Analysis of Supply Chain Risk in the Semiconductor Industry

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Abstract. Driven by globalisation and various industry trends, the business environment is increasingly uncertain. The continuous risk of unexpected disruptions in the supply chain has led companies to focus more on risk management. Affected by global trends such as trade conflicts and increased market competition, the semiconductor industry - especially chip companies - is particularly at risk. This study identifies and analyses the supply chain risk types of chip companies by contextual analysis and machine learning methods and aims to increase companies' awareness of key risks. According to the research results, the complexity and dynamics of risks borne by companies are increasing. Among the various risk types, technical risk is a key concern for companies. Based on the complexity and dynamic changes of risks, it is necessary to enhance risk management capabilities by fostering agility and resilience management.

Keywords: supply chain risk, agility, resilience, complexity, Dynamic, chip

1 Introduction

Globalisation, emerging production technologies and lean production have improved the efficiency and added value of supply chains; however, various risk events have exacerbated the uncertainty and vulnerability of supply chains (Trkman et al. 2016; Kirilmaz & Erol 2017; Birasnav & Bienstock, 2019) [30] [18] [2]. Traditional Supply Chain Risk Management (SCRM) is inadequate to address supply chain disruptions caused by risk uncertainty. The impact of risk further stimulates the complexity and dynamics of the supply chain.

Researchers and corporate managers tend to foster proactive and flexible risk management systems by increasing the emphasis on the agile and resilient development of supply chains (Fan et al., 2017; Kirilmaz & Erol 2017) [6] [18]. The various components of the supply chain are considered strategic resources of a company (Zhu & Gao, 2021) [34]. Agility and resilience can enhance the efficiency of companies in utilising strategic resources and develop sustainable competitiveness (Gligor et al., 2019) [10]. Therefore, an in-depth study into Supply Chain Risk (SCR) types through integrated risk identification can help companies to solve problems more specifically and achieve resilience.

The current literature on SCRM tends to use qualitative methods, resulting in a lack of quantitative research and the representation of some industries, such as the semiconductor industry, is also insufficient (Ho et al., 2015; Kirilmaz & Erol 2017) [13] [18]. The purpose of this research is to identify and analyse the types of SCR faced by chip companies in the

IEDM 2024, February 23-25, Kuala Lumpur, Malaysia

DOI 10.4108/eai.23-2-2024.2345901

semiconductor industry and to help companies improve their ability to respond to risk events through risk perception.

The innovation of this research is mainly reflected in three aspects. Firstly, the existing literature lacks specialised analysis of the semiconductor industry, especially chip companies and this proposed research supplements accordingly. Secondly, previous studies have used different research methods, including using financial risk indicators to construct data analysis models, literature reviews and surveys (Chiu & Choi, 2013; Ribeiro & Barbosa-Povoa, 2018; Zhu & Gao, 2021) [3] [24] [34]. However, this research uses contextual analysis and machine learning methods. Thirdly, previous literature on risk types has focused more on descriptive analysis, whereas this research quantitatively analyses the complexity and dynamic variables of risk perception based on the risk text frequency disclosed in corporate annual reports.

2 Literature Review

2.1 Theoretical Background

The definitions of SCR and SCRM are various and inconsistent (Ho et al., 2015; Fan et al., 2017; Fan and Stevenson, 2018) [13] [6] [7]. This lack of consensus and clear definitions is not conducive to communication between researchers and managers, thus making it difficult to conduct empirical research.

Identifying the source of risk is the first step in SCRM and the key stage to trigger the risk management mechanism (Fan & Stevenson, 2018; Jacobs et al., 2022) [7] [15]. Risk identification aims to identify all potential supply chain threats, including various risk types and factors (Kern et al., 2012) [17]. Proactive risk identification is conducive to the sustainable development of SCRM (Gupta et al. 2020) [12].

Based on the information processing theory, as an information processing system, a company needs to process and implement information from both external and internal environments (Daft et al., 1987) [4]. SCR information includes abnormal information about markets, politics, technology, supply chain stakeholders, etc (Kirilmaz & Erol 2017) [18]. To better process risk information, corporate managers need to devote more efforts to improve their capabilities of information processing and execution (Fan et al., 2017) [6].

