Managers' risk perception of supply chain uncertainties

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Abstract

Purpose – This paper provides a practical framework for managers to develop a sustainable supply chain. Given that rapid globalization has increased supply disruption risk, managers have been forced to establish efficient and responsive supply chain strategies. Nevertheless, diverse uncertainty factors, such as risk perception of strategies, have made practical management difficult. Quantifying managers' risk perceptions and applying them to supply chain strategies allows the authors to propose a structural and practical model for managing supply disruption.

Design/methodology/approach – The existing structural model is refined by taking subjective factors into account using the analytic hierarchy process. The applicability of the refined model is demonstrated through a comparative case study.

Findings – Managers' risk perceptions vary not only among companies but also between managing divisions within a company, which necessitates possible changes in strategy due to environmental turbulence. The principal component analysis (PCA) characterizes managers' risk perceptions that illustrate companies' emphases on disruption risk.

Practical implications – The proposed approach quantifies risk perception, which enables practitioners to deal with subjective information in quantitative form. Comparative studies clarify differences in perception given different business backgrounds. The results provide managers with in-depth insights for establishing supply chain strategies reflecting their risk perception.

Originality/value – Quantification of managers' subjective risk perception clarifies both the trend and the individual features for uncertainties. The results allow the authors to conduct the PCA, which characterizes companies. Comparative studies generalize the results of extant work, shedding light on cross-sectional differences given different business backgrounds. The effectiveness of the approach is confirmed through retrospective interviews with practitioners.

Keywords Uncertainty, Risk perception, Supply chain management, Supply disruption

Paper type Research paper

1. Introduction

Under rapid globalization, firms face increasing levels of uncertainty and, thus, a greater risk of supply chain disruption. A further problem is that supply networks now span multiple geographic regions, exposing managers to greater environmental and operational risks. For example, in 2011, the Great East Japan Earthquake and the catastrophic floods in Thailand interrupted local and global distribution channels and the latest spread of the destructive coronavirus disease 2019 (COVID-19) has locked down cities and closed ports around the world. The disasters have triggered shortage of critical components across every industry, in addition to severely damaging the lifeline logistics network. Although eight years have passed since the earthquake, the area is still struggling to recover from the disaster. This devastating situation has brought significant attention to supply chain risk management.

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William *et al.* (2015, p. 5036) defined supply chain risk management as "an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain." As one of the fatal results of supply chain risk, supply disruption is considered to be "unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain and, as a consequence, expose firms within the supply chain to operational and financial risks" (Craighead *et al.*, 2007, p. 132). Dealing with disruption risk is thus essential for managers in charge of supply chain management.

A significant number of research studies on the management of supply disruption risk have been carried out to date. Recent pioneering works began with Jüttner *et al.* (2003), which clarified the concept and the agenda of supply chain risk management. Perspectives in supply chain risk management were then clarified and the gap between theory and practice was highlighted by Tang (2006). Subsequently, Tse (2012) conceptualized and operationalized supply chain quality risk management and provided novel insights into how to reduce the risk. Also, two additional approaches to supply chain management have come to fore: cross-sectional differences and in-depth exploration of research in this field. Kristal *et al.* (2011) demonstrated that the effectiveness of different supply chain practices is affected by national culture; therefore, testing the generalizability of the findings to other countries and across other industries is important. In addition to the cross-sectional expansion of research in this area, another emphasis has been on conducting in-depth exploration to determine how to deal with risk perception in supply chain management. As Ellis *et al.* (2010, p. 36) defined, overall supply disruption risk is "an individual's perception of the total potential loss associated with the disruption of supply of a particular purchased item from a particular supplier." This definition sheds light on the importance of risk perception in establishing an effective and responsive strategy for supply chain management.

As research on risk within supply chains progressed, the risk perception and environmental uncertainties that impact supply disruption have received increasing attention. For example, Srinivasan *et al.* (2011) focused on environmental uncertainty, where they examined the relationship between buyer–supplier partnership quality and supply chain performance. More recently, Tseng *et al.* (2018a) have proposed a framework for evaluating the performance of sustainable service supply chain management under uncertainty. Tseng *et al.* (2018b) have also developed a sustainable supply chain finance model under uncertainty. The problem, however, is that risk perception caused by uncertainties in supply chain management is subjective, which makes incorporating the factor into quantitative analyses challenging. Indeed, in comparison with a great many quantitative approaches to supply chain management, qualitative research has predominated in risk perception, with risks in supply chain management identified using qualitative methods (e.g. Colicchia *et al.*, 2019).

To incorporate these factors into analyses quantitatively, Tsai *et al.* (2008) addressed risk perception by applying the analytic hierarchy process (AHP) to calibrate the relative importance of each of the risk events. Schoenherr *et al.* (2008) also used the AHP to evaluate the importance of risk factors and to determine the best alternates for a manufacturing company. Other applications of the AHP were addressed by Moktadir *et al.* (2018) to analyze subjective factors in supply chain management. Thus, risk perception of uncertainties in supply chain management has recently been addressed using a quantitative approach. Nevertheless, practical contributions covering cross-sectional differences are yet to emerge in the field. For the findings to be generalized, the questionnaire designs need to be refined and a further empirical analysis of the AHP is required (Liu and Lee, 2019). Hence, we propose the following research questions:

(1) How can we deal with subjective risk perception in supply chain management?

(2) What are the differences in perception given different business backgrounds?

(3) How can we establish efficient and responsive supply chain strategies?

