Abstract

Along with increasing supply chain risks due to economic and environmental changes, it is imperative to answer the question of how to reduce supply chain risks. This study examines supply chain collaboration as a risk mitigation strategy. The study examines three types of risks, namely supply risk, demand risk and process risk in relation to three types of collaboration, namely supplier collaboration, customer collaboration and internal collaboration, as a mechanism to mitigate those risks. The proposed relationship model is tested with data collected from 203 manufacturing companies in Australia. The results show that each area of collaboration effectively reduces its respective supply chain risk, but only the mitigation of process risk and demand risk has a direct effect on supply chain performance. In addition, both supply risk and demand risk increase process risk. We offer theoretical and practical implications of the findings.

Keywords: supply chain collaboration, risk, supply chain risk

1. Introduction

A supply chain is a network of organizations that are involved, through upstream and downstream linkages, in different processes and activities that produce value to consumers (Christopher, 1992). When supply chain management emerged as a new philosophy compared with the traditional way of managing supply chains, it was characterized by a strategic orientation toward collaborative efforts to align different supply chain entities into a unified whole (Mentzer *et al.*, 2001). It is now recognised that competition is no longer between individual companies but between different chains and that " collaborative advantage" (Kanter, 1994; Dyer, 2000) is achieved through supply chain entities leveraging resources and knowledge in the whole network (Lejeune and Yakova, 2005; Cao *et al.*, 2010).

On the other hand, due to increased globalization, higher customer expectations and environment volatility (Christopher and Peck, 2004; Norrman and Jansson, 2004), supply chains are more easily exposed to risks. Supply chain risk management (SCRM) has emerged as an important area of study. As a recent research area, the study of SCRM so far has not been adequate to meet the challenges associated with increasing supply chain risks (Khan and

Burnes, 2007; Thun and Hoenig, 2011). Extant studies have strongly focused on supply side risk (Tang and Nurmaya Musa, 2011). However, the supply chain ripple effect makes it essential to manage supply chain risks in partnership with other supply chain partners (Norrman and Jansson, 2004). A direct supply chain is composed by a focal company, its supplier and its customer (Mentzer *et al.*, 2001). Its competence is not only threatened by risks from the supply side but also from internal production and the customer side as well as their interrelations. No matter what kind of risk management approach is taken, supply chain risks should be understood and managed as a whole for an end-to-end supply chain (Rao and Goldsby, 2009). But such studies are scant in the extant literature.

Implied by the supply chain perspective, supply chain collaboration is important to mitigate supply chain risks but this approach has not been investigated thoroughly (Cheng *et al.*, 2011). The importance of collaboration has been reflected in some definitions of SCRM. For example, Tang (2006) define SCRM as the management of supply chain risks “through coordination or collaboration” among supply chain partners. Jüttner *et al.*(2003) also defines SCRM as the management of risks for the supply chain “through a co-ordinated approach” amongst supply chain members. Some studies have included collaboration into risk mitigation frameworks (e.g. Zsidisin *et al.*, 2000; Chopra and Sodhi, 2004; Christopher and Peck, 2004; Giunipero and Eltantawy, 2004; Hallikas *et al.*, 2004), but they are mainly conceptual and provide little empirical evidence.

To address these research gaps, our study tries to empirically examine the following two research questions: 1) What is the implication of supply chain risks on supply chain performance? and 2) Can supply chain collaboration reduce supply chain risks? Our study contributes to the body of knowledge on SCRM through fostering a supply chain perspective and a collaborative approach of risk mitigation. It investigates risks and collaboration from end-to-end, encompassing the supply side, production processes and the demand side. Furthermore, as a survey-based study, it contributes to the SCRM literature in which there is a pressing need for empirical studies (Tang and Nurmaya Musa, 2011; Thun and Hoenig, 2011).

The remainder of this paper proceeds as follows. In Section 2 the relevant literature and theory are reviewed, based on which the research hypotheses are formed. The applied methodology is introduced in Section 3 and the results are reported in Section 4. Section 5 is a discussion of the findings as well as theoretical and managerial implications. The paper concludes with limitations of this study as well as future research directions.

2. Theoretical background and research hypotheses

2.1 *Supply chain risk*

The main use of the term "risk" is primarily based on the variance-based view (Miller, 1992) . In the classic decision theory, risk is defined as the "variation in the distribution of possible outcomes, their likelihoods, and their subjective values" (March and Shapira, 1987, p. 1404). Large variations make the performance unpredictable and hence increase the level of risk. Implied by the concept of variance, what is inherent in the concept of " risk" is an expected value (Yates and Stone, 1992; Shapira, 1995); it is the deviation from the expected value. In this sense, risk is simply missing the target (Ellis *et al.*, 2010). Encompassing both elements into the concept of supply chain risk, we define supply chain risk as "the potential deviation from the expected value of a certain supply chain performance measure" (based on Wagner and Bode, 2008; Kumar *et al.*, 2010).