2.2 The Complexity and Dynamics of Supply Chain Risk

2.2.1 Risk Types.

Regarding the classification of risk types, different scholars have different perspectives based on different definitions of SCR. Chiu and Choi (2013) [3] proposed two types: one was supply chain disruption risk, including various natural and man-made problems that lead to supply chain disruption, such as diseases, economic fluctuations and political instability (Sodhi et al., 2012) [27]. The other was supply chain operational risk, which included changes in expectations and uncertainties in demand, such as exchange rate fluctuations (Chiu & Choi, 2013) [3].

Ho et al., (2015) [13] summarised SCR types into macro risk and micro risk. Macro risk referred to adverse and rare external events that had a negative impact on a company,

including both natural and human risks. Micro-risk referred to the risks directly arising from the company's internal activities or partnerships in the supply chain, including corporate internal manufacturing capacity, and upstream and downstream relationship stability. More detailed categories included production quality, information technology, etc. (Ho et al., 2015) [13].

Random or discrete risk events in the environment can bring SCR and lead to disruption. A holistic approach to identifying risk information needs to be supplemented by more experimental and empirical validation.

2.2.2 Complexity and Dynamic Characteristics of Supply Chain Risk.

In a dynamically changing market competition environment, supply chains have more uncertainty; this uncertainty brings more complex risk factors (Lotfi & Sghiri, 2017) [20]. The faster the adaptation of a company, the greater its sustainable competitive advantage against its competitors (Zhu & Gao, 2020; Nandi et al., 2021) [34] [21]. Furthermore, the complexity of the supply chain is correlated with organisational uncertainty (Birasnav & Bienstock, 2019) [2]. Supply chain risk is often accompanied by a high degree of uncertainty and ultimately disrupts various chains of the supply chain (Shukor et al., 2020) [26].

The complex business environment increases the types of risks faced by companies, as Ivanov (2020) [14] pointed out the high level of uncertainty caused by COVID-19 had disrupted supply and demand, logistics, and components of the supply chain. Furthermore, environmental uncertainty is a sign of market dynamics (Aslam et al., 2020) [1]. Lean supply chains are more uncertain and dynamic (Lotfi & Sghiri, 2017) [20]. The risk management process is also dynamic, which is manifested by the continuous observation of changing situations and environments (Kirilmaz & Erol, 2017) [18].

In a competitive, complex, dynamic and uncertain risk environment, companies need to respond promptly and quickly to market changes (Dubey et al., 2018) [5]. Companies can improve responsiveness and reduce instability in dynamic environment by adopting agility (Fayezi et al., 2017; Sharma et al., 2021) [8] [25]. The dynamic nature of the corporate environment requires it to change, which requires the application of dynamic capability (Aslam et al., 2020) [1] and dynamic capability is a necessary condition for achieving supply chain resilience (Gunessee et al., 2018) [11].

Companies with dynamic capabilities can achieve resilience by reallocating resources in response to risk disruptions (Gligor et al., 2019; Aslam et al., 2020) [10] [1]. By being alert to the complexity and dynamics of the supply chain, companies can sense the potential vulnerability and play an agile role in dealing with unexpected shocks and achieve resilient recovery (Pettit et al., 2019) [22]. Therefore, this research constructed complexity and dynamic indicators to measure the uncertainty of supply chains.

3 Methodology

This research constructed two variables based on the risk text disclosed in the annual reports of listed companies that manufactured chips from 2013 to 2022 and adopted a contextual analysis method. After considering the definition of risk categories by scholars and the

disclosure of chip companies' annual reports, the study summarised thirteen general risk types. Chip companies were collected from East Money database. Risk information was obtained from corporate annual report. Machine learning method was used to expand and collect risk text keyword frequencies and Python was utilised to process the data (Xue et al., 2020) [33].

3.1 Complexity

The first variable was complexity, which described the degree of diversification of external risk factors disclosed in annual reports. The risk complexity index was derived from the aggregate risk types. If a certain type of risk was disclosed in the annual report, it would be assigned a value of 1, otherwise, 0. The more types included, the higher the risk complexity.

Thirteen risk types were ranked and vector indicators were constructed, while i indicated the corresponding year. The formulas were as follows (formulas 1 and 2):

$$\text{Text}_i = (a_1, a_2, a_3, \ldots, a_{14}) \tag{1}$$

$$\text{Complexity} = \|\text{Text}_i\| \tag{2}$$

3.2 Dynamic

The second variable was dynamic, which was obtained by establishing the coefficient of textual difference between adjacent years. If the indicator was close to 1, it indicated that the company had a rapid response to risk and may have a certain degree of agility and potential resilience. If the indicator was close to 0, it indicated that the perceived risk and resilience of the company were relatively stable.