To answer these questions, we focus on risk perceptions within the Japanese beverage industries that engage in business in both Japan and Thailand. Based on our previous work (Tse *et al.*, 2016), a refined model of supply disruption risk is proposed. The model quantifies the relationship between supply disruption risk and uncertainties within a supply network that may affect managers' risk perceptions. We then clarify differences in risk perception across the two countries. This approach addresses the question as to how uncertainties within supply chains influence the risk perception of supply disruption given different business backgrounds. This perspective can then provide different parties within the network with a more in-depth picture for establishing efficient and responsive supply strategies.

This paper is organized as follows. In Section 2, we review and discuss the literature on supply chain management. Section 3 describes the research design: the original conceptual model of supply disruption risk on which this paper is based, followed by a refined quantitative model that takes the risk perception of uncertainties into account. In Section 4, the results of a case study verifying the proposed approach are shown, clarifying differences in managers' subjective risk perceptions given different business backgrounds. Section 5 summarizes the managerial implications for beverage companies in supply chain management. Section 6 concludes the paper and explores directions for future research.

2. Literature review

This section introduces early research on supply disruption risk: a review of models and methodologies in the literature, and definitions and interpretations of risk and uncertainties in supply chains.

2.1 Models and methodologies for supply chain risk management

A model of supply disruption risk takes as its point of departure the perspective of informants. As research in this field progressed, a great many models were developed. The traditional mainstream approach to risks was primarily qualitative in nature. Tsai *et al.* (2008) developed a qualitative risk model identifying the outsourcing risks of logistics functions and clarified the risk perception of outsourcing. A conceptual model for the management of supply chain network risk was also described by Trkman and McCormack (2009), who took both internal and external environmental factors into account. Quantitative approaches were also introduced. Lockamy III (2014) modeled a disaster risk profile using Bayesian networks, which clarified that the supplier disaster risks were a key element of external risk in supply chains. More recently, Revilla and Saenz (2017) have developed a single configurational model to analyze how companies manage supply chain risks. Based on a broader scope of the samples, the empirical findings showed a high level of generalizability of the implications.

The efficacy of these models was assessed using a variety of methodologies. Using the fuzzy Delphi method and the analytical network process to develop and to evaluate service sustainability measures, Tseng *et al.* (2018a) demonstrated that environmental service operation design was the most significant aspect of measures. Zubayer *et al.* (2019) also proposed a model based on a fuzzy technique for evaluating supply chain risks and identified three major risks in the ceramic sector in Bangladesh. Along with fuzzy techniques, another major analytical technique has been the AHP. Schoenherr *et al.* (2008) used the AHP to deal with risk factors, by which the best offshoring decision for a manufacturing company was determined. More recently, Moktadir *et al.* (2018) have applied the AHP in identifying and analyzing risks in the pharmaceutical supply chain. Parallel with the application of these mathematical techniques, we find case analysis to be another mainstream methodology for

verifying models. Of note is the comparative case study by Yu *et al.* (2018). Their work focused on the consistency between objective and perceived environmental uncertainties and how the relationship affected supply chain flexibility was then distinguished. These models and methodologies have contributed to the development of supply chain management. However, as Liu and Lee (2019) suggested, empirical analyses that quantitatively incorporate risk perception remain to be explored.

2.2 Uncertainties in supply chains

Uncertainty factors in supply chain management have received wide attention by researchers and practitioners. Cavinato (2004) categorized risks and uncertainties in supply chains into five categories: physical, financial, informational, relational and innovational. Based on the exhaustive work on supply chain quality risk management (Tse, 2012), Tse *et al.* (2016) conceptualized uncertainties as three exogenous factors within supply chain environments – demand, quality and logistics uncertainties – and discussed the relationship between overall disruption risk and both the magnitude and probability of disruption risk.

Demand uncertainty occurs when companies are unable to accurately predict consumer behavior associated with the predictability of demand, which can negatively affect the accuracy of demand forecasting and thus increase supply disruption risk. Therefore, ways by which retailers might mitigate the effect of uncertainty on overall profit have been considered (Chen and Yano, 2010). Recently, yield and demand uncertainty risk has been analyzed by Ye *et al.* (2018) based on a risk-sharing model, showing how to improve bioethanol supply chain resiliency and performance.

Another factor that causes supply disruption is quality uncertainty. Tse (2012, p. 25) defined quality risk as "inherent quality uncertainty of raw materials/ingredients/production/logistics/packaging in any of the supply members triggers a cascading effect that spreads through a multi-tier supply network." Quality uncertainty is therefore an area of great concern for many organizations. Tse and Tan (2012) discussed product quality risk using a marginal incremental analysis approach, claiming that low levels of product quality could result in product recalls which led to a disruption in the normal flow of goods. Tse *et al.* (2018) have also discussed a firm's quality performance in supply chains based on agency theory and showed that risk and reward sharing have a positive effect on quality performance.

One additional uncertainty should be noted under rapid globalization: logistics uncertainty. In terms of Cavinato's (2004) categories, the physical chains represent traditionally viewed logistics, in the form of transportation, warehousing, handling, processing, manufacturing and other forms of utility activities. Logistics risk has recently been investigated by Kwak *et al.* (2018) based on a dynamic supply chain logistics risk analysis model, which identified that practitioners' perception of risk consisted of four interconnected risks. Wang (2018) has also addressed the impacts of supply chain uncertainty and risk on logistics performance in the courier industry in Australia. These uncertainties in supply chain management have recently been addressed using the framework of fuzzy techniques (e.g. Tseng *et al.*, 2018a, b; Zubayer *et al.*, 2019). These contributions have had a significant impact on the research of supply chain management. Nonetheless, testing the generalizability of findings in this research area needs to be explored further.