In general, there are two types of supply chain risk, namely: operational risk and disruption risk (Kleindorfer and Saad, 2005; Tang, 2006; Knemeyer *et al.*, 2009; Wakolbinger and Cruz, 2011). Operational risk is more about supply-demand coordination and results from inadequate or failed processes, people and systems (Bhattacharyya *et al.*, 2010; Lockamy and McCormack, 2010). Examples of operational risk are quality or delivery problems. Disruption risk is caused by man-made or natural disasters such as terrorist attacks, strikes, earthquakes and floods. Disruption risk is less controllable while operational risk is relatively more controllable (Byrne, 2007). According to a global survey by Accenture in 2006, managers report that the most predominant and daunting risks to their supply chains are still those controllable risks which are associated with the performance of their supply chain partners (Byrne, 2007). Therefore, this study focuses on operational risk in supply chain contexts.

2.2 *Supply chain operational risks and their implications on supply chain performance*

The variation in a supply chain includes all those affecting the flow of goods across the supply chain and the match between supply and demand (Jüttner *et al.*, 2003). In a supply chain, the variations are raised mainly from three sides: upstream from suppliers' performance, downstream from customers' demand, and internally from the production process of the focal firm (Davis, 1993; Germain *et al.*, 2008). Correspondingly, we term the three types of supply chain operational risk as: supply risk, demand risk and process risk. The Theory of Swift, Even Flow (Schmenner and Swink, 1998) states that the more swift and even the flow of materials through a process, the more productive is that process. Therefore, the productivity of any process falls with increases in the variability associated with the flow, be that variability associated with quality, quantities, or timing (Schmenner, 2004). In light of this theory, variance-based supply chain risk (supply risk, demand risk or process risk) will undermine supply chain performance.

Supply risk is the potential deviations in the inbound supply in terms of time, quality and quantity that may result in uncompleted orders (Kumar *et al*., 2010). Inconsistency in the suppliers' performance will make their performance unpredictable and thus increase supply risk. There are many factors that can affect suppliers' performance such as production capacity constraints, lack of quality control, congestion in the production, or even a machine break down (Zsidisin and Ellram, 2003). All these can interrupt supply in terms of supply lead time, quantity and quality.

In a survey by AMR research (AMR Research, 2007), supplier failure has been found to be the No.1 risk factor. Due to the practice of outsourcing, the capability of the suppliers to assure supply is critical for the buying companies. For example, quality problems in the supplied components are a prominent threat to the buying company. As an example, in 2005 the German company Robert Bosch experienced a major loss as a result of delivering defective pumps provided by one of their sub suppliers (Thun and Hoenig, 2011). Inconsistent supply lead-time makes it unpredictable and thus increase the forecast error (Zsidisin, 2003). Problems also occur when suppliers cannot satisfy volume or mix requirements in the order. Since the buying company relies on its suppliers to maintain capable production processes, the inability of suppliers to deliver the required material, components or products will have detrimental effects on the supply chain's ability to serve its customers. With respect to the value chain model (Porter, 1985), success depends upon the seamless linkages between different activities within the chain such as inbound logistics and outbound logistics. Supply risk will have detrimental effects on outbound logistics, which will ultimately impact on the performance of the supply chain. Therefore we propose:
H1 (a): Supply risk is negatively related to supply chain performance.

Demand risk is the potential deviations of the forecasted demand from the actual demand (Kumar *et al.*, 2010). Large variations reflected in order changes make it more difficult for manufactures to forecast the demand and infuses high demand risk. Order changes could be insertion, expediting or volume changes. The changes may result from shorter product life cycle or introduction of new products in the market (Ho *et al.*, 2005; Manuj and Mentzer, 2008). They may also be "provider- induced"; some customer activities such as sales promotion and order batching will increase demand fluctuations (Lee *et al.*, 1997; Croxton *et al.*, 2002; Taylor, 2006). Furthermore, in some cases, even though the market demand is stable and the demand pattern is flat, the bullwhip effect will amplify the demand signals and increase order variability (Lee, 2002).

A fundamental purpose of a supply chain is to match supply with demand (Cohen and Kunreuther, 2007), however the unexpected changes in the demand decrease the accuracy of forecast and makes it more difficult to achieve this goal. The mismatch between the actual orders and forecast will harm the efficiency and effectiveness of the supply chain. If the forecast is higher than the actual demand, it may result in excess inventory, obsolescence, inefficient capacity utilization, or price-markdown (Sodhi and Lee, 2007), which results in inefficiency of the supply chain. If the forecast is less than the actual demand, it may result in shortages on the shelf and failure to serve the customer, which results in the ineffectiveness of the supply chain. Therefore demand risk is a vital threat for the supply chain to serve its customer. Based on this discussion, we propose:
H1(b): Demand risk is negatively related to supply chain performance.

Process risk is the potential deviations from producing the desired quality and quantity at the right time (Kumar *et al.*, 2010). Variation exists in all production systems (Melnyk *et al*., 1992). Hopp and Spearman (2000) has summarized two main types of variability in a manufacturing system. One is process variability which is mainly caused by various detractors such as machine downtime, setups or operator unavailability. The other is flow variability which is caused by the way the work is released to the system and the movement between stations. These factors may result in inconsistency in the throughput time, process yield and product quality which makes the performance of the production process unpredictable and induces process risk.

