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Towards Forest Supply Chain Risks

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ABSTRACT

Forest supply chain has drawn increasing attention worldwide. This paper develops a supply chain risk (SCR) framework in the forest industry. Forest supply chain risk has become an obstacle to gaining competitive advantages and developing sustainable forestry. However, very few studies attempt to investigate SCR in an integrated forest supply chain. It is essential to understand and manage these risks, which may impede the industry's performance improvement. An extensive literature review, and Delphi study are performed to develop and identify the major forest SCRs. The result has shown that the five types of forest SCRs are recognized. In this study, we extend SCR into the forest sector and contribute to the forest supply chain management literature. Further research is needed to address specific problems associated with types of SCRs and develop appropriate forest SCR mitigation strategies in contexts.

Keywords: *forest supply chain; risk classification; risk management; supply chain risk; sustainability*

1. INTRODUCTION

A supply chain's complexity increases the level of risks in a supply chain. In addition, COVID-19 pandemic, Brexit, China-US trade war, Russian invasion of Ukraine, etc. These unpredicted events add more risks to global supply chains (Velayutham *et al*., 2021). Supply chain risk (SCR) is a multidimensional, and hard-to-capture concept (Bandaly *et al*., 2012; Gaonkar & Viswanadham, 2007; Heckmann *et al*., 2015; Manuj & Mentzer, 2008). Many earlier studies have found that SCR has adverse impacts on firm's profit (Sodhi & Tang, 2012; Wang, 2018; Wieland & Wallenburg, 2012). The potential disruptions of the operations perceived as a threat by managers, and as a sign of unsustainable operation by stakeholders (Davis, 1993; Waters, 2011). Continuous smooth operations have the opposite effect, employees and shareholders perceive it as a guarantee of sustainability. Consequently, SCR mitigation support the industry's long-term goals, and satisfaction of stakeholders (Zsidisin & Ritchie, 2009). Furthermore, SCR is viewed as an important part of sustainable logistics and supply chain management (Grant *et al*., 2017). Although the concept of SCR has been long discussed in the literature, very few studies have been conducted on the forest supply chain.

The forest industry plays a vital role in the environment and society and contributes to the regional and national economic development in many countries. Besides, forests can reduce national, regional, and global CO2 emissions (Tubiello *et al*., 2021). In 2020, globally, the total timber harvest was 1.40 billion m^3, of which 82% was industrial roundwood and 18% was wood fuel (FAO, 2021). The COVID-19 pandemic brought great uncertainty to forest product markets worldwide in 2020, and both production and consumption were subject to rapid and extreme fluctuations (FAO, 2021). Having said that, forest production will continue to rise. Increasing forest production will be accompanied by increasing international competition, increased supply chain complexity and higher customer expectations. All this requires robust forestry risk management.

Modern forest supply chain management faces SCRs not only originating from external environments but also internally. These risks include forest supply chains fragmented with internal competition, limited information exchange, inadequate capability, inefficient business processes, poor collaboration among small forest growers, high operating costs, inadequate R&D and business innovation (Bezuidenhout, 2017; Wang, 2020). Forest supply chain risk management can help improve supply chain resilience and sustainability in the forest industry. In addition, lack knowledge on efficient and effective forest SCRs management impedes sustainable development in the forest sector. Thus, it is important to handle supply chain risks, uncertainties, unforeseen events, complexity, and vulnerability in supply chain to maintain the economic sustainability of firms (Wang *et al*., 2018b).

The objective of the paper is to posit a validated classification of forest supply chain risks through the literature review and analysis of expert responses in a Delphi study. SCR has drawn attention in industries (Jüttner *et al*., 2003; Manuj & Mentzer, 2008; Peck, 2006; Tang, 2006; Wang *et al*., 2018a; Zsidisin & Ritchie, 2009). However, there has been little discussion on forest supply chain management. Different industries have different supply chains, forest supply chain has unique characteristics. Identifying and understanding these forest supply chain risks is the baseline of risk mitigation. To fill the research gaps, we attempt to answer the following questions:

RQ1. What are the risks in a forest supply chain, and how can they be categorized?

RQ2. What are the major forest supply chain risks in New Zealand post COVID-19?

This study develops a conceptual framework of identifying SCRs in forest industry to support the sustainable development of the forestry business. Moreover, we conduct a Delphi survey to investigate the forest risk post COVID in New Zealand and verify the framework.

