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Perception of Supply Chain Quality Risk:

Understanding the Moderation Role of Supply Market Thinness

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1. Introduction

The large-scale recall of Samsung Electronic Co.'s Galaxy Note 7 smartphone has put a spotlight on quality control of electronics production. The recall of Note 7 smartphone is also raising questions about the ability of today's electronics company managing product quality in a complex supply network. Not only the mobile phone, but an increase in the number of product recalls reveals that manufacturing firms are particularly vulnerable in terms of product quality and safety where goods and materials have been sourced globally; in other words, they incur supply chain quality risk (SCQR). There are three main reasons behind these global product quality problems, namely increased global production, product complexity and customer demand for product quality and safety (Chen et al., 2009). Marucheck et al. (2011) suggest that the rise in the number of product recalls might be due both to changes in global production systems and to the increasing complexity of supply chains. Moreover, the global supply chain has been elongated, leading to increased uncertainty and managerial quality considerations regarding the final products (Huo et al., 2014). The high level of supply chain complexity can be associated with factors such as a wide variety of products, fluctuating demand and production in small batches (Gimenez et al., 2012).

Supply chain risk management (SCRM) has attracted great interest in Operations Management (OM) over the past decades, and the majority of research have focused on supply chain disruption (Baiman et al., 2000; Tomlin, 2006; Yang et al., 2009). However, the research gap relative to the managerial action to minimise the negative impact of production quality risk still remain (Bruccoleri et al., 2019), which reveals that managers and researchers have not been provided with sufficient guidance on the nature of SCQR or on how to establish appropriate risk management practices. Thus, there is a dearth of research that explore the ways to improve supply chain quality management (SCQM) in order to reduce SCQR (Viaene and Verbeke, 1998; Theodorakioglou et al., 2006; Zu and Kaynak, 2012; Huo et al., 2014; Zeng et al., 2018). To gain further understanding of the nature of SCQR, we consolidate the existing literature to conceptualize and operationalize the uncertainty factors that might impact managers' perceptions of the probability and magnitude of quality risk. The impact of uncertainty factors on managers' perception of risk has been studied by Ellis et al (2010) with the focus on supply disruption risk, while we aim to offer new insight by scrutinizing the mechanism between the uncertainty factors and perception of SCQR.

In this study, through the lens of agency theory, we investigated four uncertainty factors that might be associated with the SCQR perception. Specifically, these factors comprise technology uncertainty, testability uncertainty, traceability uncertainty and product complexity. In contrast to the research on designing and validating a set of detailed "agency-based" practices, the researchers have viewed the roots of agency problems in a more generic way. By selecting four agency-based constructs that reflecting the information asymmetry issues in a buyer-supplier relationship, this study advances the application of the agency theory in the field of business-to-business relationship research. According to Crumbly and Carter (2015), testability and product complexity are the critical challenges in SCQM. In addition, traceability and technology are seen as the key instruments in SCQM (Viaene and Verbeke, 1998; Tse et al., 2019). These concepts are highly relevant to the context of agency theory. They are essentially used to measure the level of information asymmetry between buyer and supplier regarding the supply chain quality. The testability uncertainty and product complexity focus on the uncertainties raised in the final product, while the traceability uncertainty and technology uncertainty focus on the uncertainties raised in the supply process.

Drawing from resource dependency theory (RDT), we adopt supply market thinness (SMT) as a moderator to further examine the relationships between the uncertainty factors and SCQR. SMT is represented by the degree of supplier monopoly within the supply materials market (Cannon and Perreault, 1999; Ellis et al., 2010). According to Carr et al. (2008), if buyers are highly dependent on a resource available from only a few suppliers or even a single supplier, those buyers might be more committed to the supply chain relationship. Ellis et al. (2010) suggest that high dependency on suppliers would result in greater uncertainty in the supply chain. However, Ketchen and Hult (2007) argue that interdependency between supplier and buyer might be helpful to establish a stable supply chain relationship and therefore help to manage the uncertainties in the supply chain. Given the inconsistent discussion of RDT in previous researches, investigation of the moderating role of SMT in the mechanism between the uncertainty factors and perception of SCQR can offer valuable insights for the development of RDT in OM research.

The objective of this research is to uncover the nature of the SCQR by answering the following questions: What are the uncertainty factors that drive risk, and affect managers' perceptions of SCQR? How does market thinness moderate the relationships between uncertainty factors and SCQR?

The paper is organised as follows. In sections 2 and 3, we introduce the theoretical background and develop the hypothesised model that establishes the relationships among the constructs. The research methodology, the analysis process and the testing of the hypotheses are described in sections 4 and 5. In section 6, we discuss the research findings and present conclusions. The managerial implications are provided in section 7. The concluding section discusses the limitations of this study and gives recommendations for future research.

2. Theoretical Background

2.1 Supply Chain Quality Risk (SCQR)

Risk is generally described as a situation which could lead to negative consequences, which have a certain level of probability of occurring. According to Dowling (1986), from the perspective of decision theorists: *'Risk is the situation where a decision maker has a priori knowledge of both the consequences of alternatives and their probabilities of occurrence.'* This definition explicitly draws out the fact that risk reflects both the range of possible outcomes and the distribution of respective probabilities for each of those outcomes.

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Both academics and company executives show a growing concerns about the risks of supply chain since year 2000, while the area is still developing and has undiscovered boundaries at this stage. Table 1 reports the recent studies of SCRM, with researchers have different domain expertise, diverse definition, research tools and methods have been used. In this study, we adopted the definition from the work of Tse et al (2019) that *"SCRM involves the preventive and reactive practices with the purpose of managing the potential quality risk in the upstream supply chain and lessening the negative impact of product recall in the downstream network"* because it exhibits the comprehensive understanding of the involved practice, purpose and impact of SCRM. Beside, most of the studies of SCRM are empirical and qualitative, while there are also model-based and review researches in literature. And the research focus varies from the strategies that enable supply chains to be more flexible to reduce the negative consequences of the occurrence of events associate with supply (Clemons and Slotnick., 2016), to the potential impact that firm can achieve by conducting SCRM effectively in supply chain

(Tse et al., 2019; Wiengarten et al., 2016). However, only a few studies have focus on how to design the efficient supply chains that can minimize the cost from product quality risk. This refers to the quality problems in the supply chain context, rather than in the manufacturing quality context. Proper quality risk management needs to consider both upstream, e.g. purchasing approach, and downstream, e.g. identifying potential crisis (Tse et al., 2018). Therefore, we can define SCQR by stating that 'Inherent quality uncertainty of raw materials in supply chain members triggers a cascading effect that spreads through a multi-tier supply network.'

SCQR can be viewed as a kind of product harm crisis which destroys a firm's favourable reputation, causes major revenue and market-share losses, leads to costly product recalls, and devastates a carefully nurtured brand equity (Van Heerde et al., 2007). Because of this, a growing number of researchers are looking into the impact of SCQR in the global supply chain. For example, Gray et al. (2011) investigate the SCQR in offshore manufacturing plants and find that plant location, geographic distance, and the skill level of workers could all affect SCQR. Hora et al. (2011) robustly examine the risk remedy practice in a case where SCQR triggered a destructive product recall in the toy industry. Their research investigates the relationships among different product recall strategies, time of recall, and defect type. However, the severity of quality and safety risks and their implications have not yet been fully explored in the operations management literature.