3. Research design

In this section, we first outline the original conceptual model of supply disruption risk (Tse *et al.*, 2016) on which this paper is based. A refined model of supply disruption

risk is then proposed that considers the risk perception of uncertainties within supply chains. The model focuses on differences in risk perception given different business backgrounds. How to collect information about managers' subjective risk perceptions is also introduced.

3.1 The original model of supply disruption risk

Tse *et al.* (2016, p. 33) focused on the Thai beverage industries and explored the relationship between uncertainties within supply chains and representations of supply disruption risk. Figure 1 illustrates the original conceptual model of supply disruption risk proposed in the study.

Based on the structural model, eight hypotheses shown in Figure 1 were tested. They were the three uncertainties that are positively associated with magnitude (H1, H3 and H5) and probability (H2, H4 and H6) of disruption risk and the two representations of disruption risk that are positively associated with the overall disruption risk (H7 and H8). In the analysis, the confirmatory factor analysis (CFA) was initially conducted to test the measurement model for supply disruption risk. The structural equation modeling (SEM) was then used to test the hypothesized relationships in the structural model. The relationship between the risk perception of the uncertainties and the overall disruption risk of supply chain was analyzed using SEM.

Of the eight hypotheses, five (H1, H3, H6, H7 and H8) were supported. The relationship for four (H1, H6, H7 and H8) of the five hypotheses was positive. Only one (H3) of the five supported hypotheses was found to be significant but negative, which is one of the interesting results obtained from the work. Since research on supply chain management under rapidly developing economies has received limited attention (Behara *et al.*, 2014), the focus on the Thai beverage industry in the study provided an appropriate exploration of supply chain management. On the other hand, given that national culture impacts the effectiveness of supply chain practice (Kristal *et al.*, 2011), testing the generalizability of findings given different business backgrounds needs to be explored. This paper thus focuses on Japanese beverage companies that run their business in both Japan and Thailand. The comparative case study in this paper clarifies differences in perception given diverse business backgrounds.

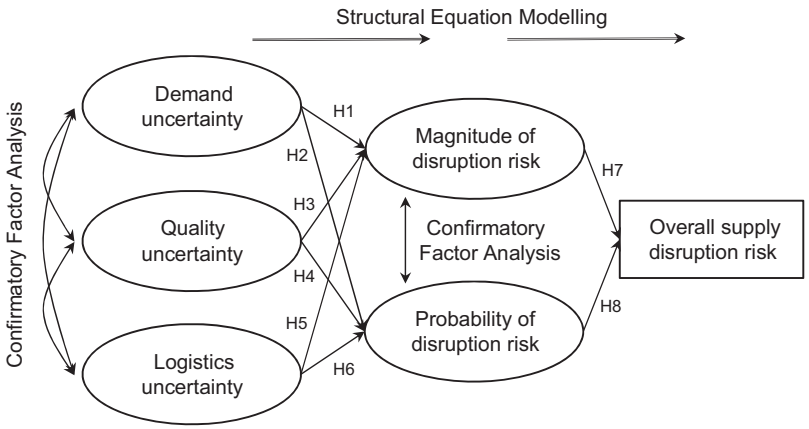

Figure 1. The original conceptual model of supply disruption risk (Tse *et al.*, 2016)

3.2 A refined model of supply disruption risk

Developing a precise supply disruption model is, by nature, challenging. One of the most difficult aspects in investigating supply disruption is how to deal with the subjective risk perception of uncertainties within supply chains. This paper thus focuses on clarifying managers' risk perceptions and investigates how the perception would affect supply chain strategies based on our original model (Tse *et al.*, 2016). The efficacy of the model that has been confirmed by both the CFA and the SEM would provide a solid foundation to the model proposed in this paper. In addition to the foundation in developing a model, to quantitatively address managers' subjective perceptions, the AHP is used in this paper. The AHP is a measure of human perception proposed by Saaty (1980), originally developed for supporting complex decision-making. Because the AHP can accurately quantify weights of criteria and alternatives (Sato, 2009), it has been applied extensively to a wide variety of decision-making cases. Here, we apply the technique in quantifying risk perception.

Based on the previous study (Tse *et al.*, 2016), we consider three environmental uncertainties within supply chains: demand, quality and logistics uncertainties. In addition, two representations, magnitude and probability, of disruption risk to the overall supply disruption are assumed. Figure 2 illustrates the refined model of supply disruption risk. In order for managers to establish effective and responsive supply chain strategies, incorporating their risk perceptions into the model is essential. By applying the AHP to the model, we clarify how managers perceive the relationship between disruption risk and uncertainties within supply chains. Furthermore, we verify the effectiveness of the proposed model by comparing our original model and the refined model that takes managers' subjective perceptions into consideration.