The corrupting role of variability in a manufacturing system has long been studied (e.g. Wacker, 1987; McKay *et al.*, 1988; Melnyk *et al.*, 1992; Mapes *et al.*, 2000). Inconsistent throughput time, output rate or the quality of the products degrades the efficiency and effectiveness of a production system. Any scrap or rework requires additional capacity and redoing an operation requires additional time (Hopp and Spearman, 2000). Longer throughput time will keep the customer waiting and lower the customer satisfaction, which finally damages the effectiveness of supply chain to serve its customers. In a nutshell, process risk undermines the capability of the manufacturer to efficiently fulfil customer orders and ultimately damage the performance of the supply chain. Based on the discussion, we propose:

H1(c): Process risk is negatively related to supply chain performance.

2.3 *The interrelationships between supply chain risks elements*

Supply risk and demand risk arise from operations external of a focal firm, while process risk stems internally. However, as implied by a system perspective, process risk can also result from external risks. Variability propagates (Hopp and Spearman, 2000). The unexpected changes in the supply or orders changes from customer induce fluctuations into the production process and increase process risk. As a demonstration of this propagating effect, to cope with changes in demand or supply, the gross requirements in a MRP system have to be changed between periods which ultimately induce fluctuations into the production process (Whybark and Williams, 1976) . This ripple effect can also result from the "quick fix" of using buffers to mitigate supply risk and demand risk. The buffers used could be inventory, capacity or quoting longer lead time to customers (Newman *et al.*, 1993). However, building up inventory only further masks the real demand (Mason-Jones and Towill, 1998), increases the inaccuracy of the forecast and thus posits higher threat to achieving smooth operation. Quoting longer lead times may lead to excessive congestion in the production process (e.g. Whybark and Williams, 1976) and compound the variations into production. According to Hopp and Spearman (2000), what underpins this ripple effect is that the highly variable outputs from the suppliers or orders from customers becomes the highly variable inputs into the production process of the manufacturer. Therefore, the variability originating in one firm can increase the variability of another firm along the supply chain (Germain *et al.*, 2008). Hence we propose:

H2: (a) Supply risk is positively related to process risk.

(b) Demand risk is positively related to process risk.

2.4 *Supply chain risk mitigation through collaboration*

Supply chain collaboration is two or more companies adopting a long-term perspective and working together to create unique value that neither partner can achieve alone (Lockström *et al.*, 2010; Nyaga *et al.*, 2010). Due to intensified competition, individual companies have found it difficult to compete alone but need to align their supply chain partners to achieve collaborative advantage (Kanter, 1994). In a collaborative culture, supply chain partners work together and communicate openly. They share information to improve the supply chain visibility which reduces uncertainty (Christopher and Lee, 2004); they also share knowledge and expertise in all joint efforts such as joint problem solving and new products development to smooth the operations and enhance the competitiveness. We expect that supply chain collaboration reduces supply chain risks.

Duo to the detrimental effect of supply risk to the buying company, one of the buying company's primary objectives is to maintain their suppliers' capability and performance (Krause, 1997). In supplier collaboration, the buying company is involved directly with the processes and activities of its suppliers. To ensure the quality of supplied items, the buying company may help suppliers to implement quality management programme in their facilities. They can visit the suppliers' premises and provide training to their employees or even locate their own employees at suppliers' bases (Krause, 1997). To reduce the damage caused by the capacity constraints of the suppliers, buying companies can assist by upgrading suppliers' technical capabilities and fostering continuous improvement programmes (Krause, 1997; Li *et al.*, 2005). They can also invite the suppliers to their plant to see how their items are used and include suppliers into their new product development processes, which enables suppliers to have a better understanding of manufacturing and thus better coordinate operations. As a result, suppliers' capability and performance is improved, operations of the two companies are better coordinated, the continuity of supply is ensured and supply risk is reduced. Therefore we propose:

H3(a): Supplier collaboration is negatively related to supply risk.

Information lies in the heart of reducing demand risk. In a collaborative relationship, customers are more likely to share timely and reliable demand information with the manufacturer and make their forecast better aligned with customer orders. Sharing information such as market trends and consumer preferences will also enable manufacturers

to better understand customers' needs and improve forecasting (McNally and Griffin, 2007). Customer collaboration especially can eliminate the demand variability which is provider-induced such as through sales promotion and order batching (Lee *et al.*, 1997; Croxton *et al.*, 2002; Taylor, 2006). A collaborative relationship will enable companies to work with their customers to coordinate these practices through forming better promotion plans and designing scheduled ordering policies (Cachon, 1999). Furthermore, the collaboration which is underpinned by a commitment to the long-term relationship will motivate the customers to commit to their orders and make fewer unexpected changes. In a nutshell, customer collaboration will provide both good quality information and relational commitment which makes it easier for matching the forecast with customer orders. Therefore, we propose:
H3 (b): Customer collaboration is negatively related to demand risk.

Process variability is "the consequence of a host of process selection, system design, quality control, and management decisions" (Hopp and Spearman, 2000, p. 282), hence it requires an systematic organisational efforts to reduce process risk. An internal cross-functional collaboration is such an effort in which different departments are considered not as functional silos. The departments share information and knowledge about production processes, logistics, quality as well as supply and demand status, which enables production to be better coordinated and managed. Furthermore, the practice of TQM is essential to avoid congestion in the process and narrow process variability (Schmenner and Swink, 1998) and cross-functional collaboration is a basis for achieving this (Flynn *et al.*, 1995). In this collaboration, cross-functional teams are formed to integrate and utilize different knowledge from different departments. The teams solve process related problems which enable a smooth flow of production; they can also increase the response speed to any unexpected changes and mobilize resources to handle the changes. Based on this discussion, we propose:
H3(c): Internal collaboration is negatively related to process risk.