2.2 Uncertainty Factors in Managing Supply Chain Quality and Agency Theory

According to Luo (2007), external uncertainty is multidimensional, and represents '*the rate of change and the degree of instability of factors in an external environment*'. We observe four external uncertainty factors as the antecedents of SCQR appraisal (i.e. of magnitude and probability). Specifically, we investigate testability uncertainty, technology uncertainty, traceability uncertainty and product complexity. These factors are selected on the grounds that they can reflect the potential agency problem in the supply chain.

We employ agency theory to explain the mechanism between the uncertainty factors and SCQR. According to agency theory, there are two basic parties in an agency relationship, namely principal and agent, where the opportunistic practice of the agent is a result of principal-agent goal conflicts and information asymmetry (Eisenhardt and Tabrizi, 1995; Kim and Mahoney, 2005; Yan and Kull, 2015). Agency theory views the agent's opportunism as the outcome of the principal's incomplete information on the agent's behaviours and task performance (Eisenhardt and Tabrizi, 1995). Moreover, the theory assumes that principal and agent always aim to serve their self-interests. The interest difference between agent and principal would lead to their conflicting goals. Therefore, principal and agent should have different risk preferences and task responsibilities (Eisenhardt, 1989).

In the context of the supply chain, the supplier can be viewed as an agent while the buyer acts as the principal who delegates the authority of the component manufacturing or raw material purchasing to the supplier (Zu and Kaynak, 2012; Starbird, 2001; Zsidisin and Ellram, 2003). If the buyer has difficulty in investigating the behaviours of its suppliers, the agency problem might occur, since the buyer cannot effectively evaluate the performance of its agent (i.e. supplier) and the agent/supplier is able to exert a high or low level of effort in secret (Zu and Kaynak, 2012; Bhattacharya et al., 2013). Thus, managing the agency relationship is a critical problem in controlling the supply chain quality (Hanna and Jackson, 2015). According to Zu and Kaynak (2012), '*buyers expect suppliers to provide good quality and to improve the quality of supplied products and/or services, but suppliers may be reluctant to invest substantially in quality, especially if they perceive that buyers are reaping all the benefits*'. The uncertainties in quality management practices (such as sample testing or material source tracing) could increase the information asymmetry in the supply chain and the agent's opportunism (Tse et al., 2019). The agency problem thus raised in the supply chain could lead to SCQR. In this paper, our interest lies in understanding the perception of SCQR, and the uncertainty factors identified from the agency theory.

3. Model Development

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3.1 Technology Uncertainty

Technology uncertainty relates to '*the rate of change in underlying technologies of a purchased product*' (Ellis et al., 2010). The uncertainty of technology development creates certain unforeseeable threats (Bensaou and Anderson, 1999), such as inability to accurately predict the development of technologies and determine changes for products' standards or specifications (Yang and Zhao, 2016; Geyskens et al., 2006), as a result of which the firm may have difficulty in establishing a quality standard (Ellis et al., 2010). From an agency theory perspective, the uncertainties of technology might lead to supplier opportunism with regard to purchased material quality, due to the increased information asymmetry. For example, the supplier might have the latest information of technology knowledge, which the buyer firm might lack. The new technology adopted in the purchased materials may affect the production process of the buyer firm. To adapt to the new uncertainty, the buyer firm will require more information, such as cost structure and quality performance of the material. As such, the buyer firm may face both safeguarding and adaptation problems when deciding to purchase new technological materials. From the above argument, the following hypotheses are proposed:

H1a. The level of technology uncertainty is positively associated with the probability of SCQR.

H2a. The level of technology uncertainty is positively associated with the magnitude of SCQR.

3.2 Testability Uncertainty

According to agency theory, if it is difficult for the principal to assess the agent's effort, this is likely to lead to agency problems (Eisenhardt, 1989). In the supply chain context, agency problems arise if the potential quality problem cannot be detected by the buyers (Zu and Kaynak, 2012). According to Crumbly and Carter (2015), testability is one of the critical challenges in supply chain quality management. In this study, we define testability uncertainty as *'the difficulty for the buyers to accurately inspect the problems of supply materials'*. The accuracy of testing depends on the technical level of the quality assurance team, and on the availability of straightforward test procedures and testing facilities (Roth et al., 2008). Moreover, counterfeiting or substitution of lower grade components may be difficult to discover, as the appropriate test may be destructive to the product (e.g., long hours' reliability test). As long as a lower grade component does not affect the quality performance during the testing period, the defective product can pass along the supply chain easily. In this case, the testability uncertainty might lead to increased perception of SCQR. Hence, we propose the following hypotheses:

H1b. The level of testability uncertainty is positively associated with the probability of SCQR.

H2b. The level of testability uncertainty is positively associated with the magnitude of SCQR.

3.3 Traceability Uncertainty

Traceability uncertainty is defined as the '*degree of difficulty to trace the materials to the country of origin and then identify the source from the upstream supply chain'.* The level of traceability depends on the type of industry. For example, in a pharmaceutical supply chain, government legislation requires that there is unique product identification (Lawson, 2009). This unique product identification can provide information about the route of a product at the package level, and a good traceability system would provide critical information when a product recall is triggered (Marucheck et al., 2011). According to Viaene and Verbeke (1998), traceability is seen as a key instrument of the SCQM, as it improves product quality by ensuring that the product is being implemented based on stakeholder's requirements (Philip et al., 2017) However, the supply chain traceability is affected by the length and complexity of the supply network, and by extensive sub-contracting (Roth et al., 2008). The failure of buyers to clarify the responsibility for ensuring product quality (i.e., who should take the responsibility) could encourage opportunism on the part of upstream suppliers. The agency theory views the monitoring ability of the principal as an effective mechanism to tackle the information asymmetry and ensure the investment of the buyer in the supply chain relationship (Bergen et al., 1992). We argue that the traceability uncertainty in the supply chain would lead to agency issues if the opportunistic activities of suppliers could not be traced when supply chain quality problems are raised. Thus, we propose the following hypotheses:

H1c. The level of traceability uncertainty is positively associated with the probability of SCQR.

H2c. The level of traceability uncertainty is positively associated with the magnitude of SCQR.

3.4 Product Complexity

According to Novak and Eppinger (2001), product complexity is measured by three areas, namely the number of product components to specify and produce, the parts coupling, and the degree of product novelty. Even though product complexity has been linked to sales growth, there is still a trade-off between enhancing product complexity and increasing operational efficiency (Salvador et al, 2002; Dubey et al, 2017), it partially because product complexity is directly related to the difficulty of managing the supply chain and ensuring the product quality (Closs et al., 2008), and negative influence of product complexity on supply chain performance has been found from previous studies, for example, Inman and Blumenfeld (2014) claimed that the more complex the product, the more vulnerable the supply chain. If the suppliers offer unique and complex products or materials, buyers usually lack the production process knowledge to assess the supplier's performance (Zu and Kaynak, 2012). From the perspective of agency theory, higher level of product complexity might lead to greater opportunism on the part of suppliers, because of the asymmetric information between buyers and suppliers and the difficulty for the buyers to evaluate the performance of suppliers. Therefore, we hypothesise:

H1d. The level of product complexity is positively associated with the probability of SCQR.

H2d. The level of product complexity is positively associated with the magnitude of SCQR.

3.5 Moderation Role of Supply Market Thinness

In this study, SMT is investigated as the moderator in the relationships between uncertainty factors and SCQR. According to Cannon and Perreault (1999), SMT is defined as the '*the degree to which a buying firm has [a limited number of] alternative sources of supply to meet a need*'. If the supply markets are thin, the buyers are exposed to risks, which they attempt to counter. Ellis et al. (2010) find that market thinness is a significant predictor of both probability and magnitude of supply disruption risk. On the other hand, Dyer and Singh (1998) argue that with few suppliers available, buyers are more likely to establish a closer relationship with their supplier, in the hope of being better served (Bensaou and Anderson, 1999). However, while the existing literature considers the pros and cons of SMT, the discussion of SMT in a buyer-supplier relationship is neither sufficient nor consistent.