2. LITERATURE REVIEW

2.1 What is Risk?

Although people often talk about risks, it is a complex concept (Flynn *et al*., 2021; Heckmann *et al*., 2015). Conventionally, early studies assess risk in terms of the frequency and the possible impacts, thus risk is a blend of the probability and the severity of consequences (Slovic, 2000). Risk can be either subjective (perceived) or objective (Emblemsvåg, 2010).

Risk is considered by some to be a subjective phenomenon (Emblemsvåg, 2010; Khan & Burnes, 2007). People may have perception of the likelihood or impacts of an event. For example, experienced managers may feel less risky than managers who have little experience when they face the same risks. From psychological capital's perspective, Wu (2015) argue that "*happiness and perceived level of risks are negatively correlated and tend to overestimate the threat*". This would help us to understand the subjective risk at individual level.

The objective concept of risk may include the risk sources, risk events, risk consequences; Risk sources may include people, resource, organization structure and/or process. Risk events refer to a specific situation where the risk occurs, such as mistake was caused by outdated information, possibility of events, etc., this may lead to various risk consequences e.g. financial loss, harm, damages, etc. It is difficult to map every single risk in the real world (Wang, 2018). Traditionally, risk comprises two components including potential losses and likelihood of those losses (Manuj & Mentzer, 2008). However, it is possible to reduce the scope of risks in certain context to prioritize the risks in terms of different purposes. In this study, we focus on the objective risks. Firstly, we map a typical forest supply chain from forest to the final customer (**Figure 1**). A conventional supply chain includes three main stages: 1) Sourcing, 2) Processing / Manufacturing, 3) Supply / Delivery (Christopher, 2005). Following this logic, we categorized SCRs.

2.2 Forest Supply Chain

In the early 1980s supply chain was an emerging management discipline; supply chains vary by the industries and businesses they serve. The supply chain link all steps of processing from sourcing raw material to the delivery for the end consumer (Zsidisin & Ritchie, 2009). Material, information and financial flows among entities to make and deliver goods from the source to the end user (Christopher, 1998; Tang & Nurmaya Musa, 2011). Therefore, forest supply chain is an integrated network of forest companies, wood product manufacturers, and retailers provide wood products and services from forest to the end users. A typical forest supply chain comprises various businesses, companies and customers. The major stakeholders include forest growers, harvesting units, wood products manufacturers, wood traders and end users (Munsell *et al*., 2017; Vanzetti *et al*., 2017).

Forest supply chain is different from other industries, it has unique characteristics. For example, Confucius say: "*If your plan is for one-year plant rice. If your plan is for ten years plant trees. If your plan is for one hundred years educate children*". It can take a long time to grow and replant forest. In addition, forest industry includes various stakeholders e.g. tree growers, plants / mills, secondary wood processors, wood traders, end users, etc., the interdependence relationships among the supply chain partners are complex (Flynn *et al*., 2016). Forest activities can be distinguished as two broad areas, the biological or agricultural process extends from tree genetics to harvesting, the other one is the industrial manufacturing from mills to the final use (Campanella *et al*., 2018). Although forest supply chain can be considered as a part of agricultural or manufacturing supply chain, forest supply chain is more vulnerable, such as it can take 20 years for a forest to recover from a hurricane and forest soils take longer to recover from fires; different manufacturing processes, different markets and types of customers that differs from other manufacturing or agriculture industries, this would increase the uncertainty, consequently add more risks into the forest supply chain. From forest to the final customer, forest industry has a long supply chain which involves multiple stakeholders and multiple decision-making groups, for example the raw materials - logs needs to go through a series of processing to reach the final customers.

Most previous studies in the forest supply chain focus on the modelling, design and planning, for instance, Gunnarsson *et al*. (2004) studied operational problem of converting forest residues into forest fuel. Radics *et al;*. (2016) introduced a multi-attribute optimization of the forestry supply chain. Vanzetti *et al*. (2017) presented a formulation for the optimum design of the forest supply chain. Broz *et al*. (2017) analyzed supply chain integration. Munsell *et al*. (2017) studied the forest certification among supply chain actors including private forest owners, logging contractors, and wood products manufacturers. Campanella *et al*. (2018) applied the mathematical tool to optimise the material flows among forest sites, plants, and customers to maximize the overall benefit. Meyer *et al*. (2019) considered the social aspect in supply chain design in Argentina. Rijal *et al*. (2020) formulated a modeling approach for forest management planning. However, lack

of knowledge or awareness of forest SCR management should draw attention of the researchers in the forestry sector.