3. Methodology

3.1 *Research instrument development*

Seven constructs were included in this study and we incorporated valid measures wherever possible. In the first step, an extensive literature review was conducted to identify relevant constructs. Since there are few extant measures for supply chain risks, we drew references from supply chain uncertainty and variability literature. Supply risk measures were based on Chen and Paulraj (2004). Their measure includes the variance of quality and an overall assessment. We added four new items to further capture the variances demonstrated through quantity and lead time as well as overall assessments of risk with the connotation of “expected value” which is integral to the concept of risk (Shapira, 1995). Based on the supply risk construct, the measures for process risk and demand risk were developed in the same manner. In terms of the measures of supply chain collaboration, we focus on the “collaborative” efforts and communication between supply chain partners. Supplier collaboration construct was adopted from Li *et al.* (2005) without the first item which is more about supplier selection. Internal collaboration was measured using the construct from Braunscheidel and Suresh (2009) and customer collaboration measures was adapted from McNally and Griffin (2007). To measure supply chain performance, we focus on the “downstream” supply chain performance and used the measure from Wagner and Bode (2008); one new item was added to measure performance in terms of quality. The measurement items are shown in Table 2.

A seven-point Likert scale from “strongly disagree” to “strongly agree” was used to measure the items. In order to prevent potential losses in response variance if all respondents choose their most important product as the context for their survey response, we adapted the method applied by Ellis *et al.* (2010). Respondents were asked to identify one product representing any percent of total sales revenue for the company and the supply chain context for this product was referred to throughout the questionnaire. As a result, the percentage represented by the chosen product ranges from 1 to 100, which enables the results of this study to be applied to a general supply chain context regarding the importance of the product.

3.2 *Data collection*

The targeted sample frame of this study consisted of 2,500 manufacturing companies randomly selected from a database purchased from a mailing list company. The respondents being sought were supply chain managers, production managers or other senior managers who were assumed to have the knowledge or be responsible for the operations of the supply chain. All mailings included a cover letter, a questionnaire and a postage-paid return envelope. The survey was mailed out in two rounds with one month interval. A total of 209 questionnaires were returned, which resulted in a response rate of 8.4% for this study. This low response rate is not uncommon in the organizational-level research due to the limited time of senior managers (Li *et al.*, 2005). After data screening, six questionnaires were excluded which resulted in an effective sample size of 203.

Almost 30% of the respondents are supply chain managers, logistic managers, purchasing managers or distribution managers who are directly involved with supply chain management. Nearly half of the respondents directly manage the manufacturing process and have a good understanding of the supply chain. The remaining 20% of the respondents are general managers, directors or CEOs who are expected to have a comprehensive knowledge of the company's supply chain operations. Half of the respondents work in medium size companies. Half of the companies have annual sales less than AUS$50million. The sample of the companies represents all the nine major industry sectors. Table 1 provides a summary of the descriptive statistics of the respondents.

Insert Table 1 near here

3.3 *Non-response bias and common method bias*

Non-response bias was checked through examining industry sector, annual sales revenue and employee numbers between early and late respondents which is also representative of non-respondents (Armstrong and Overton, 1977). All three Chi-square tests are not significant: for industry sector (χ^2 = 18.46, df=8, p=0.018), for employee numbers (χ^2 = 7.623, df=6, p= 0.26), and for annual sales (χ^2 = 7.121, df=6, p=0.31). These results indicate no non-response bias in this study.

Since the data was collected through self-reported questionnaire by one single respondent in an organization, common method bias was checked. We followed Podsakoff *et al.*'s (Podsakoff *et al.*, 2003) suggestions and took several procedural measures such as drawing measures from different sources and assuring the respondents' anonymity. Since the bias could also be reduced through carefully constructed items themselves, we conducted a pre-test and showed the items to academic and industrial experts to avoid ambiguous terms and vague concepts. In addition, we applied Harman's single-factor test to assess the bias. All items are forced into loading on one factor to examine the fit of the confirmatory factor analysis model. The model fit was very poor: $\chi2$ = 3604.77, df=625, RMSEA=0.154, NNFI= 0.73, CFI=0.74, SRMR= 0.14, and many items have loadings below 0.5, which shows that the single-factor model did not fit the data well. The results suggest that the common method bias is not an issue in this study.

4. Results

4.1 *Scale reliability and validity*

Confirmatory Factor Analysis (CFA) approach is applied due to its conceptual strengths (Bollen, 1989). Survey items, CFA factor loadings, t-values and model fit statistics are listed in Table 2. Only one item loadings (RD3) is below 0.50 and thus was deleted. In terms of the fit indexes, the RMSEA is 0.052, very close to 0.05 which indicate a very good fit. Using the 90% confidence interval for this RMSEA, its true value is between 0.045 and 0.058, thus even the upper bound is far below the cut-off value 0.08, which further support the model fit. The good model fit is solidified by the normed Chi-square = 1.54, below 2.0, and CFI=0.95, indicating very good fit. Although the SRMR is above 0.05 which is a more conservative threshold, the value of 0.063 is already far below 0.09 which indicates acceptable fit for a model with larger than 30 variables and CFI > 0.92 (Hair *et al.*, 2010). These results indicate the unidimensionality of the scale.