It can be argued that the impact of uncertainty factors on SCQR requires contingency arrangements to mitigate them. To understand the moderation role of SMT in the relationships between uncertainty factors and SCQR, consideration of resource dependency theory (RDT) is helpful. In supply chain context, if the supplier has much of the resources needed by the buyers or even a monopoly on the supply market, buyers may be more committed to the buyer-supplier relationship (Carr et al., 2008; Hsieh, 2013). The imbalance of power in buyer – supplier relationship, however, would trigger uncertainties in supply chain environment (Ellis et al., 2010). Handfield (1993) suggests that RDT is a useful theory to understand how firms can operate in their supply environments to reduce the supply uncertainty. Drawing on RDT, we posit that SMT can be used to measure the dependency of buyers upon suppliers. If buyers are more dependent on suppliers, we argue that the imbalance of power in the buyer-supplier relationship would strengthen the impact of some external uncertainty factors (such as technology uncertainty) on the buyer's perception of SCQR. Since the buyer becomes overly dependent on the supplier, the buyer may be exploited with regard to accessing the supplied product's quality standard and technology complexity. Also, the buyer firm may not be able to assess the supplier's quality assurance effort effectively, since the supplier might not share the quality information related to production in a relationship where such a power imbalance exists.

On the other hand, Ketchen and Hult (2007) critique the RDT argument that firms should not aim for independency in a buyer-supplier relationship. The dependency between buyer and supplier could help to establish a sustainable supply chain relationship. Furthermore, Provan and Skinner (1989) argue that as one party is less opportunistic when it is dependent on its supply chain partner, then if there are few upstream suppliers (i.e. high SMT), the difficulty of identifying potential quality issues will be decreased. As the other face of buyer dependency, how SMT influences the relationship between external uncertainties and SCQR is as yet unexplored. Thus, we hypothesise that SMT will moderate the relationships established in the theoretical framework in the following ways:

H3a, b, c, d: Market thinness moderates the relationship between (a) technology uncertainty, (b) testability uncertainty, (c) traceability uncertainty, (d) product complexity and the probability of SCQR.

H4a, b, c, d: Market thinness moderates the relationship between (a) technology uncertainty, (b) testability uncertainty, (c) traceability uncertainty, (d) product complexity and the magnitude of SCQR.

4. Methodology and Data Analysis

Risk perception is an abstract concept that cannot be simply captured from an individual opinion but needs to be observed in a more generalizable way. There are three points to prove the appropriateness for the adoption of quantitative research. First, to understand the mechanism of perceived SCQR, it is necessary to adopt a considerable size of the sample to validate the hypothesised model. Second, the ontology of the quantitative method, which is objectivism and focusing on the facts, fits with the research objectives. Third, a quantitative approach can test the hypotheses model holistically and identify some indirect effects using various statistical analysis techniques. In summary, to holistically investigate the managerial perception of SCQR, applying quantitative approach can benefit from using large-scale data to validate the hypotheses and generate the reliable results (Flynn et al., 1994).

4.1 Measurement and Data Collection

The unit of analysis of this study is the buyer-supplier transaction of an important material sourced from a specific key supplier. In order to adopt an appropriate set of measurement instruments, we have undertaken a comprehensive literature review to operationalise the constructs. Some of the question items are newly developed based upon the literature review and related theoretical foundations discussed in the previous section (such as the testability uncertainty and traceability uncertainty). More specifically, for the testability uncertainty, the indicators TES 1 and TES2 are related to the generic difficulty to inspect the quality issues from the supply sides, while TES3 are related to the cost of testing the supply materials/components. In addition, for the traceability uncertainty, TRU1 focuses on the issues related to the raw materials, while TRU3 focuses on the processed key components (i.e. the work-in-process materials). TRU2 and TRU4 are about tracing the information and responsibilities of the suppliers when the quality issues happened. In order to ensure the content validity, the questionnaire items have been reviewed by a panel board (comprising two academics and three practitioners). This study adopts a seven-point Likert scale to measure the extent of the agreement for each question item, where 1 = strongly disagree and 7 = strongly agree. As the research target of the study comprises Chinese managers, the original English questionnaire items were translated into Chinese. In order to ensure the accuracy of the translation, we used the back translation method proposed by Brislin (1980).

Our proposed model is tested using data collected from 202 purchasing managers in the Chinese electronics industry. The study context is selected due to its important position in the world electronics industry and its trend of growth. China's electronic industries started to growing explosively since early 1990s and became the world's the biggest exporter of electronic equipment after ten years (Zhao et al., 2007). Since joining the World Trade Organization (WTO) in 2001, many foreign enterprises that produce electronic products, e.g. mobile phone, PC, set up factories in China. The revenue from China's electronics industry increased significantly from 3883 billion RMB in 2006 to 6544 billion RMB in 2019 (National Bureau of Statistics of China, 2019). Previous researches in the electronics industry context have provided many valuable insights with regard to improving firm performance through supplier development activities and supply chain agility (Tse et al., 2016; Humphreys et al., 2011). Moreover, in 2012, out of a total of 1937 non-food product recalls in the EU, 1072 cases were of products manufactured in China, and about 26% of those Chinese manufactured recall products were electronics products (RAPEX, 2015). In the light of this, the use of Chinese electronics industry data to test the model could provide interesting insights on SCQR in an important industrial sector.

The original sample frame is a merged email list purchased from a leading marketing company in China, which contains 2,321 electronics firms. Based on the response from our first-round invitation, 1,863 of the original dataset had a valid address. To improve the response rate, we sent three waves of the survey email, at two-week intervals. At the end of this three-wave data collection period of one month and a half, we had received 258 responses, which represents a 13.85% response rate. Compared with other survey-based research, the response rate is acceptable. After removing inappropriate targets and deleting the surveys with missing data, a total of 202 completed questionnaires received from senior managers and directors in the China electronics firms were analysed. The demographic information of our respondents is provided in Table 2. To check the non-response bias, we conducted a chi-square difference test to find out whether there was any difference between the early respondents (i.e. first 100 respondents) and late respondents (i.e. last 102 respondents) (Swafford et al., 2006). As shown in Table 1, there were no significant chi-square difference results between the early and late respondents by all three demographic categories (i.e. Supply Chain Position, Company Size and Annual Income). Therefore, we can claim that the sample used in this study is free of the threat of non-response bias.

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In addition, the common method bias might be a potential threat for this study, due to the seven-point Likert scales and the fact that responses are from a single informant at one point in time (Doty and Click, 1998). The Harmon's single-factor test for common method bias indicates that the seven constructs with Eigenvalue above 1 explains 69.226% of total variance, where the first factor only accounts for 22.626% of the total variance. Kassinis and Soteriou (2003) suggest that if a general factor could account for most of the variance in the factor analysis, common method bias would be a threat. Therefore, the result of Harmon's single-factor test suggests that common method bias is not a problem here. Moreover, using AMOS 22, we apply confirmatory factor analysis (CFA) to further conduct Harman's single-factor test. The model fit indices of the single-factor model (X^2/df = 7.631, NNFI = 0.425, CFI = 0.453, and RMSEA = 0.156) are much worse than the 'rules of thumb' and worse than the same indices from the measurement model. The unacceptable model indices of the single-factor model also indicate that the common method bias is not a threat for this research.