3.3 Collection of information of practitioner's perception of disruption risk

In model analyses, managers' risk perceptions of uncertainties are crucial. To incorporate the perceptions into the analysis, we interviewed managers of beverage companies in the case study, all of whom run their business in both Japan and Thailand. In the interviews, two managers per company were targeted: one managed the Japanese market and the other managed the Thai market. In this paper, managers' risk perceptions are assumed to be represented upon both the uncertainties within supply chains and the representations of

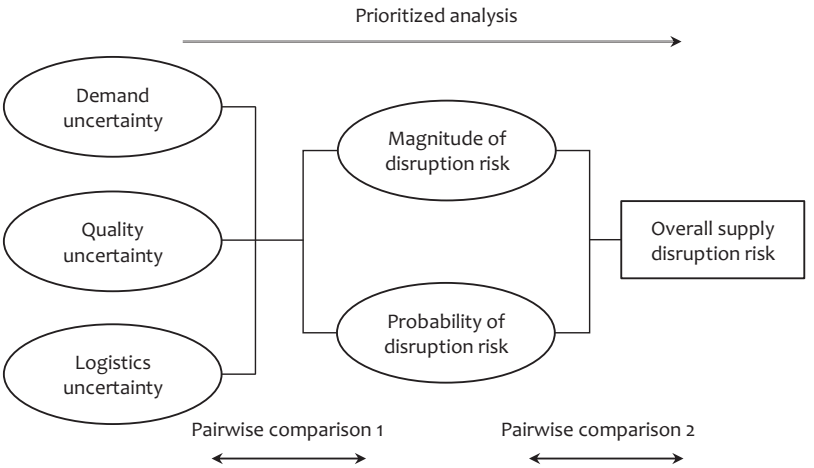

Figure 2.
The refined conceptual model of supply disruption risk

disruption risk. Since managers' risk perceptions are subjective, collecting the information needs to be similar in interviews using the AHP (e.g. Tsai *et al.*, 2008; Sato *et al.*, 2015), the managers were required to conduct pairwise comparisons (PCs) as follows: "if you pairwisely compare uncertainties within supply chain, which uncertainty do you perceive more significant to the magnitude of disruption risk for your company, demand uncertainty or quality uncertainty?" Through the interviews, we quantify managers' subjective risk perceptions of uncertainties within supply chains.

4. The model analysis

This section first outlines a case study with which we verify the proposed model of supply disruption risk. The results of the case study are addressed from two perspectives: the trend of risk perception and the individual feature of risk perception within beverage companies.

4.1 Outline of a case study

As of the end of 2017, there were 109 beverage companies in Japan whose sales ranged from small to large (EDINET, 2018). 13 out of the 109 companies sold more than $100M in fiscal year 2017, so-called major companies. Among the 13 majors, seven companies running their business in both Japan and Thailand are employed in a case study. The number of companies in the case is not large. Nevertheless, the sample in the case covers all companies necessary for clarifying differences in risk perception given different business backgrounds. The companies in the case study thus allow us to conduct ideal comparative studies in this paper. Given confidentiality agreements in the case study, none of the names of the companies can be disclosed; outlines of the companies are summarized in Appendix 1.

4.2 Results of the case study

In this section, we first show the trend of risk perceptions of the uncertainties. The analyses are based on aggregated data that take the average of responses from seven companies. The results illustrate how managers perceive uncertainties within their supply chains in both Japan and Thailand, which clarify differences in perception given different business backgrounds. We then show the individual features of each company's risk perception. Based on individual responses from the companies, both differences in risk perception within a company and those among the companies are clarified. Each company's characteristics, such as its size of business, profitability and stability, are clarified in the analyses.

4.2.1 Trend of risk perception of beverage companies. The first step of the analyses is to verify the relationship between risk perceptions of the three uncertainties within supply chains and the representations of disruption risk (Pairwise comparison 1, in Figure 2). Based on the proposed model, managers were required to assess risk perceptions from the point of view of the significance of uncertainties to the representations of disruption risk. The second step of the analyses is to evaluate the managers' perceptions of the representations of disruption risk to the overall disruption risk (Pairwise comparison 2, in Figure 2). Each manager of the seven beverage companies responsible for the Japanese division assessed the uncertainties in the Japanese market. In the assessment, each manager evaluated the degree of importance of uncertainties to the representations of disruption risk. The geometric mean a_{ij} (i, j: demand, quality and logistics uncertainties) calculated based on seven PCs a^k_{ij} ($k = 1, 2, \ldots, 7$) generates an element of a PC-matrix. The evaluations were carried similarly for the Thai market. Another manager responsible for the Thai market assessed uncertainties, whose outputs are denoted with b, that is, b_{ij} and b^k_{ij}. When using the AHP, the consistency index (CI) of a PC-matrix must be checked. The CI is defined as the ratio of inconsistent PCs included in a PC-matrix (Saaty, 1980), which equals 0 if and only if a PC-matrix is perfectly

consistent. The more inconsistent PCs are included in a matrix, the larger the CI would be. The tolerable threshold of the CI is considered to be 0.1. Leaving out the details here, the CIs of PC-matrices in the case study range from 0.00858 to 0.0928, which are smaller than the threshold.

Tables 1 and 2 respectively summarize the results of the quantified risk perceptions in the Japanese (in Roman) and Thai markets (in italics). The results represent differences in risk perception of the uncertainties between the two countries. As shown in the overall disruption risk in Table 1, the seven managers of the Japanese market emphasize the degree of importance of demand uncertainty as the highest (0.491), that of logistics uncertainty as second (0.343) and that of quality uncertainty as the lowest (0.165) in their business in Japan. On the other hand, as shown in Table 2, the other seven managers of the Thai market emphasize the degree of importance of logistics uncertainty as the highest (*0.354*), that of quality uncertainty as second (*0.334*) and that of demand uncertainty as the lowest (*0.312*) in their business in Thailand. These degrees of importance represent managers' risk perceptions of the uncertainties. These managers' risk perceptions need to be applied to their supply chain strategies to avoid supply disruption. The results obtained from the comparative studies can be interpreted as follows. Since product quality and the logistics network are stable in Japan, the degree of importance of demand uncertainty is much more emphasized than the other uncertainties. On the other hand, since the logistics network is somewhat vulnerable in Thailand, the importance of logistics uncertainty is assessed to be relatively high. The 2011 floods in Thailand might have possibly influenced this result.