Scale reliability was assessed through Cronbach's alpha and construct reliability (CR) value. As reported in Table 2, all Cronbach's alpha and CR values are well above the cut-off value 0.7, which provide evidence for good scale reliability.

Insert Table 2 near here

CFA is also used to check convergent and discriminant validity. The measurement model fit of this study is good and all the items have factor loadings of at least 0.5 as well as significant t values. The results provide evidence for convergent validity. To test discriminant validity with CFA, models are constructed for all possible pairs of constructs and the correlation between these two constructs is fixed at 1.0, which actually changes the two construct models into a single construct model. If the fits of these two models are significantly different, discriminant validity is supported (Bagozzi *et al.*, 1991). In our study all these tests were statistically significant and support the discriminant validity of the constructs.

4.2 *Results of the structural model analysis*

SEM is used to test the hypotheses. We used LISREL 8.8 with the maximum likelihood estimation method. Figure 1 reports the results of the structural model analysis. The goodness of fit index for our model are χ^2 = 951.29 with df=614, normed chi-square= 1.55, RMSEA= 0.052, 90 % confidence interval for RMSEA = (0.046; 0.059), NNFI= 0.94, CFI=0.95, SRMR= 0.076. These indices generally indicate a good model fit (Hair *et al.*, 2010).

Insert Figure 1 near here

Seven of the eight hypotheses are supported as indicated in Table 3. Process risk and demand risk both have negative relationships with supply chain performance, supporting H1b and H1c. But the relationship between supply risk and supply chain performance is found to be non-significant, failing to support H1a. The results provide support for all the hypothesized relationships between supply chain collaboration and supply chain risks, as indicated by the significant relationships between supplier collaboration and supply risk (H3a), internal collaboration and process risk (H3c) and customer collaboration and demand risk (H3b). The analysis finds a very strong positive relationship between supply risk and process risk indicated by the path estimate which is 0.61; the relationship between demand risk and process risk is not as strong but still significant (the path estimate is 0.19). H2a and H2b are both supported.

Insert Table 3 near here

5. Discussions and implications

In general, this study provides evidence that supply chain operational risk undermines supply chain performance. However, contrary to our expectations, supply risk is not found to have a direct relationship with supply chain performance. On the other hand, as demonstrated in our study, there is a very strong relationship between supply risk and process risk (the path estimate is 0.61). Therefore, one explanation of this not-supported relationship is that the negative effect of supply risk on supply chain performance is completely mediated by process risk. This mediated effect of process risk between supply risk and supply chain performance can be demonstrated again using the MRP system as an example. If there is a possible delay in the material supply, the buying firm may mitigate this risk with planning a delivery ‘window’ into MRP or make changes in the production plan between periods. This eliminates the direct impair of delayed incoming material but induces possible variations into the production processes.

Compared with supply risk which has no direct effect on supply chain performance, the findings show that demand risk has a direct negative effect on operational performance. This may suggest that firms find it more difficult to cope with demand variations than supply variations, which makes the negative effect from demand side more visible. There are two plausible explanations here. First, operational performance is concerned with finished products, while supply risk is concerned with raw materials or components. The problem with supplied materials does not directly affect the end product (i.e. output performance) since it can be rectified within the production system. For example, firms may keep some stocks of raw materials to anticipate this problem. Second, in conjunction with the inventory issue, the direct effect of demand risk on performance could suggest that firms feel more reluctant to keep inventory of finished products to counter demand fluctuations compared to keeping stock of raw materials to counter supply risk. This is probably because the potential loss (in dollars value) of keeping finished products is higher than that of raw materials.

The relative effect sizes of the path estimates provide new insights into how supply chain operational risk weakens supply chain performance. Although there is no direct effect of supply risk on supply chain performance, the total effect through process risk is 0.61(-0.35) = -0.21. The total effect of demand risk on supply chain performance is (-0.16) + 0.19 (-0.35) = -0.23. Compared with the effect of process risk on supply chain performance (the path estimate is -0.35), it is clear that process risk has the strongest effect on supply chain performance, nevertheless supply risk and demand risk equally affect the performance significantly. Furthermore, supply risk has more than three times the effect on process risk (the path estimate is 0.61) than does demand risk (the path estimate is 0.19), which implies that supply risk has a severer effect on the firm's production than demand risk. In the light of lean concept, failure in upstream supply chain will produce a chain of reaction on the downstream side. This probably explains the research finding that managers clearly perceive more supply risk than demand risk (Christopher *et al.*, 2011) .