4.2 Measurement Model

To verify the constructs, we apply confirmatory factor analysis (CFA) through AMOS 22 to check unidimensionality, convergent validity, reliability and discriminant validity. This is consistent with the two-step procedure of Anderson and Katz (1998), which suggests that the measurement model (i.e. confirmatory factor analysis) should be tested before conducting the structural equation modelling (SEM) analysis. The unidimensionality can be confirmed by the overall measurement model fit indices. Previous studies suggest that if the values of comparative fit index (CFI), non-normed fit index (NNFI) and incremental fit index (IFI) are higher than 0.90, the measurement model is a good fit (Byrne, 1989; Cao and Zhang, 2011; Papke-Shields et al., 2006). If the values of CFI, NNFI and IFI are in the range from 0.80 to 0.89, the model represents a reasonable fit (Cao and Zhang, 2011; Segars and Grover, 1998). Moreover, if the value of X^2/df is less than 5, and the root mean square error of approximation (RMSEA) is less than 0.10, the measurement model indicates a good fit. The model fit indices for the measurement model meet the recommended criteria for a good fit of the overall model, which indicates good unidimensionality (X^2=386.882, df = 231, X^2/df = 1.675, IFI = 0.925, NNFI = 0.909, GFI = 0.860, CFI = 0.923, RMSEA = 0.058) (O'Leary-Kelly and Vokurka, 1998).

We also check the convergent validity of all the items. Convergent validity is the degree to which individual items in the questionnaire measure the same underlying construct (Churchill, 1987). As shown in Table 3, the standardised item loadings of the indicators are all greater than 0.50, ranging from 0.539 to 0.909, and their *t*-values are significant at the 0.01 level. Therefore, the results provide evidence of convergent validity (Byrne, 2016). The Cronbach's alpha and composite reliability for each construct are all above 0.7. The estimates of Average Variance Extracts (AVEs) are 0.642, 0.598, 0.430, 0.606, 0.624, 0.510 and 0.552 respectively. The results suggest that the reliability for each construct is acceptable (Kristal et al., 2010; Fornell and Larcker, 1981; Tse et al., 2016; O'Leary-Kelly and Vokuraka, 1998).

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To confirm the discriminant validity, we adopt two approaches, namely pairwise comparison and AVE comparison. In the pairwise comparison model, in the first step we constrain the correlation of two constructs into one. Then we compare the constrained model with the unconstrained model. The results show that the chi-square differences between the constrained and unconstrained models are all statistically significant, which indicates discriminant validity (Cao and Zhang, 2011). In addition, the square root of AVE of each construct is compared with the correlations between constructs. As shown in Table 4, the diagonal elements (in bold), which are the square root of AVE, are greater than the inter-construct correlations. Therefore, the discriminant validity is further confirmed (Chin, 1998).

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5. Results of Structural Model

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We conduct the structural model with maximum likelihood estimation in AMOS 22 to test hypotheses H1a, b, c, d and H2a, b, c, d. Figure 2 presents the results of the baseline model with only the direct effect. The model fit indices for the structural model are all acceptable with IFI = 0.888, NNFI = 0.868, CFI = 0.886 and RMSEA = 0.075. The X^2 statistic is 384.622 with df = 181; thus the ratio of chi-square to the degree of freedom is below 5 (i.e. 2.125), which indicates a good fit. The results shown in Figure 2 support hypotheses H1a, H1c and H1d. The path coefficients indicate the significant impacts of technology uncertainty (0.373; *T*=3.941), traceability uncertainty (0.301; *T*=3.782) and product complexity (0.339; *T*=4.080) on the probability of SCQR. However, H1b is not supported, due to the insignificant results. We find that hypotheses H2a, H2b and H2c are confirmed. In other words, technology uncertainty, testability uncertainty and traceability uncertainty significantly impact on the magnitude of the SCQR. The path coefficients of 0.205 (*T* =2.270), 0.148 (*T*=2.162) and 0.185 (*T*=2.372) respectively are all significant at 0.05 level. Nevertheless, the results do not support H2d. This indicates that the product complexity has no significant influence on the magnitude of SCQR.

Surprisingly, the hypotheses are not fully supported. Therefore, we need to apply moderation analysis to explain the inconsistency (Baron and Kenny, 1986). In this research, SMT is adopted as the moderating factor. In other words, we identify whether the relationships in the baseline model (Figure 1) remain the same or invariant across different moderation groups (i.e. high SMT and low SMT group). We conduct analysis of multi-group structural invariance to test the moderating effect of SMT (Cao and Zhang, 2011; Wong et al., 2011). In this regard, we divide the sample into high (n=97) and low (n=105) SMT based on the average scores of centralised construct (i.e. 5.469) (Wong et al., 2011). Then, using AMOS 22, we conduct multiple group analysis. Table 5 reports the results of the multi-group and structural path analyses. As shown in Table 5, three types of model are tested. In the baseline model, parameters vary freely across different groups (i.e. different SMT). The constrained model, in which structural parameters are constrained to be equal across different groups, is used for comparison with the baseline model (Wong et al., 2011). The third model is the equal structural coefficients model (i.e., constrained path) (Cao and Zhang, 2011).

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Insert Table 5 here.

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As shown in Table 5, the results of moderation analysis of SMT are similar to those of the above analysis. We find a significant result in the chi-square statistics between the baseline model and the constrained model (i.e. where all structural parameters across two groups are constrained) (ΔX^2 = 25.133, with 15 *df* difference, $p<0.05$), which indicates variance of the model under high and low SMT (Wong et al., 2011). The chi-square statistics test for the relationship between testability uncertainty and magnitude of SCQR reveals a significant result (ΔX^2 = 7.716, with 1 *df* difference, $p<0.01$), which indicates the moderation effect of SMT in the relationship. The impact of testability uncertainty on magnitude of SCQR is significant under low SMT (0.371, T=3.603), while it is insignificant under high SMT (-0.042, T=-0.497). The significant moderation result suggests that H4a is supported. In addition, the relationship between traceability uncertainty and probability of SCQR is also moderated by SMT (ΔX^2 = 2.822, with 1 *df* difference, $p<0.1$). Under high SMT, traceability significantly influences the probability of SCQR (0.438, T=3.128). However, the association is not significant under low SMT (-0.108, T=-0.972). Therefore, H3c is also supported. Additionally, the chi-square difference between the baseline model and the model of relationship between technology uncertainty and magnitude of SCQR is significant (ΔX^2= 4.232, with 1 *df* difference, $p<0.05$), which suggests that the level of relationship is not the same across the two groups, and therefore H4b is supported. Typically, the technology uncertainty-magnitude relationship is significant under high SMT (0.325; T=2.803), while it is insignificant under low SMT (-0.063, T=-0.514). A similar result is found in the relationship between technology uncertainty and probability of SCQR, with a significant moderation role of SMT (ΔX^2= 4.232, with 1 *df* difference, $p<0.05$). Therefore, H3b is also supported. Although the relationship between technology uncertainty and probability of SCQR is significant (0.317, T=2.201) under low SMT, it is highly significant under high SMT (0.363, T=3.412). Last but not least, we find a significant chi-square difference result between the baseline model and model of product complexity-magnitude relationship (ΔX^2 = 5.337, with 1 *df* difference, $p<0.05$). The results indicate that the relationship between product complexity and magnitude of SCQR is significant under low SMT (0.409, T=2.881).