The data was obtained as follows: firstly, the indicators for the initial year were 0 (formula 3). Secondly, the Euclidean distance calculation was used to measure the distance between adjacent years (formula 4). Next, to ensure a value range of 0-1, the reciprocal of distance was used to indicate similarity (formula 5). Finally, the dynamic formula was obtained (formula 6).

$$\text{Dynamsim}_0 = 0 \tag{3}$$

$$\text{Distance}_i = \sqrt{\left(a_{i,1} - a_{i-1,1}\right)^2 + \left(a_{i,2} - a_{i-1,2}\right)^2 + \cdots + \left(a_{i,14} - a_{i-1,14}\right)^2} \tag{4}$$

$$\text{Similarity}_i = 1/(\text{Distance}_i + 1) \tag{5}$$

$$\text{Dynamsim}_i = 1 - \text{Similarity}_i \tag{6}$$

The manual classification method was used to review the risk disclosure section of the annual report as a robustness analysis, and it was found that the data results were similar.

4 Data Analysis and Discussion

4.1 Analysis of Supply Chain Risk Complexity

348 chip companies listed on East Money database were collected and after removing companies with missing annual reports and risk information, there were 329 remaining that

can be utilised in this research. Some companies also had incomplete ten-year annual reports due to their short time being listed.

Firstly, through the analysis of the overall risk data of 329 chip companies, Figure 1 reflects the increasing risk exposure of chip companies.

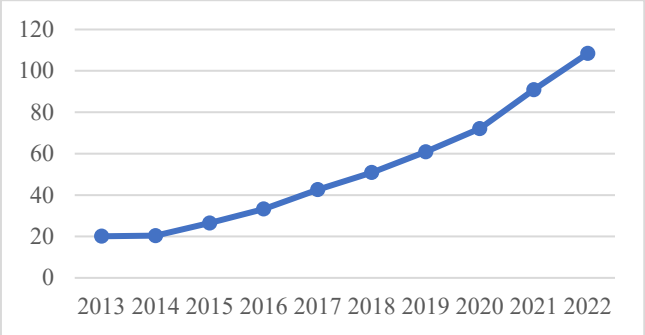

Figure 1. Industrial Risk Trends

Secondly, in terms of individual risk types, the risk borne by each firm is also rising. However, the semiconductor industry, especially chip companies, is highly sensitive to technology (Li et al., 2019) [19], which leads to excessive frequency of technical risk data in annual reports. Therefore, the technical risk is analysed separately in this research.

After excluding technical risks, the proportion of risk text frequency is: intellectual property risk (3.8%); political risk (12.41%); quality risk (2.42%); supplier risk (2.19%); cyber risk (5.97%); regulatory risk (14.01%); human resource risk (8.74%); environmental risk (20.32%); macroeconomic risk (10.54%); raw material risk (4.65%); customer risk (0.75%); and market competition risk (14.20%).

Figure 2 reflects the increasing complexity of SCR borne by companies, which matches the trend of dynamic changes in the market environment. After excluding technical risks, the increase in market competition risk is the highest, which may be related to the intensification of industry competitiveness (Dubey et al., 2018; Kazancoglu et al., 2022) [5] [16]. Due to the broad industrial development prospects, the market competition risk factors have increased, including the increase of competitors, changes in supplier and customer needs, and the increase of alternative products. However, customer risk is relatively stable. According to the annual report, it states that companies may have a relatively stable customer base or good customer relationship management. Suppliers and customers are key stakeholders of supply chain partnership, but excessive dependence on major suppliers and high concentration of customers will aggravate supply chain uncertainty. Political risk has increased dramatically since 2017 and is becoming one of the key risks. This may be related to trade conflicts caused by unstable political situations (Lotfi & Saghiri, 2017; Aslam et al., 2020) [20] [1]. ZTE is one of the typical cases affected by trade frictions.

Based on data and annual reports, environmental and regulatory risks are also ongoing concerns. The companies need to fully utilise the opportunities brought by industry support policies and establish a leading position. In addition, as current business trends and regulatory requirements emphasize green and sustainable development, companies are also considering

more potentially affected environmental risks. Although the proportion of intellectual property risk and human resource risk is not high, it is found in the manual review process that the more attention the company attaches to the cultivation of innovation and independent ability, the more concerned about these two risks. The digital nature of chip companies, the limitations of confidentiality measures and the mobility of technical personnel and other uncontrollable factors are all potentially significant risk factors for technology companies.