Here we verify the Thai results by comparing those obtained from the previous study (Tse *et al.*, 2016) which examined environmental factors and verified managers' risk perceptions in Thailand. As summarized in Section 3.1, of the eight hypotheses, five (H1, H3, H6, H7 and H8) were supported in the study. The results showed that the structural link between demand uncertainty and the magnitude of disruption risk (H1) was positive and significant, and that of logistics uncertainty and the probability of risk (H6) was also positive and significant. These findings suggest that demand and logistics uncertainties affect the perceived impact of supply chain disruption, which coincide with the results in this paper of the case of the Thai market (see Table 2). That is, the degree of importance of demand uncertainty to the magnitude of risk (corresponding to H1) is the highest (*0.395*) and that of logistics uncertainty to probability of risk (corresponding to H6) is also the highest (*0.407*). In addition, Tse *et al.* (2016) indicated that both structural links associated with the overall disruption risk were positive and significant, where the significance of the link between the probability of risk (H8)

Table 1. Risk perception of the uncertainties (Japan)

Uncertainties	Magnitude of risk 0.5918	Probability of risk 0.4082	Overall disruption risk
Demand	0.4788	0.5094	0.4913
Quality	0.1754	0.1510	0.1654
Logistics	0.3458	0.3396	0.3433

Table 2. Risk perception of the uncertainties (Thailand)

Uncertainties	Magnitude of risk *0.3506*	Probability of risk *0.6494*	Overall disruption risk
Demand	*0.3947*	*0.2665*	*0.3115*
Quality	*0.3488*	*0.3263*	*0.3342*
Logistics	*0.2565*	*0.4071*	*0.3543*

is greater than that between the magnitude of risk (H7). The difference also coincides with the results obtained from this paper. That is, the degree of importance of the probability of risk to the overall disruption risk (corresponding to H8: *0.649*) is larger than that of the magnitude of risk (corresponding to H7: *0.351*).

Figure 3 overlays the results shown in Tables 1 and 2 on to the original conceptual model. In the figure, solid lines represent the supported hypotheses and dashed lines indicate the not-supported hypotheses in the study. Numbers alongside each line denote the set of degrees of importance in Japan (in roman) and in Thailand (in italics). As shown in the figure, the degrees of importance of demand uncertainty to the probability of risk (corresponding to H2: *0.267*), quality uncertainty to the probability of risk (corresponding to H4: *0.326*), logistics uncertainty to the magnitude of risk (corresponding to H5: *0.257*) are lower than those of the other relationships. Contrary to the supported hypotheses (H1, H3, H6, H7 and H8) shown in solid lines, numbers along with dashed lines in the figure are relatively small. To sum up, Figure 3 shows that the results of the Thai market in this paper are broadly consistent with the results of Tse *et al.* (2016).

4.2.2 Individual feature of risk perception of beverage companies. In this section, we analyze individual feature of the beverage companies. Based on the responses from the seven companies, a^k_{ij} and b^k_{ij}, each company's risk perception of the uncertainties within supply chains is clarified. Leaving out the details here, the CI of every PC-matrix is sufficiently small. Table 3 summarizes the degree of importance of the uncertainties to the overall disruption risk.

As shown in Table 3, managers' risk perceptions vary among the seven companies. In addition, the most significant uncertainties to the overall disruption risk sometimes differ between the Japanese and Thai markets within a company. For example, in Japan, the manager of Company 1 primarily emphasizes the importance of demand uncertainty (0.399), while the manager of Company 2 considers quality uncertainty (0.587) as the most significant factor to the overall disruption risk. This shows the differences in emphasis among companies. In contrast, another manager responsible for the Thai division in Company 1 primarily emphasizes the importance of logistics uncertainty (*0.572*), which differs from the emphasis of the manager in the same company managing the Japanese market. These results show that managers' risk perceptions vary depending on the features of companies and those of the markets they manage.

In order to clarify differences in risk perception of the beverage companies in detail, we next conduct the principal component analysis (PCA). We characterize each company based on seven typical properties that outline beverage companies shown in Appendix 1. As shown in Appendix 2, correlation coefficients among ordinary income, net income and net assets are greater than 0.95; we thus employ net income as a representative of these three properties in the analyses that follow. Based on the five properties apart from ordinary income and net assets, we elicit the principal properties of the beverage companies using the PCA. The extracted principal components from the properties characterize each company on scatter diagrams. The distributions of the companies based on the principal components illustrate each company's risk perception of uncertainties within its supply chain.