Forest supply chains are integrated networks composed of suppliers, wood processors, and logistics providers that work across organizational boundaries to deliver goods and services to consumers (Bettinger *et al*., 2017; Sun *et al*., 2018). It also comprises many types of wood products including logs, wood panels, pellets, biomass, etc. They are used for different purposes and prices vary depending on wood quality, economic environment, and market fluctuation (Shabani *et al*., 2013). Today, scientists strive to develop new innovative wood-based materials. This will add more complexity into the forest supply chain. Moreover, supply chain is a system with complex interdependence relationships (Flynn *et al*., 2016).

A typical supply chain system includes three types of flow, physical goods, information, and finance (Christopher, 2005). The paper tries to simplify and map a typical forest supply chain, which is illustrated in **Figure 1**. The arrows represent physical goods including raw materials, work-in-progress and finished products, e.g. logs, sawnwood, plywood, veneers, chips, wood residue, etc. As discussed before, it is important to set a clear scope for risk identification, we look at a big picture of the entire forest supply chain from forest to final customers, the first stage is sourcing, including forest and harvesting; the second stage is processing / manufacturing, including various plants, mills and secondary wood processing in forestry sectors; the final stage is supply / delivery, including logistics, market demand and transport among the supply chain partners and customers.

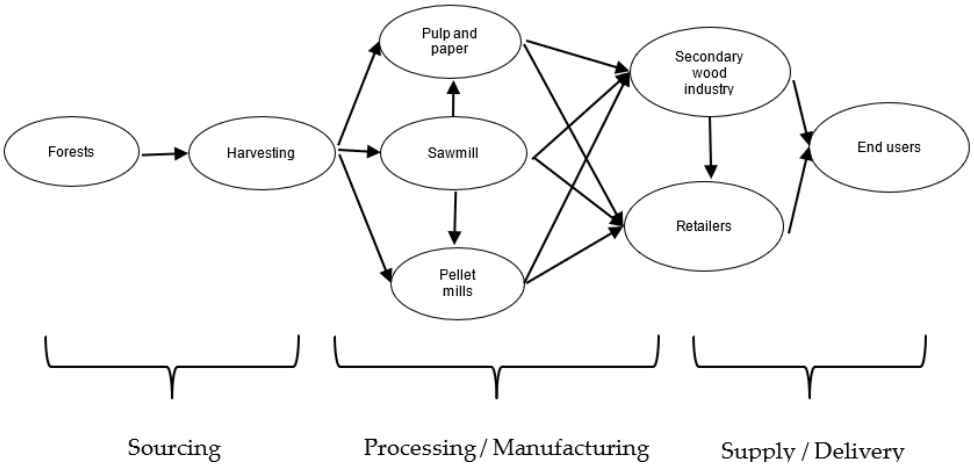

Figure 1 A Typical Forest Supply Chain

2.3 Supply Chain Risk

SCR is an important area in supply chain management (Ahlqvist *et al*., 2020; Ghadge *et al*., 2012; Sodhi & Tang, 2012; Zsidisin & Ritchie, 2009). Gaonkar and Viswanadham (2007) found that the SCR was the distribution of the loss from the variation of supply chain outcomes, their likelihood, and their subjective values. SCR may refer to operational risks or disruption risks (Ganguly & Kumar, 2019; Mullai *et al*., 2009; Tang, 2006; Zsidisin & Ritchie, 2009). Tang (2006) stressed that the business impact of disruption risks was higher than that of the operating risks in most cases. The current study focuses on the SCR which may cause negative impacts on forestry.