The study shows that supply chain collaboration can decrease supply chain risk. The rational underlying this could be explained from two perspectives. First, in supply chain collaboration, sharing information reduces uncertainty. Information is the counterpart of uncertainty (Downey and Slocum, 1975). Uncertainty results from "lacking sufficient information to predict accurately" (Milliken, 1987, p. 136). In the supply chain context, Christopher and Lee (2004) demonstrate through the "risk spiral" to describe how lack of information leads to a "self-perpetuating descent into chaos" (p. 389). Without visibility of upstream and downstream flows, managers are uncertain about the order cycle time, demand forecasts, suppliers' capability to deliver, etc. Hence, they rely on double guessing which leads to overreaction that further masks the visibility and increases risks. Information sharing is the starting point of supply chain collaboration (Bowersox et al., 2003). Along with the operational or/and strategic information available across the supply chain, better visibility is achieved and risk is reduced.

This collaborative approach to mitigate risk is also underpinned by the inherent association between knowledge and variance-based view of risk. "Variation and knowledge are inversely related; i.e. large process, product, and service variation indicate less knowledge" (Anderson and Rungtusanatham, 1994, p. 485). Bohn (1994) has categorized eight stages of knowledge to understand processes, ranging from complete ignorance to complete knowledge. In the first three stages it is impossible to control processes, while control starts in Stage Four although it is not precise, and Stage Five is control of variance indicating precise control. Hence less variance indicates more knowledge. This relationship not only holds in production processes but also the supply chain. Supply chain variability is "as a proxy for depth and breadth of knowledge" (Germain *et al.*, 2008, p. 567). The required knowledge covers not only the internal production processes but also the whole supply chain environment, including both upstream and downstream. Supply chain collaboration provides a superior approach than market or hierarchical governance to collect and integrate such knowledge (Grant and Baden-Fuller, 1995). Knowledge of supplied items, production processes, technology development, market trends and customer preferences is shared in joint problem solving and other collaborative activities, which deepens supply chain partners' understanding of the whole supply chain environment and enables them to better control and reduce the variability of the flow. There is also new knowledge generated through joint product design, collaborative research, or joint process innovation, which enhances the capability of the supply chain to response promptly to environmental changes. Hence, our research implies that supply chains provide a primary mechanism for supply chain risk mitigation (Cohen and Kunreuther, 2007) through building up a knowledge-based supply chain.

5.1 *Theoretical and managerial implications*

The theoretical contribution of this study is underlined by the application of the theory of Swift, Even Flow in supply chain contexts. This theory was first proposed in 1998 (Schmenner and Swink, 1998) but there has been limited research to use this theory and test its propositions. Schmenner (2001) has supported the validity of this theory through using it as an explanation of productivity gain in history. Bendoly and Kaefer (2004) used the theory as a theoretical lens to understand the benefits of ERP in B2B commerce, Seuring (2009) applied this theory to develop a framework of product-relationship-matrix in supply chain design. Fredendall *et al.* (2009) conducted a case study to examine the application of this theory in a hospital operations. Our study expands the application of this theory to a direct supply chain, examining the flows between supplier, manufacturer and customer, and also empirically tested its propositions in survey based research. This answers the call for verification of the theory through empirical testing (Schmenner, 2004) and expands the application of the theory within a focal company to the supply chain level.

Our research also contributes to the knowledge-based view. As an outgrowth of resource-based view, the knowledge-based view posits knowledge as the most strategically important resource of a firm to achieve sustainable competence (Grant, 1996). While much research has been conducted to understand how knowledge within organizations improves performance, there is a lack of studies examining performance enhancement offered by supply chain knowledge (Craighead *et al.*, 2009). Our results vis-a`-vis supply chain risk lend support to this theory. Furthermore, our study also implies an expansion of the view from firm level to supply chain level. In the knowledge-based view of the firm (Grant, 1996), a firm is the integrator of knowledge; it allows individuals to develop their own expertise as well as a establishing mechanism through which individuals integrate their different knowledge. Along with the competition moving from the firm level to the supply chain level, supply chains could be posited to be the integrator of knowledge. It permits individual firms to develop their own speciality while integrating knowledge across the chain to build up collaborative advantage. The study advocates a knowledge-based view of supply chain.

This study informs managerial practice in two important ways. One is the importance of enhancing the internal capability of manufacturing. While managing supply chain partners (i.e. supplier and customers) is (increasingly) important, this study has shown that managers must not lose guard on the internal processes of the firms. Our research shows that the process risk has the severest direct effect on supply chain performance, and more importantly, the majority of external risks, either from the supply or the demand side, is mediated through process risk. It thus would be imperative for companies to build responsive and robust production processes to respond to any external changes, which minimizes their effects on supply chain performance. In this sense, internal manufacturing capability of being responsive and robust acts as a hedge for external supply chain risk. The other is the importance of building a knowledge-based supply chain to compete in a more uncertain environment. Environment uncertainty has the potential to be destructive of current knowledge in terms of both "know about" and " know how" as well as a held competence (Germain *et al.*, 2001). "In an economy where the only certainty is uncertainty, the one sure source of lasting competitive advantage is knowledge" (Nonaka, 1991, p.96). Deep rooted knowledge and the speed to replace old knowledge with new knowledge are distinctive to achieve competency in a changing environment. Managers have a greater need for the capability to identify, collect and integrate knowledge at the supply chain level. A knowledge base could be established and a mechanism is needed to store, share and generate knowledge within the whole networks.