In the PCA, we employ the results of PCs carried out by the managers, that is, two sets of seven eigenvectors. Table 4 summarizes the results of the PCA. As shown in the table, the cumulative proportion of the top three components reaches 90.8%; these three components, C_m ($m = 1, \ldots, 3$), are thus employed in characterizing the companies. Table 5 shows the component score of each property. As shown in the table, each component has the following characteristics. Component 1 (C_1) is significantly positive on net income and profit ratio, neutral with equity ratio; Component 2 (C_2) is significantly positive on sales and number of employees, neutral with profit ratio; Component 3 (C_3) is significantly positive on equity ratio. This paper, therefore, defines each component as C_1: profitability, C_2: size and C_3: stability, of

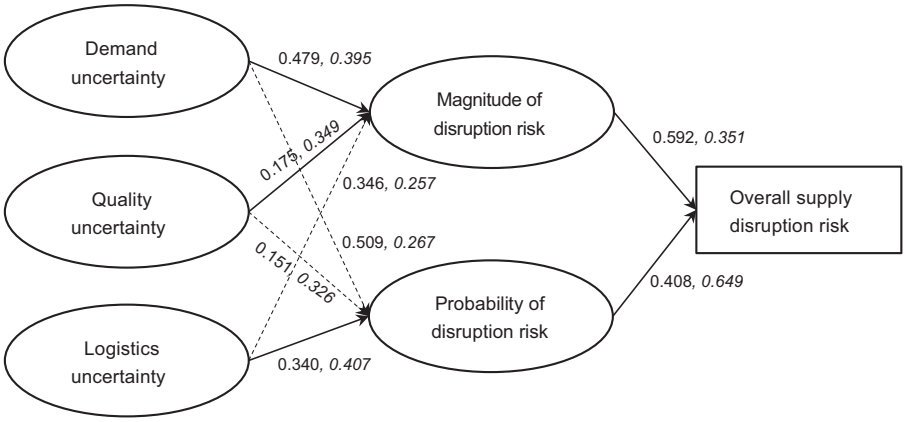

Figure 3.
The results of the prioritized analysis

a company. Table 6 summarizes the principal component loading of each Company k ($k = 1, \ldots, 7$).

Based on Table 6, Figures 4 and 5 respectively illustrate the distributions of the seven beverage companies plotted on C_1C_2-plane and C_1C_3-plane. In the diagrams, each marker represents a beverage Company k ($k = 1, \ldots, 7$), which is made up of a set of two letters. The left (right) letter in bold (in italic) of a maker represents the most significant uncertainties to the overall disruption risk in Japan (Thailand) for a company. The letters denote: "D" for demand uncertainty, "Q" for quality uncertainty and "L" for logistics uncertainty.

4.2.2.1 Analysis on C_1C_2-plane. If we look at the case of Japan, the beverage companies marked "**D**" ($k = 4, 7$) are plotted in the third quadrant in Figure 4. This result shows that small to medium-sized companies with relatively low profitability consider that the perturbation of demand in market would seriously affect their supply chain. On the other hand, the profitability of the companies marked "**Q**" ($k = 1, 5, 6$) is higher than that of other companies. This means that relatively profitable companies give greater importance to the quality of their products. The companies marked "**L**" ($k = 2, 3$) distribute in the second quadrant, which suggests that large companies with rather low profitability emphasize the importance of their logistics network stability.

In the Thai market, the companies marked "*L*" ($k = 2, 3, 4, 7$) are plotted in the second and third quadrants. This result shows that companies with rather low profitability consider that they need to develop a robust logistics network regardless of the size of the company. The companies marked "*Q*" ($k = 5, 6$) are rather small companies with moderate profitability, which means that such companies place greater importance on the quality of their products. In contrast, Company 1 is the only company marked "*D*" in Figure 4, which is relatively large and the most profitable company. This result suggests that the company may have already developed a robust supply chain network and may have confidence in the quality of its products. The remaining concern in business in Thailand is thus the perturbation of the demand in market. As a dominant beverage company in Thailand, Company 1 might be concerned about competition gaining market share, which results in "*D*" being the most significant factor to the overall disruption risk.

4.2.2.2 Analysis on C_1C_3-plane. Japanese case data in Figure 5 show that the degree of stability of a company may affect the risk perception of the beverage companies. The companies marked "**L**" ($k = 2, 3$) show high stability, while the companies with moderate stability ($k = 4, 7$) perceive "**D**" as the most important factor. In contrast, the stability of the

companies marked "**Q**" ($k = 1, 5, 6$) is low. These results can be interpreted as follows. Stable companies give greater importance to develop a robust logistics network, while companies with moderate stability consider that the perturbation of demand in market would seriously affect their supply chain. In contrast, unstable companies emphasize the importance of their product's quality.

The case of the Thai market is similar to that of the Japanese market in that the degree of stability of a company features risk perceptions of the companies. The stability of the companies marked "*L*" ($k = 2, 3, 4, 7$) range from moderate to high; the companies with low

Company (k) \ Uncertainties	Demand	Japan Quality	Logistics	Demand	Thailand Quality	Logistics
1	0.3989	0.3194	0.2817	*0.2785*	*0.1491*	*0.5724*
2	0.3274	0.5870	0.0856	*0.2116*	*0.1547*	*0.6337*
3	0.3684	0.3711	0.2605	*0.3208*	*0.5861*	*0.0931*
4	0.3657	0.0744	0.5599	*0.2995*	*0.1748*	*0.5257*
5	0.5861	0.0642	0.3497	*0.4038*	*0.2395*	*0.3567*
6	0.6515	0.0624	0.2861	*0.4314*	*0.3795*	*0.1891*
7	0.1389	0.5672	0.2939	*0.1889*	*0.3327*	*0.4784*

Table 3. Risk perception of the uncertainties to overall disruption risk

	Initial eigenvalue			Extracted sum of squares of loadings		
Component	Sum	Proportion	Cumulative proportion	Sum	Proportion	Cumulative proportion
1	1.8829	37.6588	37.66	1.7731	37.6588	37.6588
2	1.4456	28.9123	66.57	1.4137	28.9123	66.5711
3	1.2099	24.1990	90.77	1.3349	24.1990	90.7701
4	0.3657	7.3131	98.08			
5	0.0957	1.9145	100.00			

