selection. This TFM divides the research area into east, west, central and northeast. Among them, the east includes: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The west includes: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The central part includes: Shaanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. Northeast includes: Liaoning, Jilin and Heilongjiang.

This questionnaire consists of three parts. The first part is related to the questionnaire, which mainly introduces the main research content of the questionnaire and the main purpose of the research to the respondents, and explains the confidentiality commitment to data and privacy to the respondents. The second part is the basic information of the respondents and the company, which mainly asks the basic information of the respondents' gender, education level, position, age, scale, nature and geographical location of the company. The third part is the main part of the questionnaire, which is

mainly to investigate the factors affecting the elasticity of the steel supply chain and the elasticity of the steel supply chain. A total of 42 items are set for 8 variables, and the Likert-5 scale is used to measure each item. Divided into five progressive attitudes, the individual respondents are required to score according to their understanding of each item description in combination with the actual situation of their own companies. The scoring standards are: "1 means completely disagree", "2 means somewhat disagree ", "3 means general", "4 means somewhat agree", "5 means completely agree".

The official survey time of the questionnaire is from April 10th to June 1st, 2023. The subjects of the survey were employees of steel manufacturing enterprises. The questionnaire platform was used to distribute and collect questionnaires in a targeted manner. A total of 280 questionnaires were distributed. After strict review and screening, 233 valid questionnaires were finally answered, with an effective recovery rate of 83.21%. In addition, Zhou Jian (2017) believed that when using hierarchical regression to analyze data, the sample size should be 5 to 10 times the number of measurement items to ensure the high accuracy of the research results. There are 42 measurement items in this study. According to the above standards, the optimal number of questionnaires should be 210 to 420. In fact, a total of 233 questionnaires were recovered, which better meets the requirements of the number of samples.

In the upcoming questionnaire data analysis, descriptive statistical analysis will be conducted on the basic data of the survey respondents. Descriptive statistical analysis is a statistical method used to summarize and describe the overall status of things, as well as the correlation and categorization relationships between things. Through statistical processing, a few statistical values can be used concisely to represent the centrality of a set of data. Descriptive statistical analysis provides the initial understanding of the data source, including the central tendency, dispersion, and frequency distribution of the data. It is generally used for summarizing and analyzing the basic characteristics of the survey respondents, enabling further analysis after gaining this understanding. Subsequently, the questionnaire data will be analyzed for reliability and validity. Reliability refers to the consistency or reliability of the measurement experiment results. Validity analysis utilizes confirmatory factor analysis. Confirmatory factor analysis is a research method used to examine whether the correspondence between factors and measurement items is consistent with the researcher's predictions. Since the

questionnaire for this study is designed based on existing mature scales, using confirmatory factor analysis is reasonable.

Finally, the questionnaire data will be analyzed using hierarchical regression analysis.

Hierarchical regression analysis is a statistical method that examines whether the addition of independent variables, one by one or in layers, has a significant impact on the regression model. The independent variables are gradually added in order to determine whether the addition of each variable or group of variables has statistical significance.

The main steps of the hierarchical regression method are as follows:

a) Conduct a comprehensive factor analysis of the decision problem to identify the logical relationships between influencing factors and construct a hierarchical structure of the factors.

b) Compare each factor pairwise on the same level and construct a judgment matrix.

c) Calculate the relative weights of each factor based on the judgment matrix.

d) Calculate the composite weights of each factor and rank the influencing factors based on their weights.

According to Long(2004), in the determination of factor weights in the hierarchical regression method, a judgment matrix is constructed first. The judgment matrix represents the relative importance of elements in the previous level compared to elements related to the current level, and this comparison is expressed numerically in the form of a judgment matrix, as shown in Figure 4-1.

Figure 4-1: Judgment Matrix

	B1	B2	….	Bn
B1	b11	b12	….	B1n
B2	b21	b22	….	b2n
….	….	….	….	….
Bn	bn1	bn2	….	bnn

Then, the weights are calculated using the eigenvalue method, with the formula: AW = λ_{max}W, where A is the judgment matrix, Xmax is the maximum eigenvalue of A, and W

is the corresponding eigenvector. The obtained W is then normalized, and the normalized result represents the weight vector of each factor. Finally, the model is validated using the R-square statistic. R-square is a scale-invariant statistic that indicates the proportion of variation in the target variable explained by the linear regression model. A higher R-square indicates a greater amount of variation explained by the model.

$$R\text{-square} = (TSS - RSS) / TSS$$

RSS is the residual sum of squares, which represents the sum of squares of the differences between actual values and predicted values of the linear regression model. By using the residuals, we can determine the sum of squared residuals.

TSS is the total sum of squares, which refers to the sum of squares of the differences between actual values and their mean value.

Essentially, it focuses on the importance of newly added independent variables that come later in the analysis. In the research methodology of supply chain elasticity, previous literature has often employed methods such as optimization models, explanatory structural models, and simulations, which overlook the phased characteristics of supply chain elasticity and the spillover effects of elasticity factors on subsequent stages. (Deng, 2021)

4.2. Analysis of questionnaire data and results

4.2.1. Descriptive statistical analysis

Basic information of the survey respondents can be found in Table 4-1. Among them, there are 106 males, accounting for 45.5%, and 127 females, accounting for 54.5%. In terms of education, 2.6% hold a doctoral degree, 21.5% have a master's degree, 70.8% have a bachelor's degree, and 7.7% have a high school diploma or below.

Regarding the job positions, 7.7% are senior managers, 34.3% are middle-level managers, 26.2% are grassroots managers, and 31.8% are regular employees.

In terms of company data, companies established less than 5 years account for 19.3%, those established between 5-10 years account for 39.5%, those established between 10-

20 years account for 25.3%, and those established over 20 years account for 25.3%. Companies with less than 500 employees account for 35.6%, those with 500-1000 employees account for 37.8%, those with 1000-2000 employees account for 18.5%, and those with over 2000 employees account for 8.2%. State-owned enterprises account for 24.5%, private enterprises account for 56.7%, foreign-invested (joint-venture) enterprises account for 17.6%, and collectively-owned enterprises account for 1.3%. Eastern enterprises account for 39.9%, central enterprises account for 39.9%, western enterprises account for 17.2%, and northeastern enterprises account for 3%.

From the perspective of descriptive statistical analysis results, the gender ratio in this survey is relatively balanced, with a slightly higher proportion of females. The surveyed individuals are primarily concentrated in the higher-educated group, with a significant proportion holding management positions. In terms of the surveyed companies, they are predominantly located in the eastern and central regions. There is a higher proportion of companies that have been established for a longer period of time, indicating larger scales.