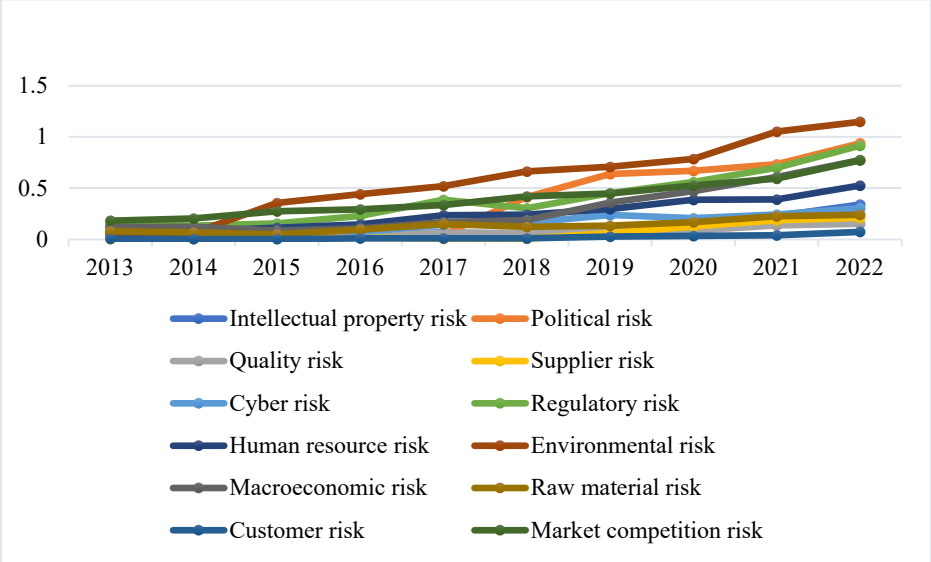

Figure 2. Risk Types Trends

Figure 3 shows that technical risk is also increasing rapidly. Chips are considered to be one of the keys to economic development and are critical to national information security (Villard et al., 2015) [31]. The growing market demand and trade restrictions require Chinese chip companies to reduce their dependence on imports. Recognising the importance of improving technology in the semiconductor industry, China has formulated corresponding policies to support this industry (Wu et al., 2015; Li et al., 2019) [32] [19].

Flexibility and agility encourage companies to adopt transformational technology (Dubey et al., 2018) [5]. Companies can improve supply chain traceability and automation through technology and cultivate agility and resilience for sustainable development (Ivanov, 2022; Kazancoglu et al., 2022) [14] [16]. Emerging technologies such as those powering Industry 4.0 drive companies to improve their technological capabilities to derive higher value from efficient resource consumption (Shukor et al., 2020) [26].

Rapid advances in technological innovation imply that delays or disruptions can result in product obsolescence, product development failure, or technological iteration failure. Technology is the core competitiveness of chip companies, which encourages companies to strengthen management in core technology talents cultivation, patent protection and technical leakage prevention.

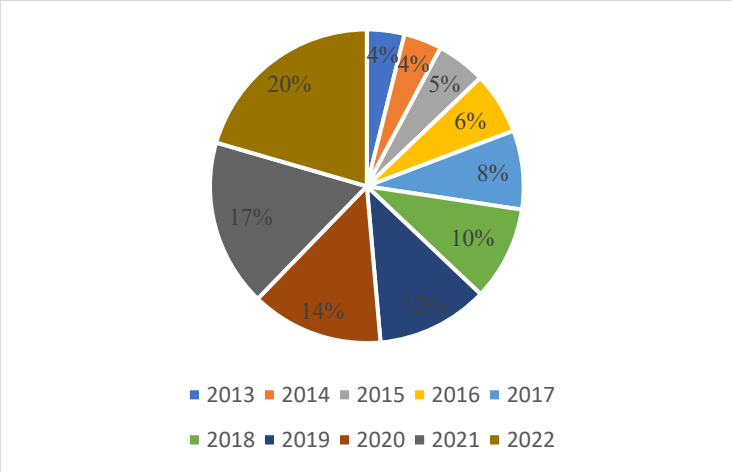

Figure 3. Technical Risks

In terms of risk complexity, companies are generally exposed to more than three risk types. The maximum complexity of risks borne by the company is 10 types of risks within a year and the minimum value is 0.