However, it is insignificant under high SMT (0.008, T=0.091). In this case, H4d is supported. The insignificant results of chi-square difference test between high and low SMT groups for the relationships between testability uncertainty and probability of SCQR, traceability uncertainty and magnitude of SCQR, and product complexity and probability of SCQR, indicate that H3a, H4c and H3d are not supported.

6. Discussion

Based on the empirical verification of our theoretical model, this research has offered a comprehensive understanding of the mechanism of SCQR. Four external uncertainty factors related to supply chain quality management are selected from agency theory: technology uncertainty, testability uncertainty, traceability uncertainty and product complexity. We generate and develop the items of uncertainty factors and of perception of SCQR based on the existing literature (Ellis et al., 2010; Prater et al., 2001; Spekman and Davis, 2004). Using a dataset of 202 senior managers in the Chinese electronics industry and applying rigorous statistical methodologies (such as confirmatory factor analysis, construct reliability, convergent validity and discriminant validity), the scales used in this research are shown to be valid and reliable. The valid measures of the uncertainty factors and perception of SCQR form the basis for an accurate understanding of the structural relationships in the theoretical model. In addition, drawing upon RDT, SMT has attracted broad interest from academia (Ellis et al., 2010). However, the literature lacks a comprehensive understanding of its value in explaining the mechanism between the external uncertainties and SCQR. The results of moderation analysis confirm that the uncertainty-SCQR relationship can be explained by our selected theories – RDT and agency theory.

First, the finding that technology uncertainty significantly and positively influences both magnitude and probability of SCQR indicates that the problems of adoption of new technology and of safeguarding that arise from supplier knowledge transfer could not only trigger destructive product recalls, but could also increase the occurrence of SCQR. The significant results of the relationship between technology uncertainty and perception of SCQR indicate the difficulty for electronics companies to ensure supply chain quality under technological uncertainty. Due to the product characteristics of electronics products, which are technology intensive (Hatzichronoglou, 1997), it is clear that technology uncertainty is an important uncertainty factor impacting on the perception of SCQR. Covin et al. (1990) theorize that high technology uncertainty is associated with high ambiguity and the sophistication of the technology information, which leads to the unpredictable company development. Drawing on the agency theory and risk perception literature, we predict, and find support for, a higher level of technology uncertainty results in higher perceived SCQR. This result is also consistent with the research of Ellis et al. (2010), which finds that technology uncertainty is an important factor impacting on the buyer's perception of supply disruption risk (in both probability and magnitude). Although SCQR differs from supply disruption risk, the importance of understanding the technology uncertainty in SCRM is further confirmed.

Secondly, it appears that testability uncertainty does not directly increase managers' perception of the probability of SCQR. However, the results strongly support the claim that testability uncertainty positively influences the magnitude of SCQR. A possible explanation for these results is that some serious and/or unsafe problems of various electronics product components may not be discovered during normal quality testing but will increase the severity of the SCQR. As an electronics product might contain hundreds of components, it will be costly, and perhaps impossible, for the manufacturers to check every one of them. Therefore, the perception of SCQR as triggered by testability uncertainty might be low, but once an incident occurs, the

SCQR could be very serious for the firms concerned. This result also supports the argument of the agency theory regarding *"outcome measurability"*, that is the degree to which the agent's (i.e. supplier's) performance can be correctly measured (Eisenhardt, 1989). According to Whipple and Roh (2010), the outcome measurability has a highly significant impact on buyer vulnerability, because of the information asymmetry. When buying firms are unable to conduct reliable tests for the supply materials, they may find it difficult to verify the suppliers' actual effort in product quality and could face serious agency problems.

Thirdly, the results show that traceability uncertainty significantly impacts on both components of the SCQR. This can be explained by the fact that, in the context of the electronics industry, a product recall will be severely aggravated if the firm lacks the ability to trace the defective material. Once a product quality problem is raised by the customer firm, managers in the manufacturing firm need to trace the root cause of the problem and identify the problematic batches. However, because the supply chain in the electronics industry is long and multi-tier (Kuk, 2004), it is difficult for the electronics manufacturers to trace the source of the problematic components from their upstream supply chain. These results are consistent with the agency theory, whereby, if the supplier (i.e. agent) knows the buyer (i.e. principal) will have difficulty tracing back to their responsibility in the supply chain, this might encourage the supplier to engage in opportunism (Bergen et al., 1992). Without well-documented tracing and tracking information, companies may need to invest more in monitoring product quality problems. Echoing this interpretation, Regattieri et al. (2007) state that a traceability system enables *"more efficient control of supply chain in terms of improving control of the stock situation, and production monitoring"* (P. 351). Moreover, this study suggests that where there is incomplete tracing information, the companies concerned would not respond efficiently in the recall management process. As a result, the losses related to a product quality crisis could not be efficiently controlled. This is consistent with the argument of Tang (2008) that in a product quality crisis, delay in making the decision to issue a recall will result in higher losses and more reputational damage to the firm.

In addition, product complexity does not directly impact on risk magnitude but does directly increase managers' perception of risk probability. This might be because the increased product complexity could threaten product quality. This is consistent with Zu and Kaynak's (2012) argument that the more complex the products offered by the supplier, the more difficult it is for the buyer to assess the supplier's performance. In this case, according to agency theory, information asymmetry would increase the probability of SCQR. For example, complex manufacturing processes and the large number of components needed by electronics manufacturers offer the opportunity for opportunistic practices, such as counterfeiting or substitution of lower grade components. However, the insignificant relationship between product complexity and magnitude of SCQR is contrary to our expectation. A possible explanation is that although higher complexity might increase the likelihood of defective products, it might affect only the function and reliability of the products, while not having destructive consequences.

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Insert Table 6 here.

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The integration of agency theory and RDT is supported by the result indicating that testability uncertainty has a greater influence on the magnitude of SCQR under low SMT. In this case, the buyer firm may benefit from greater choice and have flexibility to adopt a multi-sourcing strategy, since more suppliers are available in the market to provide the component. Different suppliers may provide a component with similar functions but different characteristics. Therefore, inspection strategies would vary among components from different suppliers, thus increasing the cost of testing. It is difficult for buyers to allocate resources across a wide range of inspection tests to deal with components from different suppliers, because the complexity of the testing will involve significant differences in sampling size, testing procedures, the number of tests and the component testing priority. Therefore, under low SMT, product testing failure might result in a larger scale product recall, which means that the consequence of the SCQR will be more severe.

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Insert Table 7 here.

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Insert Table 8 here.

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Our findings confirm the theory that product complexity will have a greater impact on magnitude of SCQR under low SMT. That is, low SMT will amplify the threat of product complexity in ensuring the product quality. In an interdependent supply chain, within a stable relationship, supply chain management practices such as joint-planning could assist the company in dealing with the quality issues of a complex product. However, if buyers deal with a large number of supply companies, the opportunity to change the sourced materials is increased, and this in turn increases the difficulty for technical staff to comprehensively understand the whole manufacturing process. In this case, the assembly of the complex product might be more prone to error, because of the non-proficiency of the technical staff. Clearly, inaccurate production would lead to products of inferior quality and potentially even to a large-scale product recall.

On the other hand, SMT shows a different moderating effect in the relationships between technology uncertainty, traceability uncertainty and perception of SCQR. Our results indicate that under high SMT, the impact of traceability uncertainty on the probability of SCQR will be strengthened. If there are few suppliers, buyers will be more reliant upon them. In that case, if product quality problems occur, the buyers might have difficulty in tracing the sub-suppliers. According to RDT, if the suppliers have more power in a dependency relationship, they might be unwilling to provide buyers with the tracking information of their sub-suppliers, or might even intentionally engage in opportunistic behaviour, such as providing substandard components in order to lower the production cost. A possible theoretical contribution is that the greater the resource dependence of the buyer upon the supplier, the more serious the agency problem. Also, our results confirm the traditional RDT, which suggests that the relationship between technology uncertainty and perception of SCQR (i.e. magnitude and probability) will be strengthened under high SMT. In the context of a thin supply market, the supplier might have the competitive advantage of possessing more technology knowledge. To sustain the winning position, suppliers might strive to keep the information asymmetry in technology knowledge. In this case, buyers might face a more severe threat with regard to ensuring product quality under high SMT.