6. Conclusions, limitations and further research

This research is a survey-based study to verify two relationships: one is supply chain risk undermines supply chain performance, and the other is supply chain collaboration mitigates supply chain risk. The perspective taken in this study is consistent with the supply chain philosophy which emphasises on a system view of a supply chain rather than a set of fragmented parts (Mentzer *et al.*, 2001). The supply chain risks studied are from end-to-end encompassing supply risk, internal production process risk and demand risk. The collaboration is also examined from both internal and external perspectives. The research results support that: first, as stated by the Theory of Swift, Even Flow, the evenness of flow predicates performance. Second, through supply chain collaboration, supply chain risk can be better managed and mitigated.

This study has several limitations which provide further research opportunities. Since this study collected data only from Australian manufacturing companies, generalization of the findings to other industries such as service industry or another country which is very different from Australia should be done with caution. Causal inferences should be made also with caution due to the use of cross-sectional data. Our research supports the Theory of Swift, Even Flow with examining the flow evenness. Further research focusing on the "swiftness" component of the theory should be conducted. Moreover, this study focused on operational risk and adopted the variance-based view of risk. Further research could take other perspectives of risk into account to enrich risk management strategies. This research advocates a knowledge-based view of supply chain, the conceptualization and operationalization of which needs to be further explored.

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Table 1 Descriptive statistics of the respondents

Characteristics	Frequency	Percent of sample
Respondent position		
Supply Chain / Logistic Manager	42	20.1
Operations/Production/Plant/Site Manager	91	43.5
Purchasing/Distribution Manager	13	6.2
General Manager/Director/CEO/VP	41	19.6
Other Senior Managers (finance, technique, HR, etc.)	18	8.6
Missing	4	1.9
Industry sector		
Food, Beverage and Tobacco Manufacturing	48	23
Textile, Clothing, Footwear and Leather Manufacturing	6	2.9
Wood and Paper Product Manufacturing	6	2.9
Printing, Publishing and Recorded Media	7	3.3
Petroleum, Coal, Chemical and Associated Product Manufacturing	27	12.9
Non-Metallic Mineral Product Manufacturing	8	3.8
Metal Product Manufacturing	20	9.6
Machinery and Equipment Manufacturing	51	24.4
Other Manufacturing	16	7.7
Missing	20	9.6
Number of employees		
Less than 20	20	9.6
20-49	41	19.6
50-99	44	21.1
100-249	44	21.1
250-499	21	10
500-999	17	8.1
1000 or more	20	9.6
missing	2	1
Annual sales volume (in AUS$ millions)		
Less than 10	35	16.7
10-19	32	15.3
20-49	38	18.2
50-99	31	14.8
100-249	35	16.7
250-999	11	5.3
1000 or more	17	8.1
Missing	10	4.8

Table 2 Construct items, factor loadings, t value and scale reliabilities

Items		Factor loading[b]	t value
Supply risk[c]	**Cronbach's alpha=0.90, CR= 0.90**		
RS1: Our suppliers meet our quality specification requirements on a consistent basis.		0.66	10.26
RS2:Our suppliers meet our required delivery lead times on a consistent basis.		0.81	13.65
RS3:Our suppliers meet our volume requirements on a consistent basis.		0.79	13.08
RS4:Our suppliers consistently meet our overall requirements.		0.88	15.44
RS5:Our suppliers always deliver our orders as promised.		0.81	13.51
RS6:Our suppliers have the capacity to meet our requirements.		0.69	10.75
Process risk[c]	**Cronbach's alpha=0.81, CR= 0.81**		
RP1:The process has very low variance in daily production output rate.		0.52	8.3
RP2:The process has very low variance in production lead times.		0.53	8.38
RP3:The process has very low variance in product quality.		0.60	8.9
RP4:The process consistently fulfils customer orders.		0.77	11.89
RP5:The process always produces as planned.		0.76	11.65
RP6:The process has the capacity to fulfil customer orders.		0.68	10
Demand risk[c]	**Cronbach's alpha=0.86, CR= 0.85**		
RD1:Our customers place orders consistent with their forecasted demand volume.		0.89	13.4
RD2:Our customers place orders consistent with their nominated delivery lead time.		0.67	9.43
RD3[d]:Our customers place orders consistent with their nominated product specification.		—	—
RD4:Our customers provide us reliable forecasts on their demands.		0.81	16.37
RD5:Our customers commit to their demand forecasts.		0.68	13.74
RD6:Our customers' actual demands are consistent with our forecasts.		0.55	8.01
Supplier collaboration	**Cronbach's alpha=0.80, CR= 0.78**		
SCR1: We have helped our suppliers to improve their product quality.		0.73	9.9
SCR2: We regularly solve problems jointly with our suppliers.		0.85	12.24
SCR3: We have continuous improvement programs that include our suppliers.		0.62	10.61
SCR4: We include our suppliers in our planning and goal-setting activities.		0.50	8.99
SCR5: We actively involve our suppliers in new product development processes.		0.52	8.11
Internal collaboration	**Cronbach's alpha=0.81, CR= 0.81**		
ICR1: In our firm, we use cross functional teams to solve problems.		0.66	9.64
ICR2: In our firm, senior management communicates frequently about goals and priorities.		0.73	11.14
ICR3: In our firm, formal meetings are routinely scheduled among various departments.		0.68	9.7
ICR4: In our firm, informal, face-to-face meetings often occur when problems or opportunities arise.		0.64	9.31
ICR5: In our firm, we encourage openness and teamwork.		0.72	10.75
Customer collaboration	**Cronbach's alpha=0.87, CR= 0.86**		
CCR1:We have committed to the relationship with our customers.		0.71	13.15
CCR2: We are willing to make adjustments to support this relationship.		0.69	12.8
CCR3: We maintain interactive, two-way communications with our customers.		0.79	12.51
CCR4: We cooperate with our customers to ensure smooth operations.		0.85	12.97
CCR5: We regularly solve problems jointly with our customers.		0.70	10.2
Supply chain performance	**Cronbach's alpha=0.87, CR= 0.88**		
PERF1: Product quality		0.56	8.3
PERF2: Order fill capacity		0.83	13.97
PERF3: Delivery dependability		0.85	14.61
PERF4: Delivery speed		0.79	13.06
PERF5: Customer satisfaction		0.81	13.48