4.2 Analysis of Supply Chain Risk Dynamic

In terms of dynamic indicators, the maximum annual dynamic value of a company is 0.99 and the minimum value is 0.5, after excluding 0 in the first year. The growing trend in Figure 4 indicates that the overall SCR borne by the company is dynamic, among which indicators exceeding 0.9 accounts for 43.14%. If the dynamic value is close to 1, it indicates that the company faces various risks regularly. Otherwise, if the dynamic value is close to 0, it means that the annual risks of the company are similar. The company has a relatively stable risk exposure environment or a stable risk management system.

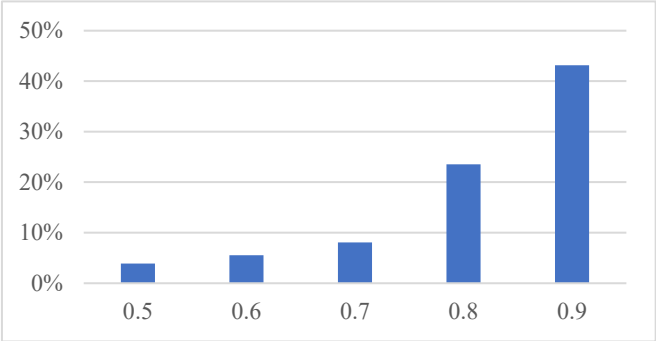

Figure 4. Dynamic Trends

4.3 Analysis of ZTE case

ZTE is one of the global high-tech companies, and its globalization strategy highly values the

maintenance of partnership. It establishes stable and valuable customer relationship by strengthening customer communication, and improves market competitive advantages and technical capabilities through various forms of cooperation (Fu et al., 2018) [9]. However, as Li et al. (2019) [19] pointed out, China's semiconductor industry was highly dependent on imports. Analysts estimated that US suppliers provided approximately 25-30% of the key components in ZTE's products (Stecklow et al., 2018) [28]. As a result, in the 2018 US trade sanctions, ZTE suffered significant losses due to supply chain disruptions. The disruption of the supply chain has a negative economic impact on ZTE's supply chain partners. Some suppliers and customers have more bargaining power due to the weak position of ZTE, resulting in an increase in operating costs for ZTE (Jacobs et al., 2022) [15]. The uncertainty caused by political risks arising from international trade issues has prompted other Chinese companies such as ZTE to reduce their dependence on US suppliers and increase their capacity for independent innovation.

It can be found that political risk is a long-term concern of ZTE from ZTE's annual reports, which may be the reason why ZTE can recover from the trade shock. In addition, ZTE's annual reports also reflect the SCRM tactics in ZTE's development strategy, including long-term and continuously increasing R&D investment, supply chain relationship initiatives strengthening, and strategies to gather outstanding talents. It should be noticed that since the disclosure of the 2021 annual report, ZTE has proposed the concept of building resilient organizations to achieve sustainable development. And in the annual report of 2022, ZTE proposes to further strengthen resilience, which illustrates ZTE's efforts in the development of SCRM resilience.

5 Contribution and Conclusion

On the one hand, this research aims to theoretically supplement the existing literature on SCRM in the semiconductor industry. On the other hand, by integrating the common types of risks faced by chip companies, it is also intended to encourage companies to identify and manage significant risks in advance as managerial implications. The ability of supply chain stakeholders to respond to risk uncertainty significantly affects the resilience management of companies (Pettit et al., 2019; Piprani et al., 2020; Tarigan et al., 2021) [22] [23] [29].

The continuity innovation and sustainable development of the supply chain require participants to identify various risk barriers and analyse effective response strategies (Gupta et al., 2020; Zhu and Gao, 2020) [12] [34]. Companies need to be more agile and use a resilient management approach to prevent interruptions caused by risks and improve resource utilisation efficiency. However, the current resilience efforts of the company are insufficient (Birasnav & Bienstock, 2019; Kazancoglu et al., 2022) [2] [16]. The research findings reflect the importance of technical risk to the semiconductor industry, especially chip companies. Future risk research in the semiconductor industry is recommended to concentrate more on technical risk.

There are, however, some limitations to this research. Firstly, since this risk identification is only for chip companies in the semiconductor industry, it is suggested that future research should expand and supplement risk information in other industries. Secondly, the research method focuses on quantitative analysis and, consequently, lacks qualitative methods such as

expert judgments and staff interviews. Therefore, it is suggested that future research can be supplemented by adopting qualitative methods.

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