7. Managerial Implications

The researches of traditional SCRM leave a blank to tackle and address the issues regarding to production quality risk. As the body of literature is revealed (Theodorakioglou et al., 2006; Zu and Kaynak, 2012; Huo et al., 2014), the existing knowledge cannot satisfy the needs of organizations in connecting their SCRM activities and quality risk management in an effective way (Bruccoleri et al., 2019). There isn’t either a well-grounded guideline of what factors drives product risk, or suitable prescription for how to diminish SCQR. Thus, this research fills the gap by providing a developed model and the empirical findings that presented a comprehensive picture of the SCQR mechanism, and they offer helpful guidance for managers, particularly supply chain buyers, to scrutinise the product quality risk raised in the supply chain.

The definition and valid measurement of the presentation of risk (i.e. probability and magnitude) can help managers to accurately understand and define the specific meaning of SCQR. The scales of SCQR can also assist managers to minimise risk assessment failure and bias.

For manufacturers, SCQR could be fatal, because it will lead to loss of company reputation, financial earning and even brand equity (Van Heerde et al., 2007). Therefore, in today's dynamic market, managers need to reconsider the uncertainty factors that might lead to SCQR. In particular, this study provides some hints for managers to identify the root causes of SCQR. Managers can directly apply the constructs in our model (i.e. technology uncertainty, testability uncertainty, traceability uncertainty and product complexity) to identify potential problems. For example, if the buyer perceives great technological uncertainty in the upstream supply chain, they should be aware that SCQR might pose a threat to their company. The questionnaire items used in this research can act as a check list of uncertainty factors for companies' risk management planning.

The analysis of the moderation effect of SMT shows the importance of understanding the mechanism of SCQR in a contingent perspective. Our empirical findings suggest that under different degrees of SMT, the uncertainty factors may affect the representations of probability and magnitude of SCQR in different ways. This is particularly helpful for managers to prioritise their resources to check the uncertainty factors based on the characteristics of the supply chain relationship. For instance, based on the results of the moderation analysis, we would suggest that a company with high SMT, where the supply chain relationship is characterised by high dependency of buyer upon supplier, should allocate more resources to tackle the uncertainties in technology and traceability.

8. Conclusion

Although a great number of researches have produced constructive understandings and analysed the supply chain risks' nature, little research has been to raise risk considerations that focus on the production quality problem. This study has focused exclusively on conceptualising supply chain uncertainty factors, and their impact on SCQR (magnitude and probability). Specifically, the work strives to understanding what SCQR means, and which uncertainty factors influence the management of SCRQ through the lens of agency theory, and by considering the moderator role of supply market thinness, how to deploy strategies regarding uncertainty factors that will effectively reduce SCQR is designed. Our empirical findings provide new insights for the risk representation of SCQR from the buyer's perspective. The structural model provides additional perspectives on SCQR, illustrating the relationships among external uncertainties and SCQR. The proposed model forms a basis for academics and managers to understand SCQR, and provides direction for managers to identify potential uncertainty factors in their supply chains. Moreover, this study develops SCQR research by examining the moderation effect of SMT on the impacts of different uncertainty factors on the SCQR. From the perspectives of RDT and agency theory, this study offers a new approach to examine how and why the influences of external uncertainty factors on SCQR might be strengthened. Therefore, the study can serve to caution managers establishing a comprehensive risk management strategy to respond to uncertain environments.

Although this research provides practical insights for understanding SCQR, it has some limitations, which should be considered in future research. The relationship between external uncertainties and SCQR is extremely complex. In order to fully scrutinise the mechanism, it is suggested that future research investigate more contingency effects, such as industry, supply network complexity, and power centralisation. Another limitation is that the model has been observed only from the perspective of a single nation, namely China. Although China is a world manufacturing hub, the results may lack generalisability. It is suggested that future research could extend the current model to different country contexts. We would also suggest that future research could compare the risk perception of managers from developed and developing countries. Moreover, the mechanism whereby uncertainty factors affect each other, and how this mechanism might act with other possible uncertainty factors that might affect the risk perception, are not fully understood. We would suggest that future research could conduct cross-firm case studies to identify a more comprehensive mechanism whereby the uncertainty factors affect SCQR. In addition, the existing model in this research could be re-specified.

Figures

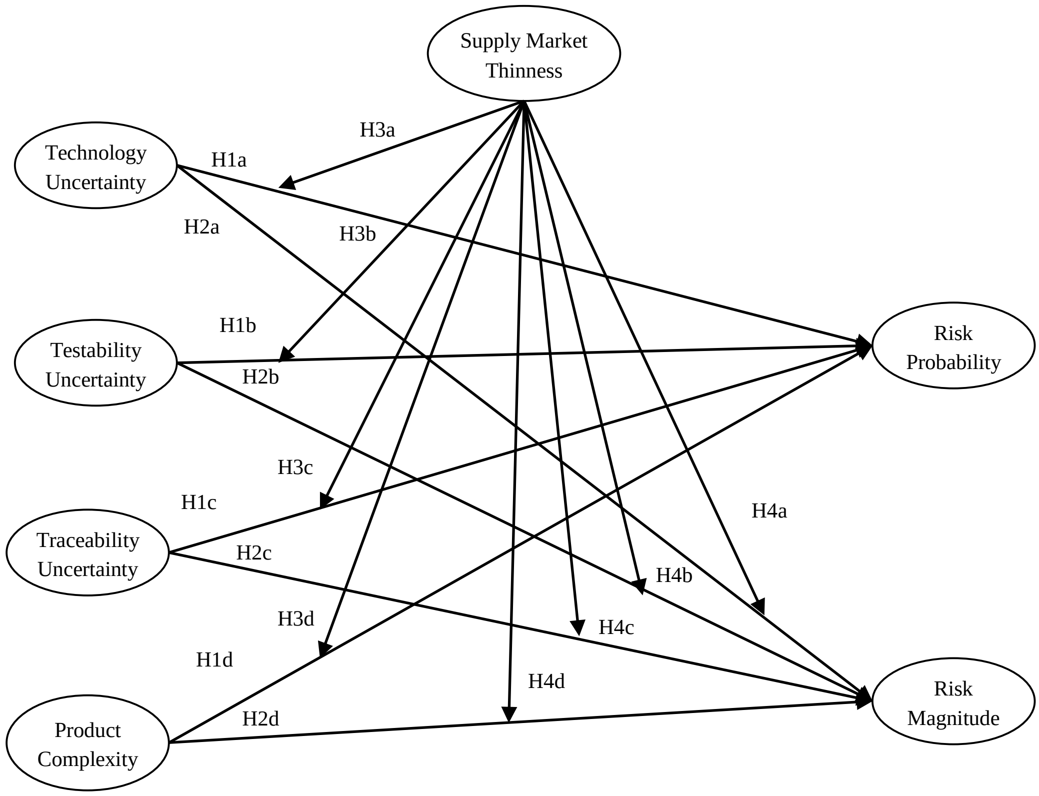
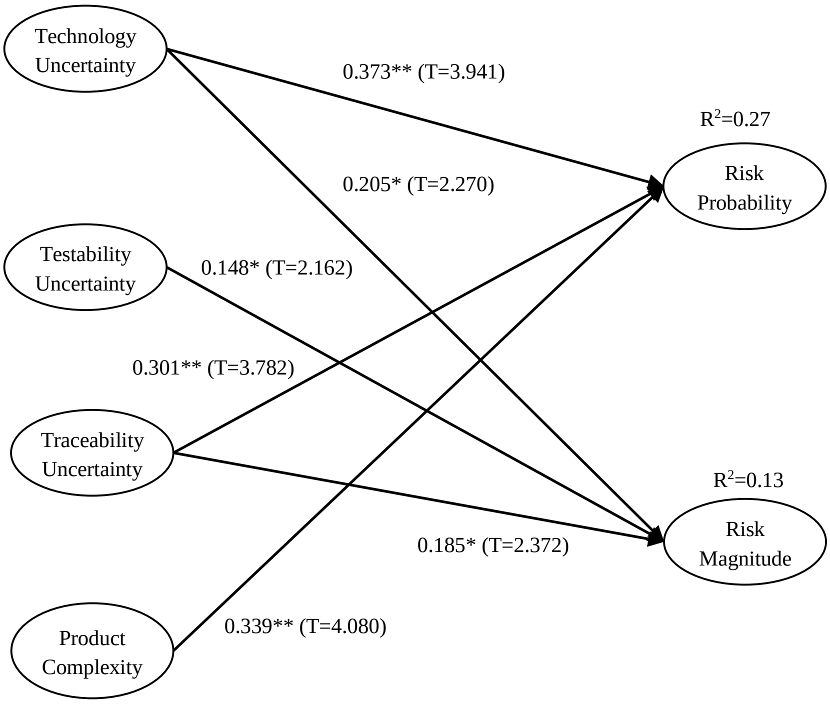