Table 4-1: Descriptive statistics analysis results of the surveyed object

Variable	Question Option	Quantity	Percentage	Mean	Std. Deviation
Gender	Male	106	45,5%	1.55	0.499
	Female	127	54,5%		
Education	Ph.D.	6	2,6%	2.84	0.586
	Master	44	18,9%		
	Undergraduate	165	70,8%		
	High school and below	18	7,7%		
Job title	Senior managers	18	7,7%	2.82	0.97
	Middle managers	80	34,3%		
	Basic managers	61	26,2%		
	Ordinary employees	74	31,8%		
Company age	0-5 years	45	19,3%	2.38	0.971
	5-10 years	92	39,5%		
	10-20 years	59	25,3%		
	More than 20 years	37	15,9%		
Size of company	Less than 500 people	83	35,6%	1.99	0.933
	500-1000 people	88	37,8%		
	1000-2000 people	43	18,5%		
	More than 2000 people	19	8,2%		
Nature of company	State-owned enterprises	57	24,5%	1.96	0.687
	Private enterprises	132	56,7%		

	Foreign-funded (joint venture) enterprises	41	17,6%		
	Collective enterprises	3	1,3%		
Location of company	East	93	39,9%	1.83	0.816
	Central	93	39,9%		
	West	40	17,2%		
	Northeast	7	3,0%		

Based on the data analysis from Table 4-2, we can observe the following findings. The variable "Quality of supply chain structure" has the highest average value of 3.82 with a standard deviation of 0.86. This indicates a relatively stable and average level of supply chain structure quality among the surveyed companies. "Supply chain collaboration" has an average value of 4.07 and a small standard deviation of 0.808, suggesting a relatively good overall level of supply chain collaboration. The variable "Visibility" has the highest average value of 4.02 with a standard deviation of 0.798, indicating a good overall level of supply chain visibility. "Predictive power" has an average value of 4 and a small standard deviation of 0.827, suggesting a good overall level of supply chain predictive ability.

"Information sharing" has an average value of 4.01 with a standard deviation of 0.835, indicating a relatively good overall level of information sharing. "Flexibility" has an average value of 3.95 and a small standard deviation of 0.825, suggesting a good overall level of supply chain flexibility. "Reconfigurability" has an average value of 3.93 with a large standard deviation of 0.892, indicating a relatively poor overall level of supply chain reconfigurability.

"Supply chain integration" has an average value of 3.98 with a standard deviation of 0.861, indicating a good overall level of supply chain integration. "Supply chain risk management" has an average value of 4.04 with a small standard deviation of 0.846, suggesting a good overall level of supply chain risk management. "Enterprise innovation" has an average value of 3.99 with a standard deviation of 0.831, indicating a good overall level of enterprise innovation. Lastly, "Steel Supply Chain elasticity" has an average value of 3.95 with a standard deviation of 0.854, suggesting a good overall level of elasticity in the steel supply chain.

In summary, except for the relatively poor overall level of supply chain reconfigurability, the other variables demonstrate relatively good overall levels. Supply

chain collaboration and supply chain risk management have higher average values, indicating strong performance in these aspects of supply chain management. On the other hand, the average value of supply chain reconfigurability is relatively low, suggesting a need for improvement. These findings provide valuable insights for further research and enhancement in supply chain management practices.

Table 4-2: Descriptive statistics analysis of questionnaire scale variables

Variable	Question	Min	Max	Mean	Std. Deviation
Quality of supply chain structure	Our company usually chooses to procure steel from multiple regions simultaneously.	1	5	3.82	0.86
	Our company will choose to procure steel from multiple suppliers in the same region simultaneously.	1	5	3.94	0.871
	Our company will choose to transport steel using multiple routes simultaneously.	1	5	3.91	0.874
	Our company usually selects multiple transportation methods to transport steel.	1	5	4.11	0.769
Supply chain collaboration	Our company has established clear communication channels with suppliers to exchange information and provide feedback on supply chain issues.	2	5	4.03	0.809
	Our company frequently shares production plans and inventory information with suppliers to ensure better coordination and collaboration.	2	5	4.1	0.822
	We have established long-term partnerships with suppliers to ensure a stable and reliable supply of materials and products.	1	5	4.13	0.777
	We have built mutual trust and respect with suppliers to promote effective collaboration and problem-solving.	2	5	4.11	0.791
Visibility	Our company will stay informed about the logistics and inventory status in the supply chain.	2	5	4.1	0.787
	We track the production and shipment of suppliers to ensure timely delivery.	2	5	3.96	0.798
	Our company typically implements tracking and monitoring along the supply chain to ensure shipment visibility.	2	5	4	0.799
	We utilize modern technology to visualize the supply chain for better control of supply chain risks.	1	5	4	0.823
Predictive power	Our company frequently conducts in-depth analysis of market trends to predict future sales situations.	1	5	4.01	0.898
	We conduct research on the raw material market to predict future price fluctuations and supply conditions.	1	5	4.02	0.782

	We have thorough communication and collaboration with suppliers and partners to forecast future supply chain risks.	1	5	3.94	0.844
	Our company predicts future market share and competitiveness based on market trends and competitor behavior.	2	5	4.01	0.785
Information sharing	Our company typically shares information with suppliers regarding steel demand and inventory levels.	2	5	4.03	0.819
	We share information with our suppliers concerning quality control and inspection standards.	2	5	4.01	0.809
	Our company encourages suppliers to share information about potential disruptions in the supply chain. such as natural disasters or strikes.	1	5	4.08	0.822
	We regularly share information with suppliers about customer preferences and market trends to assist them in making informed production decisions.	1	5	3.94	0.891
Flexibility	Our company typically maintains spare production equipment to address equipment failures or damages.	1	5	3.95	0.839
	Our company can flexibly adjust production lines to cope with changes in raw material prices.	1	5	4.03	0.838
	Our company can make quick adjustments to logistics plans to respond to unexpected events.	1	5	3.93	0.803
	Our company usually includes contingency plans for unforeseen events in contracts with suppliers.	1	5	3.99	0.856
Reconfigurability	Our company can adjust the supply chain structure at any time based on market demand and changes.	1	5	3.9	0.935
	We usually collaborate closely with suppliers during the supply chain restructuring process to ensure successful implementation.	1	5	3.92	0.8
	Our company frequently undergoes supply chain restructuring to reduce costs and improve efficiency.	1	5	3.97	0.935
Supply chain integration	Our company collaborates with partners in the supply chain to plan and manage logistics activities.	1	5	3.95	0.854
	We cooperate with partners in the supply chain to develop quality standards and control measures.	1	5	3.95	0.854
	Our company coordinates production and delivery plans with partners in the supply chain.	1	5	4.03	0.873
Supply chain risk management	Our company's supply chain management strategy includes risk assessment and planning.	1	5	4.11	0.898
	We assess the supply capacity of our suppliers to ensure they are capable of meeting order requirements.	1	5	4.04	0.85