The SCR inherent in decisions, networks, people, equipment, organization structure, business processes and activities (Zsidisin, 2003). And SCR sources may originated from interorganizational transactions (Jüttner, 2005). There are different ways to classify the SCRs in terms of purposes. Hauser (2003) studied manufacturers' risks include supplier risk, product liability manufacturing risk and transportation risk. Jüttner *et al*. (2003) classified SCR into three categories: internal to the supply chain, external to the supply chain, and network related. Joseph (2004) applied physical, financial, informational, and relational innovational identification. Chopra and Sodhi (2004) studied supply risks, catastrophes, systems, forecast, intellectual property, inventory and capacity. Sodhi and Lee (2007) identified demand, supply, and contextual risks in the consumer electronics industry. Manuj and Mentzer (2008) suggested that risk was the projected outcome of a probable event, the impact of losses, speed of risk and frequency are important dimensions of risk in the global supply chain. There are four types of global SCRs including supply risks, demand risks, operational risks and security risks. Sreedevi and Saranga (2017) investigated supply risk, manufacturing process risk and delivery risk. Brusset and Teller (2017) discussed external SCRs and internal SCRs. Wang (2018) studied the SCRs in logistics and transport operations incorporating demand, operation, and environment uncertainty and risk.

3. METHODOLOGY

We adopted a two-phase approach in this study. The phase one is an extensive literature review regarding SCR and forest supply chain. Relevant studies are discussed. The paper also delineates a typical forest supply chain network to help the readers better understand the SCRs Classification Framework. The second phase is to categorise and identify the main SCRs in forest industry. In the second phase, a Delphi survey is applied to investigate the forest supply chain risks post COVID-19 in New Zealand. We used the framework to demonstrate the main forest supply chain risks post COVID-19.

3.1 Framework Development for the Forest Supply Chain Risk

In the literature review phase, Scopus, Web of Science and Google scholar were used to find relevant journal articles for forest SCR, forest supply chain, SCR mitigation studies in English language. Keywords included: forest supply chain, risk, SCR, risk management, risk identification, and forest. Selection of appropriate databases and screening of references according to relevance to the topic and abstract. Due to limited number of forest SCR studies appeared in forest literature, we also search relevant SCR studies, total 65 papers have been reviewed and analyzed for the proposed forest supply chain risks framework in this study. The key journals referred including Journal of Supply Chain Management, International Journal of Logistics Management, Journal of Cleaner Production, International Journal of Production Research, Operations and Supply Chain Management, International Journal of Production Economics, etc. To ensure that the classification of the forest supply chain risk is reliable and valid, we adopt the types of risk from logistics and supply chains including supply, demand, manufacturing, transport, and environment (Ho *et al*., 2015). Section 4 presents the classification of the forest supply chain risk.

3.2 Application of the Delphi survey

The Delphi method is a systematic process to evoke expert opinion (Dalkey & Helmer, 1963; Sourani & Sohail, 2015). It is an anonymous survey tool to collect data. In the second phase, the Delphi survey technique is used to gather opinions and develop a consensus among a group of experts including forest research scientists, academics, forest managers and government consultant have been invited to participate the Delphi study. According to the expert opinion, we validate the main types of SCRs across an entire forest supply chain network. An analysis of classification framework is used to propose a forest SCR framework. The types of forest SCR are proposed in terms of the previous studies (Ho *et al*., 2015; Mullai *et al*., 2009), and the characteristics of forest industry.

The initial list of expert panel contains 25 individuals mainly from New Zealand. Most of the experts have worked in the New Zealand forest sector for more than 10 years. The first round of the Delphi study was conducted in July 2020, we asked the experts to express risks and concerns in the New Zealand forest supply chain at the beginning of COVID. An online questionnaire was sent via email to the expert panel. 20 respondents (n=20) replied to the online questionnaire in the first round of the Delphi study. They include 6 managers/directors, 4 research scientists, 4 academics, 3 government consultants, and 3 forest owners. The second round of the Delphi study was conducted in Oct 2022, we followed up the experts, and emailed them to obtain the latest opinion about the forest supply chain risk post COVID. Some people changed jobs, we could not get hold of them, and some people retired, we have 12 experts participated (n=12) in the second round of the Delphi study. it is recognized that a minimum appropriate size would include seven or eight experts (Sourani & Sohail, 2015). The size of panels in this study is sufficient. Three authors have reviewed and verified the codes.

Based on a literature review and a qualitative text analysis using NVIVO, a classification of forest supply chain risk has been developed. The Delphi study identified major forest supply chain risks in New Zealand post COVID-19.