Figure 1 Theoretical Model



Regression weight p-values: *p<0.05; **p<0.01

Model Fit Index: χ^2=384.622; df=181; χ^2/df=2.125; CFI=0.886; NNFI=0.868; IFI=0.888; RMSEA=0.075

Figure 2 Structural Model

Tables

Article	**Definition and connotation of key term**	**Sample**	**Method**	**Key findings**
Tse et al (2019)	**SCRM** involves the preventive and reactive practices with the purpose of managing the potential quality risk in the upstream supply chain and lessening the negative impact of product recall in the downstream network.	209 manufacturing firms in China	Survey	1. Formal control and social control are both found positively influence the two types of risk management, i.e. supplier development and proactive product recall. 2. Risk management practice significantly contribute to financial performance and quality performance. 3. The moderating roles of control mechanisms on the relationship between risk management practice and firm performance has been tested.
Baryannis et al (2019)	**SCRM** encompasses the collaborative and coordinated efforts of all parties involved in a supply chain to identify, assess, mitigate and monitor risks with the aim to reduce vulnerability and increase robustness and resilience of the supply chain, ensuring profitability and continuity	276 articles from Scopus database	Review and mapping study	1.The comprehensive analysis of the existing knowledge SCRM in AI-related capabilities. 2.A detailed identification of the research gaps and future research directions with regard to applying AI technologies in SCRM
Fan and Stevenson (2018)	**SCRM** is the identification, assessment, treatment, and monitoring of supply chain risks, with the aid of the internal implementation of tools, techniques and strategies and of external coordination and collaboration with supply chain members so as to reduce vulnerability and ensure continuity coupled with profitability, leading to competitive advantage.	354 articles from Business Source Complete and Web of Science databases	Review	1.The comprehensive definition of SCRM is provided. 2. A state-of-the-art assessment of SCRM research is presented. 3. The used theory in s SCRM research has been assessed.

Wiengarten et al (2016**)**	**SCRM** is the integrated process of identification, analysis and either acceptance or mitigation of uncertainty and risk in the supply chain	637 samples from 19 countries	Survey and secondary data analysis	1.Supply integration is effective in weak rule of law environment. 2.Taking SCRM practices in risky environments helps firms to complement and strengthen the performance impact of their supplier integration practices.
Clemons and Slotnick (2016)	**SCRM i**s the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity (Tang, 2016)	19 different input variables with multiple levels has been used.	Simulation study	1.Policies that sensibly allocate demand between suppliers can mitigate the expenditure of supply chain disruption. 2.Firm must consider the quality level of supplier when choosing supplier developing policies. 3. The effectiveness of knowledge transfer between a firm and a supplier has a significant impact on profit and should be considered beforehand.
Nooraie, and Parast, (2016)	SCRM is the development and implementation of strategies to manage both day-to-day and exceptional risks along a supply chain, with the objective of reducing vulnerability and ensuring business continuity.	/	Heuristic model	Increasing supply chain capabilities is a mitigation strategy that enables a firm to reduce the total expected cost of a supply chain subject to disruptions.
Ho et al (2015)	**SCRM** is an inter-organisational collaborative endeavour utilising 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	224 journal article	Review	1.Present and categorise SCRM research in a certain period of time. 2.Provide a detailed review in supply chain risk definition, types, risk factors and management. 3.Exploring the potential research gap in SCRM researches.
Lavastre et al (2014)	**SCRM** the management of risk that implies both strategic and operational horizons for long- term and short-term assessment. It refers to risks that can modify or prevent part of the movement and/or efficient flow of information, materials and products between	164 French company in various of industries	Survey	1.The length of partner relationship is important in SCRM as it influence the methods partners used. 2. SCRM needs to be considered at a strategic level and required long-term and strategic information exchanges with partners.

	the actors of a supply chain within an organisation, or among actors in a global supply chain.			3. Even though firms will experience temporary profit loss by practising SCRM, long-term beneficial impact will be found as a long-term result.
Wieland (2013)	**SCRM** is the identification and management of risks for the supply chain through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole	/	Mathematical model	1.Resilience is appropriate in the case of high supply chain risk probability and impact, and rigidity if both values are low. 2.When only risk impact is low, robustness is optimal, whereas agility is optimal when only risk probability is low.
Tse and Tan (2012)	**SCRM** takes precautionary actions in the supply chain for protecting the consumer and reducing risk.	A toy manufacturer company in mainland China	Case study	1.The product quality risk and visibility of the potential suppliers should work together for comprehensive evaluation. 2. The selection of low risks quality criteria in the decision process can mitigate product quality risk. 3.An evaluation of the product quality risk in supply chain layers has been provided

Table1. Existing knowledge of quality risk in supply chain management

	Number of firms	Firs-wave frequency	Second and third wave frequency	Chi-square test for non-response bias	Total Percentage (%)
The position of respondent					
CEO	13	5	8	$X^2 =$ 4.166 df = 4 p = 0.384	6.4
Vice President	18	9	9		8.9
Purchasing Director	116	63	53		57.4
Supply Chain Manager	45	19	26		22
Others	10	3	7		5
Firm Size (Number of employees)					
< 250	121	64	57	$X^2 =$ 1.820 df = 1 p = 0.177	59.9
> 250	81	35	46		40.1
Income (Chinese Yuan - MILLION)					

< 10	38	16	22	$X^2 =$ 0.037 df = 3 p = 0.998	24.4
10-50	90	44	46		44
50-200	56	27	29		22.6
> 200	18	14	4		9.1

Table 2. Profile of the respondents (n = 202)