	Our company regularly inspects and maintains warehouses and equipment to ensure safety and reliability.	1	5	3.98	0.79
Enterprise innovation	Our company encourages employees to propose new ideas and improvement suggestions.	1	5	3.96	0.848
	Our company is willing to collaborate with other businesses and organizations to create new opportunities.	1	5	4.03	0.878
	We provide training and resources to support employees in developing innovative solutions.	1	5	3.97	0.803
	Our company rewards and recognizes employees for their contributions to innovation.	2	5	3.99	0.833
Steel Supply Chain elasticity	When the steel supply chain faces external disruptions. our company has sufficient measures to reduce the impact of the disruptions.	1	5	4.01	0.833
	When the steel supply chain faces external disruptions. the likelihood of our company's supply chain being disturbed is low.	1	5	4	0.791
	When there is an interruption in the steel supply chain. our company can quickly take appropriate measures to adjust the operational status of the supply chain.	1	5	3.82	0.86
	After an interruption in the steel supply chain. our company can promptly take measures to restore normal operation of the supply chain.	1	5	3.94	0.871
	After an interruption in the steel supply chain. our company can take reasonable and effective measures to restore the performance level of the supply chain to a higher level.	1	5	3.91	0.874

4.2.2. Reliability of questionnaire scale

First, Cronbach's alpha coefficient is used to conduct reliability tests for all variables. The results of the tests are shown in Table 4-3.

Table 4-3: Cronbach's alpha coeficient

Variable	Question	Cronbach’s α
Quality of supply chain structure	Our company usually chooses to procure steel from multiple regions simultaneously. Our company will choose to procure steel from multiple suppliers in the same region simultaneously. Our company will choose to transport steel using multiple routes simultaneously. Our company usually selects multiple transportation methods to transport steel.	0.758

Supply chain collaboration	Our company has established clear communication channels with suppliers to exchange information and provide feedback on supply chain issues. Our company frequently shares production plans and inventory information with suppliers to ensure better coordination and collaboration. We have established long-term partnerships with suppliers to ensure a stable and reliable supply of materials and products. We have built mutual trust and respect with suppliers to promote effective collaboration and problem-solving.	0.799
Visibility	Our company will stay informed about the logistics and inventory status in the supply chain. We track the production and shipment of suppliers to ensure timely delivery. Our company typically implements tracking and monitoring along the supply chain to ensure shipment visibility. We utilize modern technology to visualize the supply chain for better control of supply chain risks.	0.799
Predictive power	Our company frequently conducts in-depth analysis of market trends to predict future sales situations. We conduct research on the raw material market to predict future price fluctuations and supply conditions. We have thorough communication and collaboration with suppliers and partners to forecast future supply chain risks. Our company predicts future market share and competitiveness based on market trends and competitor behavior.	0.805
Information sharing	Our company typically shares information with suppliers regarding steel demand and inventory levels. We share information with our suppliers concerning quality control and inspection standards. Our company encourages suppliers to share information about potential disruptions in the supply chain, such as natural disasters or strikes. We regularly share information with suppliers about customer preferences and market trends to assist them in making informed production decisions.	0.769
Flexibility	Our company typically maintains spare production equipment to address equipment failures or damages. Our company can flexibly adjust production lines to cope with changes in raw material prices. Our company can make quick adjustments to logistics plans to respond to unexpected events. Our company usually includes contingency plans for unforeseen events in contracts with suppliers.	0.796
Reconfigurability	Our company can adjust the supply chain structure at any time based on market demand and changes. We usually collaborate closely with suppliers during the supply chain restructuring process to ensure successful implementation. Our company frequently undergoes supply chain restructuring to reduce costs and improve efficiency.	0.775

Supply chain integration	Our company collaborates with partners in the supply chain to plan and manage logistics activities. We cooperate with partners in the supply chain to develop quality standards and control measures. Our company coordinates production and delivery plans with partners in the supply chain.	0.761
Supply chain risk management	Our company's supply chain management strategy includes risk assessment and planning. We assess the supply capacity of our suppliers to ensure they are capable of meeting order requirements. Our company regularly inspects and maintains warehouses and equipment to ensure safety and reliability.	0.795
Enterprise innovation	Our company encourages employees to propose new ideas and improvement suggestions. Our company is willing to collaborate with other businesses and organizations to create new opportunities. We provide training and resources to support employees in developing innovative solutions. Our company rewards and recognizes employees for their contributions to innovation.	0.815
Steel Supply Chain elasticity	When the steel supply chain faces external disruptions, our company has sufficient measures to reduce the impact of the disruptions. When the steel supply chain faces external disruptions, the likelihood of our company's supply chain being disturbed is low. When there is an interruption in the steel supply chain, our company can quickly take appropriate measures to adjust the operational status of the supply chain. After an interruption in the steel supply chain, our company can promptly take measures to restore normal operation of the supply chain. After an interruption in the steel supply chain, our company can take reasonable and effective measures to restore the performance level of the supply chain to a higher level.	0.836

Overall, the coefficients of all variables are above 0.7, indicating good measurement reliability. Furthermore, the construct validity of the questionnaire was assessed. Generally, a higher Kaiser-Meyer-Olkin (KMO) coefficient indicates better structural validity of the questionnaire. The result shows a KMO coefficient of 0.953, suggesting good structural validity of the questionnaire. Additionally, the significance level of the Bartlett's sphericity test is less than 0.05, indicating satisfactory structural validity of the questionnaire.

5. Results

5.1. Confirmatory factor analysis

A factor analysis was conducted on the variables to determine the retention or removal of each variable option based on factor loadings. According to the perspective in "Structural Equation Modeling and Its Applications," options with factor loadings below 0.45 can be considered for removal. For the sake of model fit, options with factor loadings below 0.6 will be removed. Due to low factor loadings below 0.6, the following options will be excluded: the second option of supply chain structure quality "Our company will choose to procure steel from multiple suppliers in the same region simultaneously, the third option of information sharing "Our company encourages suppliers to share information about potential disruptions in the supply chain, such as natural disasters or strikes," and the second option of steel supply chain elasticity "When the steel supply chain faces external disruptions, the likelihood of our company's supply chain being disturbed is low." The results of the factor analysis for each variable are shown in Table 5-1.