Table 4. Results of the principal component analysis

Component	Sales	Net income	Profit ratio	Equity ratio	Employees
1	0.2035	0.8163	0.7330	0.07351	−0.3659
2	0.9024	0.09887	−0.03393	−0.1255	0.7969
3	−0.2106	−0.1314	0.3536	0.8417	0.5357

Table 5. Component scores

Company (k)	Profitability	Size	Stability
1	0.98182	0.45914	−0.89625
2	−0.12819	0.93118	0.49152
3	−0.64008	0.22036	0.78254
4	−0.23509	−0.10330	0.22986
5	0.41357	−0.22118	−0.50730
6	−0.01602	−0.67598	−0.27109
7	−0.37601	−0.61022	0.17071

Table 6. Principal component loading of companies

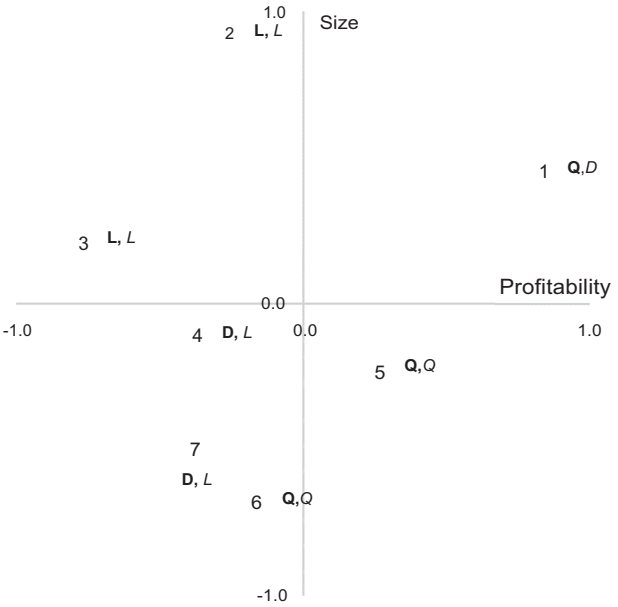

Figure 4.
Distribution on C_1C_2-plane

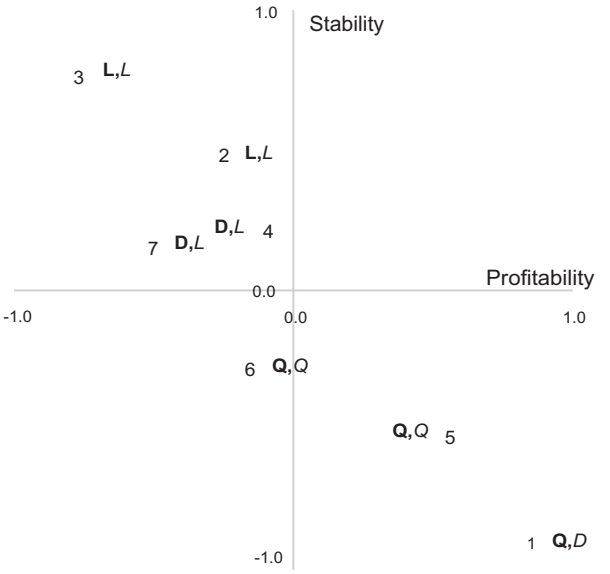

Figure 5.
Distribution on C_1C_3-plane

stability (k = 5, 6) consider "Q" as the most important uncertainty factor. In contrast, Company 1 is again the only company marked "D" in Figure 5, whose stability is the lowest and whose profitability is the highest among the seven companies. This result may imply that the perturbation of demand significantly affects its supply chain due to its low stability.

5. Managerial implications for supply chain management

In this section, we clarify managerial implications for supply chain management based on inferences drawn from the analyses in Section 4. The contributions to both academic and practical fields are shown with practical insight and theoretical backgrounds of this paper. The following three implications are gained from the analyses.

(1) The quantification of managers' risk perceptions enables practitioners to deal with subjective information in quantitative form.

(2) Comparative studies between Japan and Thailand clarify differences in perception given different business backgrounds.

(3) The proposed model provides managers with in-depth insights into establishing supply chain strategies to which their risk perceptions are applied.

Tables 1 and 2 clarify the trends of risk perception of beverage companies given different business backgrounds. The differences in the degree of importance of the uncertainties shown in the tables illustrate the trend of risk perception of the beverage companies. The results suggest how supply chain strategies should be adjusted when the risk perception of uncertainties varies. Specifically, Table 1 (Japanese market) indicates that companies emphasize the importance of addressing demand uncertainty to avoid supply disruption. This trend might be robust since managers' risk perceptions of demand uncertainty are predominant in light of both the magnitude and the probability of disruption risk (0.479 and 0.509, respectively). On the other hand, Table 2 (Thai market) shows that companies focus on developing a sustainable logistics network to reduce the risk of supply disruption. This trend, however, may vary with little changes in business environments. Indeed, the degrees of importance of the uncertainties range from *0.312* to *0.354*, which is quite small. The managers judge demand to be the most important uncertainty factor from the viewpoint of the magnitude of disruption risk (*0.395*), while logistics uncertainty is the most significant (*0.407*) in light of the probability of disruption risk. This result thus suggests that managers' decisions regarding supply chain management would likely vary in accordance with exogenous changes, such as natural disasters.