Item Name	Scale item	Standardised Item Loading	SE	*t*-value*
Testability Uncertainty (Newly Designed) (composite reliability = 0.843; Cronbach's Alpha = 0.837; AVE = 0.642)				
TES1	In this industry, it is more difficult to identify defective products now than in the past.	0.846[a]	-	-
TES2	In this industry, it is hard to discover whether the supplier has substituted lower grade components.	0.836	0.073	12.106
TES3	We need to allocate more resources (e.g. training, purchasing new equipment) than in the past to obtain a reliable test result.	0.716	0.072	10.526
Traceability Uncertainty (Newly Designed) (composite reliability = 0.855; Cronbach's Alpha = 0.851; AVE = 0.598)				
TRU1	In this industry, it is hard to trace the origin of the raw materials.	0.860[a]	-	-
TRU2	In this industry, it is hard to obtain the information about our sub-tier suppliers.	0.840	0.080	13.623

TRU3	In this industry, it is difficult to trace the processed key component all the way back to the source of raw materials.	0.655	0.077	9.917
TRU4	When product problems are of the product is found, it is difficult to trace the corresponding supplier who provides the material.	0.720	0.078	11.212
Technology Uncertainty (Ellis et al., 2010) (composite reliability = 0.746; Cronbach's Alpha = 0.741; AVE = 0.430)				
TU1	During new product development, technology development is unpredictable.	0.776[a]	-	-
TU2	The industry producing our critical part undergoes frequent technology developments.	0.554	0.109	6.767
TU3	Rapid changes in the industry producing our critical part necessitate frequent product modifications.	0.720	0.124	8.198
TU4	Technology changes affect our production in more ways now than in the past.	0.539	0.103	6.600
Product Complexity (Novak and Eppinger, 2001) (composite reliability = 0.859; Cronbach's Alpha = 0.852; AVE = 0.606)				
PC1	The manufacturing process of the product is complex.	0.885[a]	-	-
PC2	The production process of the product is complex.	0.829	0.069	13.630
PC3	The structure of our product is complex.	0.692	0.078	10.812
PC4	The work treatment after manufacturing the product is complex.	0.689	0.078	10.741

Probability of SCQR (Ellis et al., 2010, Prater et al., 2001) (composite reliability = 0.830; Cronbach's Alpha = 0.817; AVE = 0.624)				
MA1	It is highly unlikely that we will receive lower grad materials from our key supplier (reversed code)	0.909[a]	-	-
MA2	There is a high probability that our key supplier cannot maintain top product quality in every order.	0.801	0.072	12.042
MA3	We always worry that our key supplier may not supply the product which conforms to the agreed quality specifications.	0.636	0.080	9.931
Magnitude of SCQR (Ellis et al., 2010; Spekman and Davis, 2004) (composite reliability = 0.752; Cronbach's Alpha = 0.756; AVE = 0.510)				
MQ1	Lack of awareness of the usage of defective purchased material in our product would have severe negative financial consequences for our business.	0.785[a]	-	-
MQ2	Key suppliers' inability to supply material that conforms to agreed specifications would seriously jeopardisze our business performance.	0.659	0.117	7.519
MQ3	We would incur significant costs and/or losses in revenue if we were unaware of the usage of defective purchased material in our product.	0.693	0.113	7.692
Supply Market Thinness (Cannon and Perreault, 1999; Ellis et al., 2010) (composite reliability = 0.783; Cronbach's Alpha = 0.762; AVE = 0.552)				
MT1	The supply market for our major supply materials is very competitive.	0.868[a]	-	-

MT2	We have few suppliers to provide the materials we need.	0.583	0.098	7.705
MT3	Our supplier almost has a monopoly for our major supply materials.	0.751	0.090	9.431
Notes: n = 257; fit statistics: x^2=386.882, df = 231, x^2/df = 1.675, IFI = 0.925, NNFI = 0.909, GFI = 0.860, CFI = 0.923, RMSEA = 0.058; *: All item loadings are significant *p*<0.01 level a: Fixed parameter				

Table 3. Measurement Items

	TEU	**TRU**	**TU**	**PC**	**PRO**	**MAG**	**SMT**
TEU	**0.802**						
TRU	0.559	**0.773**					
TU	0.160	0.047	**0.655**				
PC	-0.119	-0.164	0.299	**0.778**			
PRO	-0.192	-0.333	0.363	0.401	**0.790**		
MAG	0.285	0.286	0.249	0.104	0.169	**0.714**	
SMT	0.371	0.461	0.035	-0.239	-0.372	0.194	**0.743**
Note: TEU = Testability Uncertainty; TRU = Tractability Uncertainty; TU = Technology Uncertainty; PC = Product Complexity; PRO = Probability; MAG = Magnitude; SMT = Supply Market Thinness							

Table 4 Discriminant Validity Test

Models	x^2	df	X^2/df	ΔX^2	ΔDf	X^2 difference test	High	Low
1. Baseline Model	643.99	362	1.779					
2. Constrained Model	669.123	377	1.775	25.133	15	$p<0.05$		
3. Constrained Paths (Uncertainty Factors – SCQR)								
3a. TESU – Probability	646.387	363	1.781	2.397	1	insignificant	-0.14(-1.72)	0.111(1.007)
3b. TESU – Magnitude	651.706	363	1.795	7.716	1	p<0.05	-0.042(-0.497)	0.371(3.603)**
3c. TRAU – Probability	646.812	363	1.782	2.822	1	p<0.1	0.438(3.128)**	-0.108(-0.972)
3d. TRAU – Magnitude	644.863	363	1.776	0.873	1	insignificant	0.248(1.737)	0.058(0.594)
3e. TU – Probability	648.222	363	1.786	4.232	1	p<0.05	0.363(3.412)**	0.317(2.201)*
3f. TU – Magnitude	648.222	363	1.786	4.232	1	p<0.05	0.325(2.803)**	-0.063(-0.514)
3g. PC – Probability	644.285	363	1.775	0.295	1	insignificant	0.322(3.729)**	0.220(1.409)

3h. PC – Magnitude	649.327	363	1.789	5.337	1	p<0.05	0.008(0.091)	0.409(2.881)**
T Values are in brackets; a = Path Coefficients; * *p*<0.05 ***p*<0.01								

Table 5 Multi-group analysis for SMT

Independent Variables	**Dependent Variables: Overall SCQR Construct**
Technology Uncertainty	0.013
Testability Uncertainty	0.173**
Tractability Uncertainty	0.267*
Product Complexity	0.148^{+}
Coefficient of determination (R^2)	0.10
Model Fit Index: χ^2=258.350; df=101; χ^2/df=2.558; CFI=0.880; NNFI=0.858; IFI=0.882; RMSEA=0.088	

Table 6. Post hoc analysis of overall SCQR

	Structural link	**Supported or not?**

H1a	Technology Uncertainty -> Probability	Support
H2a	Technology Uncertainty -> Magnitude	Support
H1b	Testability Uncertainty -> Probability	Not support
H2b	Testability Uncertainty -> Magnitude	Support
H1c	Traceability Uncertainty -> Probability	Support
H2c	Traceability Uncertainty -> Magnitude	Support
H1d	Product Complexity -> Probability	Support
H2d	Product Complexity -> Magnitude	Not support

Table 7. Results of the baseline model

Structural Link	**High SMT**	**Low SMT**
Testability Uncertainty -> Magnitude	/	Strengthened
Traceability Uncertainty -> Probability	Strengthened	/
Technology Uncertainty -> Probability	Strengthened	/
Technology Uncertainty -> Magnitude	Strengthened	/
Product Complexity -> Magnitude	/	Strengthened

Table 8. Results of the moderation analysis

Reference

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