Table 5-1: Confirmatory factor analysis

Variable	Question	Standardized regression weights	AVE	CR
Quality of supply chain structure	Our company usually chooses to procure steel from multiple regions simultaneously.	0.752	0.52	0,76
	Our company will choose to transport steel using multiple routes simultaneously.	0.762		
	Our company usually selects multiple transportation methods to transport steel.	0.645		
Supply chain collaboration	Our company has established clear communication channels with suppliers to exchange information and provide feedback on supply chain issues.	0.703	0.50	0,80
	Our company frequently shares production plans and inventory information with suppliers to ensure better coordination and collaboration.	0.698		
	We have established long-term partnerships with suppliers to ensure a stable and reliable supply of materials and products.	0.708		
	We have built mutual trust and respect with suppliers to promote effective collaboration and problem-solving.	0.72		

Visibility	Our company will stay informed about the logistics and inventory status in the supply chain.	0.748	0.50	0,80
	We track the production and shipment of suppliers to ensure timely delivery.	0.68		
	Our company typically implements tracking and monitoring along the supply chain to ensure shipment visibility.	0.691		
	We utilize modern technology to visualize the supply chain for better control of supply chain risks.	0.711		
Predictive power	Our company frequently conducts in-depth analysis of market trends to predict future sales situations.	0.699	0.51	0,80
	We conduct research on the raw material market to predict future price fluctuations and supply conditions.	0.726		
	We have thorough communication and collaboration with suppliers and partners to forecast future supply chain risks.	0.709		
	Our company predicts future market share and competitiveness based on market trends and competitor behavior.	0.715		
Information sharing	Our company typically shares information with suppliers regarding steel demand and inventory levels.	0.715	0.53	0,77
	We share information with our suppliers concerning quality control and inspection standards.	0.706		
	We regularly share information with suppliers about customer preferences and market trends to assist them in making informed production decisions.	0.754		
Flexibility	Our company typically maintains spare production equipment to address equipment failures or damages.	0.717	0.50	0,80
	Our company can flexibly adjust production lines to cope with changes in raw material prices.	0.695		
	Our company can make quick adjustments to logistics plans to respond to unexpected events.	0.705		
	Our company usually includes contingency plans for unforeseen events in contracts with suppliers.	0.702		
Reconfigurability	Our company can adjust the supply chain structure at any time based on market demand and changes.	0.757	0.54	0,78
	We usually collaborate closely with suppliers during the supply chain restructuring process to ensure successful implementation.	0.692		
	Our company frequently undergoes supply chain restructuring to reduce costs and improve efficiency.	0.76		
Supply chain integration	Our company collaborates with partners in the supply chain to plan and manage logistics activities.	0.713	0.52	0,76
	We cooperate with partners in the supply chain to develop quality standards and control measures.	0.737		
	Our company coordinates production and delivery plans with partners in the supply chain.	0.706		
Supply chain risk management	Our company's supply chain management strategy includes risk assessment and planning.	0.815	0.57	0,80

	We assess the supply capacity of our suppliers to ensure they are capable of meeting order requirements.	0.713		
	Our company regularly inspects and maintains warehouses and equipment to ensure safety and reliability.	0.733		
Enterprise innovation	Our company encourages employees to propose new ideas and improvement suggestions.	0.687	0.53	0,82
	Our company is willing to collaborate with other businesses and organizations to create new opportunities.	0.716		
	We provide training and resources to support employees in developing innovative solutions.	0.758		
	Our company rewards and recognizes employees for their contributions to innovation.	0.739		
Steel Supply Chain elasticity	When the steel supply chain faces external disruptions, our company has sufficient measures to reduce the impact of the disruptions.	0.766	0.54	0,82
	When there is an interruption in the steel supply chain, our company can quickly take appropriate measures to adjust the operational status of the supply chain.	0.664		
	After an interruption in the steel supply chain, our company can promptly take measures to restore normal operation of the supply chain.	0.752		
	After an interruption in the steel supply chain, our company can take reasonable and effective measures to restore the performance level of the supply chain to a higher level.	0.753		

Average Variance Extracted (AVE) is a measure used to assess convergent validity. Typically, when AVE is above 0.5, it indicates that the observed variables adequately explain the variability of the latent variable. Composite Reliability, also known as construct reliability, reflects the consistency with which all items in a latent variable explain that variable. A construct reliability above 0.70 indicates good reliability for the latent variable. Based on the table above, it can be observed that the AVE values for each dimension in the scale are all greater than 0.5, and the CR values are all greater than 0.7. Therefore, it can be concluded that the scale demonstrates good convergent validity.

5.2. Multicollinearity testing

Multicollinearity testing is a method used to assess the presence of high correlation among multiple independent variables in regression analysis. A common approach for multicollinearity testing is the Variance Inflation Factor (VIF). VIF measures the correlation between each independent variable and the other variables, with higher

values indicating more severe collinearity issues. Strictly speaking, if a variable's VIF exceeds 5, it is considered to have a strong multicollinearity problem.

Table 5-2:Multicollinearity testing

	Tolerance	VIF
Gender	0,944	1,06
Education	0,754	1,327
job title	0,755	1,325
Company age	0,841	1,189
Size of company	0,827	1,209
Nature of company	0,858	1,165
Location of company	0,921	1,086
Structure Quality	0,57	1,755
Collaboration	0,403	2,482
Visibility	0,379	2,638
Predictive power	0,244	4,091
Information sharing	0,328	3,047
Flexibility	0,32	3,124
Reconfigurability	0,423	2,365
Integration	0,324	3,084
Risk management	0,416	2,403
Innovation	0,367	2,722
Dependent Variable: Steel Supply Chain elasticity		

From Table 5-2, it can be observed that all independent variables have VIF values below 5, indicating the absence of multicollinearity issues.

5.3. Hierarchical regression analysis

Before conducting hierarchical regression analysis, it is important to examine the relationship between demographic variables of the survey respondents and elasticity using correlation analysis.

Table 5-3: correlation analysis

	Gender	Education	job title	Company age	Size of company	Nature of company	Location of company
Gender	-	-	-	-	-	-	-
Education	0.01	-	-	-	-	-	-
job title	0.097	0.395**	-	-	-	-	-
Company age	-0.026	-0.005	-0.152*	-	-	-	-
Size of company	-0.11	-0.152*	-0.178**	0.284**	-	-	-
Nature of company	-0.007	-0.135*	-0.115	0.083	-0.007	-	-
Location of company	0.034	-.129*	-0.065	-0.018	-0.013	-0.044	-
Supply Chain elasticity	-0.139*	-0.009	-0.151*	0.210**	0.181**	-0.149*	-0.073

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

According to Table 5-3, it can be seen that at a significant level of p less than 0.01, there is a significant negative correlation (-0.151) between firm age and supply chain elasticity. This means that the level of supply chain elasticity tends to decrease as firms age. Considering the reality, long-term operating companies often have relatively complex and rigid organizational structures and decision-making mechanisms. This may lead to a slow decision-making process and multiple levels of decision-making, making it difficult to quickly make flexible supply chain adjustments and decisions. There is a significant positive correlation (0.284) between firm size and supply chain elasticity. This suggests that larger firms tend to have higher levels of supply chain elasticity. Considering the actual situation, large companies usually have more resources and economic strength, and can invest in establishing a more sound and powerful supply chain system, which has better supply chain elasticity. Although there is a significant correlation between these variables, the absolute value of the correlation coefficient is very small, indicating that there is only a weak correlation between them, which will not affect the follow-up research.