a. Measurement model fit statistics: χ^2 = 929.99, df=604, normed chi-square= 1.54, RMSEA=0.052, NNFI= 0.94, CFI=0.95, SRMR= 0.063.

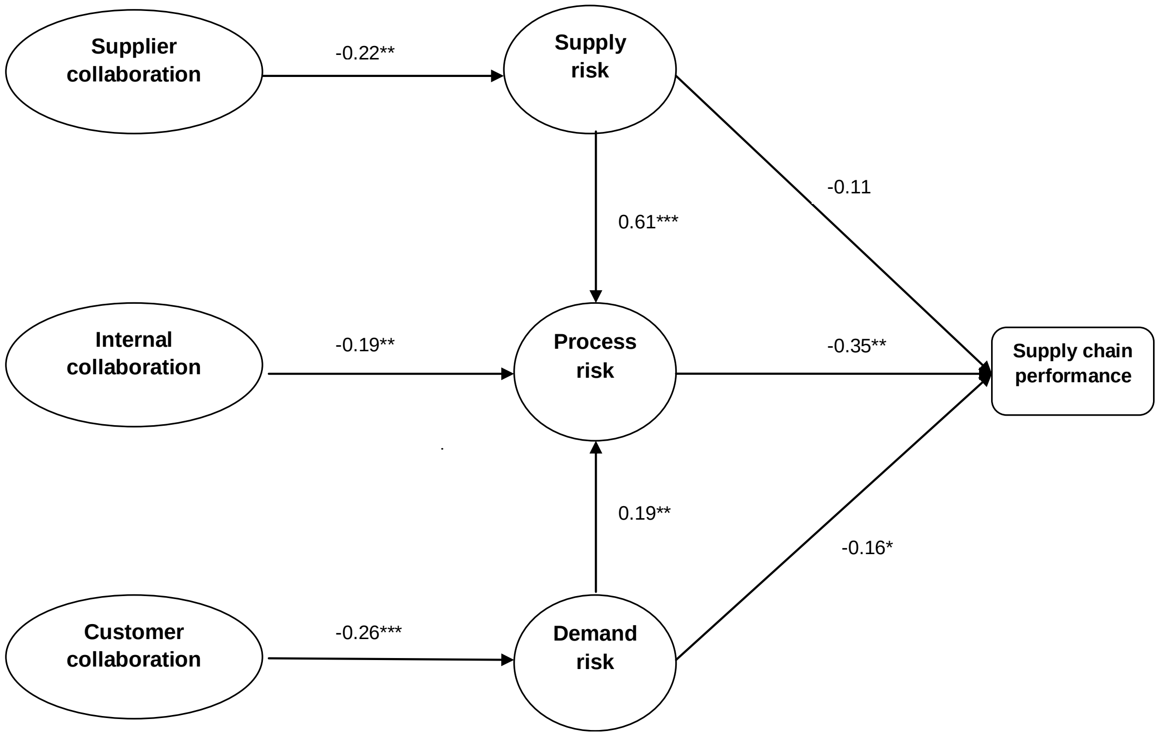
b. Standardized coefficients; all significant at $p<0.001$
c. Reverse-coded
d. Dropped due to low factor loading

Table 3 Results of hypotheses using SEM

Path	Standardized coefficient	t-value	Result
Supply risk → Supply chain performance	-0.11	-1.10	H1a: not supported
Demand risk → Supply chain performance	-0.16	-2.10*	H1b: supported
Process risk → Supply chain performance	-0.35	-2.80**	H1c: supported
Supply risk → Process risk	0.61	5.43***	H2a: supported
Demand risk → Process risk	0.19	2.68**	H2b: supported
Supplier collaboration → Supply risk	-0.21	-2.71**	H3a: supported
Customer collaboration → Demand risk	-0.27	-3.32***	H3b: supported
Internal collaboration → Process risk	-0.19	-2.56**	H3c: supported

* $p<0.05$, ** $p< 0.01$, *** $p<0.001$

Figure 1 Results of the structural model analysis



a. Model fit statistics: χ^2 = 951.29, df=614, normed chi-square=1.55, RMSEA=0.052, NNFI= 0.94, CFI=0.95, SRMR= 0.076.

b. * p< 0.05, ** p<0.01, *** P < 0.001