In addition to the trend of beverage companies, Table 3 summarizes individual features of risk perception of the beverage companies. The results show that managers' risk perceptions vary not only among companies but also between managing divisions within a company. Column-wise comparison in the table clarifies the differences in risk perception of the uncertainties among the companies ($k = 1, \ldots, 7$) and row-wise comparison shows those between the markets (Japan and Thailand). For example, Company 1 is one of the biggest beverage companies in Japan, which sold more than $10B in 2017 fiscal year. The company started its business in the liquor market and had focused on liquor traffic in Japan. The market, however, has been shrinking due to the recent social trend of health consciousness, making it necessary for the company to pursue market developments over the last several years. The change in the market can be considered one of the reasons why the manager of the company in Japan primarily emphasizes the importance of demand uncertainty (0.399). In contrast, the company's two subsidiaries in Thailand had each expanded into healthy food products and refreshing beverages. Despite this, the company was immensely damaged by the 2011 floods in Thailand, in which its supply chain was severely damaged. This experience might be one of the reasons that the company focuses on logistics uncertainty (*0.572*). Thus, the table suggests how each company and each division of a company should address its supply chain strategy when the risk perception of the uncertainties changes.

The quantification of managers' risk perceptions further provides practitioners with managerial implications. As summarized in Tables 4 and 5, the proposed model allows us to

conduct the PCA, which characterizes the beverage companies. The emphasis of each company is clarified (Table 6) as illustrated in Figures 4 and 5. These results enable managers to gain in-depth insights into the evaluation of the sustainability of supply chains. As a result, the proposed model can provide managers with a framework for considering the impact of uncertainties within supply chains. This paper thus contributes to establishing an effective and responsive supply chain strategy for beverage companies that engage in business given diverse business backgrounds. Based on the retrospective interviews with the managers (14 personnel in total) of the beverage companies, the proposed model of supply disruption risk might help them with their future supply chain management. In the interview, we asked them how well our model would contribute to refining their strategies. Table 7 summarizes the results of the interview, by which we can confirm the applicability of the proposed approach in this paper.

6. Concluding remarks and future research

This study extended the previous conceptual model of supply chain risk (Tse *et al.*, 2016) to a quantitative model, in which the relative significance of managers' risk perceptions was clarified. The results enable academics and practitioners to deal with subjective risk perception in quantitative form. In addition to the expansion of the previous model, the comparative case study carried out in the analysis sheds light on cross-sectional differences given different business backgrounds. That is, the generalizability of the findings was verified in the analysis. Since this research focused on the quantification of risk perception, companies' emphases on the uncertainties within supply chains were characterized by the PCA. Through the visualization of the emphases, the results could provide more transparent and solid insights into establishing supply chain strategies than could the extant approach. In addition to these developments, the practical applicability of this study was confirmed through the retrospective interview.

Nonetheless, the proposed approach has some limitations. As introduced in Section 3.1, the significant and negative relationship between quality uncertainty and magnitude of disruption risk (H3) is one of the interesting results obtained from the previous study. This result, however, cannot be verified with the proposed model since the AHP quantifies only the relative importance among risk perceptions. How to represent absolute importance in the results needs to be explored further. Another issue that needs to be addressed is an information technology-related exploration of this research area. Colicchia *et al.* (2019) have recently suggested that a lack of cyber and information risk in management is crucial. Also, limited attention has been received in the relationship between big data analysis and the sustainability of supply chain management (Shokouhyar, *et al.*, 2020). These up-to-date issues need be explored in future research. Finally, an important limitation of this paper is the lack of verification of the relationship between risk perception and the actual behavior of a company based on rational models. Drawing from the results of this paper, managers' risk perceptions of the uncertainties would affect establishing strategies for supply chain management, though this paper has not verified their actual behavior. We need to follow up with interviews over the long-term to determine how the strategies of the companies participating in this study vary in accordance with changes in risk perception.

Table 7. Responses from mangers ($N = 14$)

Division	S. agree	Agree	Neutral	Disagree	S. disagree	N/A
Japan	28.6%	42.9%	14.3%	14.3%	0%	0%
Thailand	42.9%	28.6%	14.3%	0%	0%	14.3%

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Appendix 1

Company (k)	Sales	Ord. Income	Net income	Net assets	Profit ratio	Equity ratio	Employees
1	$$$	$$$	$$$	$$$	H	L	x
2	$$	$$	$$	$$	M	H	xx
3	$$	$	$	$	L	M	xxx
4	$$	$$	$$	$$	H	M	xx
5	$$	$$$	$$$	$$$	H	L	x
6	$	$	$	$	L	L	x
7	$	$	$	$	M	M	xx
Legend	>$10B: $$$	>$1B: $$$	>$1B: $$$	>$10B: $$$	>5%: H	>60%: H	>5000: xxx
	$3B–$10B: $$	$200M–$1B: $$	$200M–$1B: $$	$3B–$10B: $$	3–5%: M	40–60%: M	1000–5000: xx
	<$3B: $	<$200M: $	<$200M: $	<$3B: $	<3%: L	<40%: L	<1000: x

Table A1. Outline of beverage companies

Appendix 2

Table A2. Correlation among properties of beverage companies

Correlation	Sales	Ord. Income	Net income	Net assets	Profit ratio	Equity ratio	Employees
Sales	1						
Ordinary income	0.50067	1					
Net income	0.59676	0.97701	1				
Net assets	0.71073	0.95005	0.95652	1			
Profit ratio	0.16801	0.58619	0.55665	0.50443	1		
Equity ratio	0.04597	−0.49975	−0.55145	−0.34115	−0.10223	1	
Employees	−0.10370	−0.46208	−0.46503	−0.52019	−0.15001	0.34085	1