This section uses hierarchical regression analysis to test the hypotheses regarding the impact of variables and their interactions on the elasticity of the steel supply chain. Based on the previous analysis, it is known that factors in the earlier stage of elasticity capacity dimension radiate and influence the effects of factors in the later stage on the

elasticity of the steel supply chain. Moreover, the elasticity of the steel supply chain overall is the comprehensive result of the synergistic matching between elasticity capacity dimensions at various stages. Hierarchical regression aims to incorporate all independent variables and their interaction terms into the regression model in a hierarchical relationship, including control variables, independent variables, and interaction terms within the same elasticity capacity dimension. At the same time, this study will sequentially incorporate and analyze the factors of each elasticity capacity dimension into the entire model based on the sequential representation of the elasticity of the steel supply chain throughout the disruption process.

a. Validation of Absorptive Capacity Dimension

To test the hypotheses regarding the impact of factors and their interactions within the absorptive capacity dimension on elasticity, three models were constructed. In Model M1, elasticity of the steel supply chain was set as the dependent variable, and control variables (company age, company size, nature of company, and company location) were included. In Model M2, based on the variables from Model M1, structural quality of the supply chain, forecasting ability, visibility, and collaboration were added to the regression model. Subsequently, in Model M3, the variables of structural quality, forecasting ability, visibility, and collaboration were centered, and interaction terms were created by multiplying them. Based on the variables from Model M2, the interaction term of structural quality × forecasting ability × visibility × collaboration was included in the regression model. The regression analysis results of the absorptive capacity dimension factors are shown in Table 5-4.

Table 5-4: Validation of Absorptive Capacity Dimension

Visibles	M1	M2	M3
Company age	0.187**	0.061	0.064
Size of company	0.125	0.091*	0.087*
Nature of company	-0.166**	0.049	0.05
Location of company	-0.075	-0.006	0.005
Structure Quality	-	0.107*	0.101
Collaboration	-	0.215***	0.26***
Visibility	-	0.075	0.089
Predictive power	-	0.474***	0.469***
4 item interation of absorptive	-	-	0.096*

R Square	0.092	0.616	0.622
Adjusted R Square	0.076	0.602	0.607
F Change	5.797***	76.22***	3.977*
R Square Change	0.092	0.523	0.007

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level
*** Correlation is significant at the 0.001 level

In Model M1, the variables of company nature, company size, company location, and company age accounted for 9.2% of the explained variance in elasticity of the steel supply chain. The explanatory power of Model M1 reached statistical significance ($F=5.797$, $p<0.001$). This indicates that Model M1 is effective and warrants further discussion. Specifically, in Model M1, company age had a significant positive impact on supply chain elasticity at the $p<0.05$ level, while company nature had a significant negative impact on supply chain elasticity at the $p<0.05$ level, This result is the same as Deng (2021) conclusion that firm age and firm nature have a significant positive impact on supply chain elasticity.

In Model M2, the variables of structure quality, collaboration, visibility, and predictive power accounted for 61.6% of the explained variance in elasticity of the steel supply chain. The explanatory power of Model M2 reached statistical significance ($F=76.22$, $p<0.001$). This indicates that Model M2 is effective and warrants further discussion. Specifically, in Model M2, structure quality had a significant positive impact on supply chain elasticity at the $p<0.05$ level, while collaboration and predictive power had a significant positive impact on supply chain elasticity at the $p<0.001$ level, this result is the same as that of Bai (2018). Hypotheses Ha1, Ha3, and Ha4 are supported.

In Model M3, the interaction terms of the four variables accounted for 62.2% of the explained variance in elasticity of the steel supply chain. The explanatory power of Model M3 reached statistical significance ($F=3.977$, $p<0.05$). Specifically, in Model M3, the interaction terms of the four variables had a significant positive impact on supply chain elasticity at the $p<0.05$ level. Hypothesis Ha5 is supported.

b. Validation of Adaptive Capacity Dimension

To validate the hypotheses regarding the impact of factors and their interactions on elasticity in the adaptability dimension, two models were constructed. In Model M4, the variables of Information sharing, Flexibility, and Reconfigurability were included in

the regression model based on the variables from Model M3. In Model M5, the variables were centered and interaction terms were created before incorporating the Information sharing × Flexibility × Reconfigurability interaction term into the regression model. The regression analysis results for the adaptability dimension factors are shown in Table 5-5.

Table 5-5: Validation of Adaptive Capacity Dimension

Visibles	M4	M5
Company age	0.027	0.027
Size of company	0.028	0.028*
Nature of company	0.038	0.037
Location of company	0.031	0.03
Structure Quality	0.045	0.045
Collaboration	0.064***	0.063***
Visibility	0.063	0.062
Predictive power	0.072**	0.073*
4 item interation of absorptive	0.017	0.017
Information sharing	0.063*	0.063
Flexibility	0.062***	0.062***
Reconfigurability	0.051	0.053
3 item interation of adaptive	-	0.01*
R Square	0.692	0.701
Adjusted R Square	0.675	0.683
F Change	16.633***	6.36**
R Square Change	0.07	0.009

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level
*** Correlation is significant at the 0.001 level

In Model M4, Information sharing, Flexibility, and Reconfigurability accounted for 69.2% of the explained variance in elasticity of the steel supply chain. The explanatory power of Model M4 reached statistical significance ($F=16.633$, $p<0.001$). This indicates that Model M4 is effective and warrants further discussion. Specifically, in Model M4, Information sharing had a significant positive impact on supply chain elasticity at the $p<0.05$ level, while Flexibility had a significant positive impact on supply chain elasticity at the $p<0.001$ level. Hypotheses Hb1 and Hb2 are supported.

In Model M5, the interaction terms of Information sharing, Flexibility, and Reconfigurability accounted for 70.1% of the explained variance in elasticity of the steel supply chain. The explanatory power of Model M5 reached statistical significance

(F=6.36, p<0.01). The interaction terms of the three variables had a significant positive impact on supply chain elasticity at the p<0.05 level. Hypothesis Hb4 is supported.

c. Validation of Recovery Capacity Dimension

To validate the hypotheses regarding the impact of factors and their interactions on elasticity in the recovery dimension, two models were constructed. In Model M6, the variables of Integration, Risk management, and Innovation were included in the regression model based on the variables from Model M5. Then, in Model M7, the interaction term of Integration × Risk management × Innovation was incorporated into the regression model. The regression analysis results for the recovery dimension factors are shown in Table 5-6.

Table 5-6: Validation of Recovery Capacity Dimension

Visibles	M6	M7
Company age	0.036	0.041
Size of company	0.054	0.057
Nature of company	0.049	0.036
Location of company	-0.006	0.007
Structure Quality	0.057	0.064
Collaboration	0.189***	0.14*
Visibility	-0.07	-0.067
Predictive power	0.163*	0.236***
4 item interation of absorptive	0.086*	0.092*
Information sharing	0.124*	0.032
Flexibility	0.33***	0.268***
Reconfigurability	0.012	0.058
3 item interation of adaptive	-0.066	-0.091*
integration	-0.033	0.029
risk management	-0.045	0.032
innovation	0.261***	0.311***
3 item interation of recovery	-	-0.215***
R Square	0.726	0.75
Adjusted R Square	0.705	0.73
F Change	6.538***	20.473***
R Square Change	0.025	0.024

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level
*** Correlation is significant at the 0.001 level

In Model M6, Integration, Risk management, and Innovation explain 72.6% of the variance in elasticity in the steel supply chain. The explanatory power of Model M6

reaches a statistically significant level (F=6.538, p<0.001). This indicates that Model M6 is effective and warrants further discussion. Specifically, in Model M6, Innovation has a significant positive impact on supply chain elasticity at a statistical level of p<0.001. Hypothesis Hc3 is supported.

In Model M7, the interaction term of Integration, Risk management, and Innovation explains 75% of the variance in elasticity in the steel supply chain. The explanatory power of Model M7 reaches a statistically significant level (F=20.473, p<0.001). The interaction terms of the three variables have a significant negative impact on supply chain elasticity at a statistical level of p<0.001. Hypothesis Hc4, indicating an inverse relationship, is supported.

5.4. Summary of Research Results

The empirical results indicate that some hypotheses have been supported through empirical testing, while others have not. A summary of the research hypotheses and their testing results is presented in Table 5-7.

Table 5-7: Conclusion of hypothesis verification

No.	Context	Conclusion	Literature with same result
Ha1	Predictive power has a significant positive impact on the elasticity of steel supply chain	Supported	Bai, Yuanlong (2018); Liu, Jiaguo et al. (2012)
Ha2	Visibility has a significant positive impact on the elasticity of steel supply chain	Not Supported	-
Ha3	Supply chain collaboration has a significant positive impact on the elasticity of steel supply chain	Supported	Yu et al. (2019)
Ha4	Supply chain structure quality has a significant positive impact on the elasticity of steel supply chain	Supported	Liu, Jinling (2018); Kamalahmadi (2016)
Ha5	4 interaction items have a significant positive impact on the elasticity of steel supply chain	Supported	-
Hb1	Information sharing has a significant positive impact on the elasticity of steel supply chain	Supported	Bai, Yuanlong (2018);
Hb2	Flexibility has a significant positive impact on the elasticity of steel supply chain	Supported	Dubey et al. (2020)

Hb3	Reconfigurability has a significant positive impact on the elasticity of steel supply chain	Not Supported	-
Hb4	3 interaction items have a significant positive impact on the elasticity of steel supply chain	Supported	-
Hc1	Supply chain integration have a significant positive impact on the elasticity of steel supply chain	Not Supported	-
Hc2	Supply chain risk management have a significant positive impact on the elasticity of steel supply chain	Not Supported	-
Hc3	Enterprise innovation have a significant positive impact on the elasticity of steel supply chain	Supported	Sabahi et al. (2020)
Hc4	3 interaction items have a significant positive impact on the elasticity of steel supply chain	Reversely Supported	-

From the perspective of absorptive capacity, in situations where the steel supply chain absorbs external disturbances without experiencing disruptions, Predictive power, Supply chain collaboration, and Supply chain structure quality all have a significant positive impact on the elasticity of the steel supply chain. However, Visibility does not have a significant positive impact on the elasticity of the steel supply chain, and its influence coefficient is relatively small. This could be due to the fact that supply chain visibility can provide real-time information, but it may be subject to limitations and challenges such as the cost of information collection and sharing, dependence on technological infrastructure, and concerns about information security and privacy. These limitations may restrict the direct impact of visibility on the absorptive capacity of the supply chain elasticity.

It is worth noting that in terms of the degree of influence, Predictive power has the highest positive impact on elasticity (0.474). This indicates that, at the level of absorptive capacity, the predictive power of the company is the most important. Uncertainty faced by the supply chain is one of the main challenges affecting absorptive capacity. Predictive power can help reduce the uncertainty in the supply chain. By accurately predicting future events and demand, the supply chain can better plan and allocate resources, including manpower, logistics, inventory, etc., to meet fluctuations and changes in demand, thereby enhancing the absorptive capacity of the supply chain elasticity.

From the perspective of adaptive capacity, in situations where the steel supply chain gradually adapts to disturbances during periods of supply chain interruption, Information sharing and Flexibility both have a significant positive impact on the elasticity of the steel supply chain. However, Reconfigurability does not have a significant positive impact on the elasticity of the steel supply chain, and its influence coefficient is relatively small. This could be because steel manufacturing involves complex production processes and large-scale equipment, which may be relatively rigid and difficult to reconfigure quickly. In the steel supply chain, reconfiguring production processes may require a significant amount of time and resources, and it may have adverse effects on production efficiency and costs. Therefore, although the supply chain has reconfigurability capability, its implementation may be limited in the context of steel manufacturing. Flexibility has the most significant positive impact on elasticity. This indicates that, at the level of adaptive capacity, flexibility is the most important for companies. The production process in the steel industry is complex, involving multiple stages and various resources. The flexibility of the supply chain enables steel companies to quickly adjust their product portfolios to meet changing market demands. This production flexibility can reduce production risks, lower production costs, and enhance the supply chain's ability to adapt to market changes and supply chain disturbances. The steel supply chain involves multiple suppliers and partners, including raw material suppliers, transportation providers, and distributors. The flexibility of the supply chain can help establish stable supplier relationships and effective coordination mechanisms with partners, reducing the impact of supply chain disturbances on the steel supply chain.

From the perspective of recovery capacity, in situations where the steel supply chain recovers after a disruption in the supply chain, Innovation has a significant positive impact on the elasticity of the steel supply chain. On the other hand, Integration and Risk Management have a negative impact on the elasticity of the steel supply chain, and their influence coefficients are relatively small. The steel industry's supply chain typically needs to meet certain technological and quality standards and follow specific production processes. This may result in an overly rigid supply chain that is difficult to adapt quickly to market changes and external disturbances. Supply chain integration, which centralizes decision-making authority, can lead to slow or constrained decision-making responses, limiting the elasticity recovery capability of the supply chain.

Additionally, the steel industry's supply chain often faces characteristics such as imbalances in supply and demand, long production cycles, and poor liquidity. In such an environment, overly conservative and cautious risk management strategies may prevent companies from making timely adjustments in the face of market changes and demand fluctuations. Measures that excessively control risks can restrict the adoption of flexible response measures in the supply chain, thereby affecting the elasticity recovery capability of the supply chain.

Besides, Innovation has the most significant positive impact on elasticity in terms of the degree of influence. Supply chain innovation encourages collaboration and coordination among different stakeholders in the steel supply chain, including mines, steel companies, distributors, etc. Through innovation, closer collaborative relationships can be established, allowing for the sharing of information and resources to collectively address challenges in the supply chain. This collaboration and cooperation can enhance the elasticity recovery capability of the supply chain, enabling each link to respond more flexibly to changes and disturbances. By introducing new technologies and processes, the supply chain can continuously learn and adapt to new market demands, technological changes, and competitive environments. This learning and adaptive capacity makes the supply chain more resilient, enabling it to adjust and recover more quickly.

6. Conclusion

6.1. Strategies to improve the elasticity of steel supply chain

1) Enhancing Predictive Capability

   a) Market Trend Analysis and Demand Forecasting

The steel supply chain should establish a robust market monitoring system to collect and analyze market data. By monitoring market trends and demand fluctuations, the supply chain can stay informed about market dynamics and predict potential demand changes. Additionally, advanced technologies and algorithms can be utilized to accurately forecast market demand, material price fluctuations, and supply chain disruptions. The forecasted results can be used for supply chain planning and resource allocation, ensuring timely adjustments in production capacity, inventory levels, and logistics arrangements to accommodate demand fluctuations and changes.

b) Risk Assessment and Uncertainty Management

The supply chain should identify and assess potential risk and uncertainty factors. These may include natural disasters, policy changes, fluctuations in raw material prices, and other relevant factors within the supply chain. By evaluating risks, the supply chain can develop corresponding strategies, such as inventory strategies, diversified supplier selection, and the application of supply chain financial tools. These strategies aim to improve risk identification and response capabilities, thereby reducing the impact of risks on the supply chain.

2) Facilitating Supply Chain Collaboration

a) Establishing Stable Cooperative Relationships

The supply chain should enter into long-term cooperative agreements with key partners to establish stable collaborative relationships. This can enhance trust among supply chain partners, reduce cooperation risks, and ensure the stability of the supply chain. Additionally, engaging in joint planning and collaborative decision-making allows for joint responses to supply chain disruptions and changes, sharing of risks and resources, and improvement of overall supply chain elasticity.

b) Strengthening Information Sharing and Communication Mechanisms

Information sharing and communication mechanisms should be strengthened among different stages of the supply chain. Establishing a supply chain information platform for real-time data sharing can enhance the speed of response and the

quality of decision-making within the supply chain. Organizing regular supply chain cooperation meetings and workshops facilitates communication and coordination among supply chain parties, promoting the development of collaborative relationships. This enables better problem-solving, sharing of best practices, and timely adjustments of supply chain strategies to meet evolving demands.

3) Optimizing the quality of supply chain structure

a) Optimizing production processes and logistics networks

The supply chain should optimize the steel production process and logistics network. By optimizing the production process, improve production efficiency and flexibility, reduce production cycle and waste. Optimizing the logistics network can reduce transportation costs, shorten delivery time, and improve the response speed and delivery capacity of the supply chain. Optimize resource allocation, improve production efficiency and flexibility, so that capacity and product mix can be adjusted quickly. At the same time, establish diversified supply sources and distribution channels to reduce dependence on a single source and reduce the risk of supply chain disruption.

b) Optimize supplier relationship and cooperation mechanism

The supply chain should establish strategic partnerships with key suppliers. Establishing a long-term and stable supplier relationship can ensure the reliability and quality of supply. At the same time, develop supplier performance evaluation indicators to motivate suppliers to continue to improve. Through close cooperation and joint efforts with suppliers, the overall performance and quality of the supply chain can be optimized.

4) Strengthen information sharing

a) Real-time data sharing and collaboration platform

The supply chain should establish a mechanism and collaborative platform for real-time data sharing. Establish a real-time monitoring and data sharing platform to ensure the smooth flow of information in all links in the supply chain. Participants

in different links can share key data and information in real time, thereby improving the synergy of the supply chain. By sharing information such as market demand, production capacity, inventory, and transportation status, the response speed and decision-making accuracy of all parties in the supply chain can be improved, the adaptability of the supply chain can be enhanced, and potential problems and changes can be dealt with in a timely manner.

b) Improving the transparency of supply chain information

Increase supply chain transparency and compliance by providing supply chain performance reports and metrics to track supply chain activities and information flow in real time. Such transparency helps supply chain managers better monitor supply chain operations, discover problems and bottlenecks in a timely manner, and take corresponding measures to adjust and improve.

5) Improve supply chain flexibility

a) Flexible production scheduling and resource allocation

The supply chain should implement flexible production scheduling and resource allocation mechanisms. By adopting advanced production planning and scheduling systems, the supply chain can better respond to fluctuations and changes in market demand. At the same time, optimize resource allocation, establish flexible contracts and agreements with suppliers and distributors, so that order adjustments and delivery arrangements can be made according to changes in demand.

b) Diversified Product Portfolio and Inventory Management

The supply chain should provide a diversified product portfolio to meet different market demands. Through a flexible product mix strategy, the supply chain can quickly adjust production and supply when market demand changes. In addition, optimizing inventory management can reduce inventory costs and increase inventory turnover, thereby increasing the flexibility and responsiveness of the supply chain.

6) Introducing Innovation

a) Technological innovation and digital transformation

The supply chain should actively introduce technological innovation and digital transformation. The operability and decision-making capabilities of the supply chain can be improved by applying new technologies, such as the Internet of Things, artificial intelligence, and big data analytics. Digital transformation can accelerate the digitization of information flow and business processes, and improve the efficiency and accuracy of the supply chain. Establish an innovative cooperation platform to promote exchanges and cooperation among all parties in the supply chain, and jointly solve challenges in the supply chain.

b) Process innovation and business model innovation

The supply chain should carry out process innovation and business model innovation. Supply chain flexibility and efficiency can be improved by redesigning and optimizing supply chain processes. At the same time, new supply chain value and business opportunities can be created by exploring new business models, such as sharing economy and circular economy.

6.2. Research Summary

In the current complex international economic and political environment, as well as the impact of the post-COVID-19 economic situation, the supply, demand, and transportation of steel face high levels of risk and uncertainty. Accurately identifying the multiple influencing factors of steel supply chain elasticity and deeply analyzing the impact mechanisms of these factors and their combinations on elasticity are crucial for effectively enhancing the overall level of risk resistance in the steel supply chain.

The main conclusions and innovations of this TFM are as follows:

a) To better reflect the essential characteristics of stage-based and dynamic elasticity in the steel supply chain, this study identifies the influencing factors of steel supply chain elasticity from the perspective of elasticity capabilities. Through a literature review, ten key influencing factors are identified: supply chain structural quality, forecasting ability, visibility, and supply chain collaboration in the absorptive capacity dimension; information sharing,

flexibility, reconfigurability in the adaptability dimension; and enterprise risk management, innovation, and supply chain integration in the recovery capacity dimension.

b) A theoretical model of the impact mechanism of steel supply chain elasticity factors is constructed, which fully reflects the overall structure, operational continuity, and progressive impact of the steel supply chain. Based on this model, using questionnaire survey data and applying hierarchical regression analysis that matches the aforementioned characteristics, the impact mechanism model of elasticity factors is empirically examined. The study reveals that supply chain structural quality, forecasting ability, and supply chain collaboration have a positive impact on elasticity in the absorptive capacity dimension. The combination of these four factors has the greatest impact on elasticity forecasting ability, indicating that improving an enterprise's forecasting ability can enhance its capacity to absorb disturbances before an interruption in the steel supply chain. Information sharing and flexibility in the adaptability dimension positively affect elasticity, and the combination of these three factors also has a positive impact on elasticity, with flexibility having the greatest influence. This indicates that increasing supply chain flexibility can effectively enhance the steel supply chain's ability to adapt to interruptions. Innovation has a positive impact on elasticity in the recovery capacity dimension, while enterprise risk management, supply chain integration, and the combination of these three factors have a negative impact on elasticity. This suggests that overly conservative risk management strategies may hinder timely adjustments to market changes and demand fluctuations. Supply chain integration may lead to excessive centralization of decision-making and slower response speeds, limiting the recovery capacity of the supply chain. The combination of these three factors may interact and restrict each other, preventing the supply chain from flexibly responding to external disturbances and market changes, thus reducing elasticity.

c) Based on the research findings, corresponding recommendations are provided for enhancing the elasticity of the steel supply chain in the new situation.

d) Limitations of this study: Due to the specificity of the research subject, this study was subject to certain limitations in sample selection and data acquisition channels. Future research could expand the scope of survey subjects and adopt a comprehensive approach using multiple data sources and triangulation to further enhance the generalizability and scientific rigor of the results.

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APPENDIX

Questionnaire on Factors Affecting the Resilience of Steel Supply Chains

Dear Sir/Madam: Thank you for participating in this survey. This survey is an in-depth investigation on the elasticity of the steel supply chain and its influencing factors, aiming to fully reveal the impact mechanism of multiple factors on the elasticity of the steel supply chain. This questionnaire is answered anonymously, there is no right or wrong answer, and the survey will take about 3-5 minutes of your time. All the content you fill in is only used for academic research and will be kept strictly confidential, so please rest assured! Your truthful filling will be of great help to the research, thank you again for your support!

Part I Basic Personal and Business Information
Please choose the appropriate option in the following questions according to your personal situation and the basic situation of your company.

1. Your gender is
A. male B. female

2. Your educational level is
A. Ph.D. B. Master C. Undergraduate D. High school and below

3. Your job title is
A. Senior managers B. Middle managers C. Basic managers D. Ordinary employees

4. What is the age of your company
A.0-5 years B.5-10 years C.10-20 years D.More than 20 years

5. What is the size of your company's workforce?
A. Less than 500 people B. 500-1000 people C. 1000-2000 people D. More than 2000 people

6. The nature of your company's business is
A. State-owned enterprises B. Private enterprises C. Foreign-funded (joint venture) enterprises D. Collective enterprises

7. The geographic location of your company is
A. East B. Central C. West D Northeast

Part II Factors Affecting Steel Supply Chain Resilience
Please combine the actual situation, consider the degree of conformity between the statements in the following topics and the performance of your company and partners, and choose the most appropriate option among the 5 levels from "totally disagree" to "totally agree".
(1) Absorptive capacity dimension
Quality of supply chain structure
8. our company usually chooses to purchase steel from multiple regions at the same time

9. our company will choose to source steel from multiple suppliers in the same region at the same time.

10. our company will choose multiple routes to transport steel at the same time.

11. our company usually chooses a variety of transportation methods to transport steel products.

12. our company's cooperative suppliers can usually make preparations for resisting risks in advance.

Supply chain collaboration

13. our company has established clear communication channels with our suppliers to exchange information and feedback on supply chain issues.

14. Our company often shares production plans and inventory information with our suppliers to ensure better coordination and collaboration.

15. We have established long-term partnerships with our suppliers to ensure stable and reliable supply of materials and products.

16. We have established mutual trust and respect with our suppliers to facilitate effective collaboration and problem-solving.

Visibility

17. our company will keep abreast of the logistics and inventory situation in the supply chain.

18. our company tracks suppliers' production and shipments to ensure timely deliveries.

19. our company typically implements tracking and monitoring along the supply chain to ensure shipment visibility.

20. our company uses modern technology to visualize the supply chain in order to better control supply chain risks.

Predictive power

21. Our company often conducts in-depth analysis of market trends to predict future sales.

22. Our company conducts research on raw material markets to predict future price fluctuations and supply conditions.

23. Our company fully communicates and collaborates with suppliers and partners to anticipate future supply chain risks.

24. Our firm forecasts future market share and competitiveness based on market trends and competitor behavior

(2) Adaptive capacity dimension

Information sharing

25. our company usually shares information on steel demand and inventory levels with its suppliers.

26. our company shares information on quality control and inspection standards with its suppliers.

27. our company encourages suppliers to share information on potential supply chain disruptions such as natural disasters or labor strikes.

28. our company regularly shares information on customer preferences and market trends with its suppliers to help them make informed production decisions.

Flexibility

29. Our company usually has spare production equipment in case of equipment failure or damage.

30. Our company can flexibly adjust production lines to cope with changes in raw material prices.

31. Our company can adjust the logistics plan in a short time to deal with emergencies.

32. Our company usually agrees with suppliers on contingency plans for emergencies in the contract.

Reconfigurability

33. Our company can adjust the supply chain structure at any time according to market demand and changes.

34. Our company typically works closely with suppliers during the supply chain restructuring process to ensure successful implementation.

35. Our companies often reduce costs and increase efficiency through supply chain restructuring.

Supply chain integration

36. Our company plans and manages logistics activities together with partners along the supply chain.

37. Our company works with partners in the supply chain to develop quality standards and controls.

38. Our company coordinates production and delivery planning with partners in the supply chain.

Supply chain risk management

39. Our company's supply chain management strategy includes risk assessment and planning.

40. Our company will evaluate the supplier's supply capacity to ensure that it has the ability to meet the order requirements.

41. Our company regularly inspects and maintains warehouses and equipment to ensure safety and reliability.

Enterprise innovation

42. Our company encourages employees to suggest new ideas and improvements.

43. our company is open to collaboration with other businesses and organizations to create new opportunities.

44. our company provides training and resources to support employees in developing innovative solutions.

45. our company rewards and recognizes employees for their contributions to innovation.

Part Ⅲ Steel Supply Chain Resilience

Please combine the actual situation, consider the degree of conformity between the statements in the following topics and the performance of your company and partners, and choose the most appropriate option among the 5 levels from "totally disagree" to "totally agree".

46. When the steel supply chain faces external disturbances, our company has sufficient countermeasures to reduce the impact of the disturbances.

47. When the steel supply chain faces external disturbances, our company's supply chain is less likely to be disrupted.

48. When the steel supply chain is interrupted, our company can quickly take corresponding measures to adjust the operation status of the supply chain in a timely manner.

49. After the steel supply chain is interrupted, our company can quickly take measures to restore the normal operation of the supply chain as soon as possible.

50. After the steel supply chain is interrupted, our company can take reasonable and efficient measures to make the performance level of the supply chain resume high.