4. RESULTS

4.1 Classification of Risks in the Forest Supply Chain

SCRs may include types of risks due to variations in information, goods and financial flows from the first supplier to the delivery of the goods to the end user (Tang & Nurmaya Musa, 2011; Wang, 2018). Lack of proper information flow across the forest supply chain causes significant stresses and value loss (Radics *et al*., 2019). SCR can be a mismatch between supply and demand (Zsidisin, 2003) or caused by knowable uncertainties or unforeseeable circumstances (Wang, 2018). In this study, we have created a forest SCR classification framework (**Figure 2**), which includes five types of forest SCR. They are supply / source risk, manufacturing risk, logistics and transport risk, demand / market risk and environmental risk. Based on a literature review from previous studies in SCR literature (Ho *et al*., 2015; Manuj & Mentzer, 2008; Sodhi & Tang, 2012; Wang *et al*., 2018b), and a qualitative analysis of experts' responses, five types of forest SCRs are derived. **Table 1** illustrates a summary of SCR in forestry. Each type of risk is described as follows. This would address the first research questions in this study.

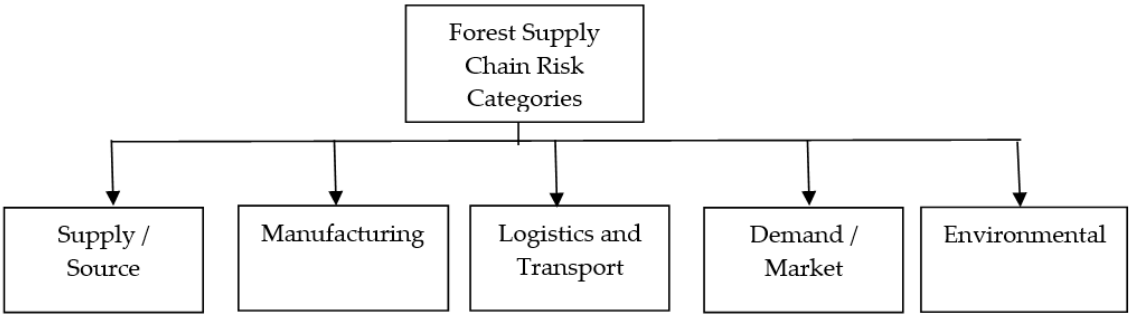

Figure 2 Forest SCRs Classification Framework

4.1.1 Supply / Source Risk

The SCRs may be caused by the problems of coordinating supply and demand (Kleindorfer & Saad, 2005). Conventionally, supply risk includes the probable risk events with inbound supply that can have significant negative impacts on the downstream supply chain (Sreedevi & Saranga, 2017; Zsidisin, 2003). In the forest supply chain, supply / source risk includes risks associated with forest management, including nursey, replanted management, and pre-harvest risks. Forestland plays a vital role in the forest supply chain; it directly influences the wood supply / source across the forest supply chain. This risk may influence the upstream supply chain, such as production, and manufacturing. This supply /source risk focused on both inbound supply risk and forest plantations risks excluding the natural environmental risks.

4.1.2 Demand / Market Risk

Demand / Market risks mean negative impacts from the downstream supply chain including markets (Ho *et al*., 2015; Zsidisin, 2003). Demand / market risk is the results of risk events in the outbound flows that changes the probability of clients making orders, and/or uncertainty in the magnitude and variety desired by the clients (Manuj & Mentzer, 2008). All the customer-side and market risk are considered in the demand risk (Wang *et al*., 2020). In a forest supply chain, a change in demand can significant influence the price and forest operations (Shabani *et al*., 2013). The forest markets may include both domestic and international markets. China is the world's largest importer of timber, pulp, and paper (Richards *et al*., 2022).

4.1.3 Manufacturing Risk

Manufacturing firms, mills and processors are significant in the forest supply chain to add value, produce and deliver goods for customers. In this paper, manufacturing risk is the probability of risk events within the company that impact the company's ability to provide goods and services, quality and timeliness of production, and/or the profit (Manuj & Mentzer, 2008). Harvesting is an important manufacturing process in the forest supply chain, the harvesting risk is considered as a part of the manufacturing risk in this framework.

4.1.4 Logistics and Transport Risk

Logistics risk, consisting of sources of organizational risk, lies within the boundaries of the supply chain and ranges from delivery to vehicles failure (Jüttner *et al*., 2003). It is a type of operational risk associated with logistics and transport operations (Wang *et al*., 2018b). In the forest supply chain, logs and wood products heavily relied on the infrastructure, land and/or water transport. The logistics and transport risk closely associated with operational cost and supply chain efficiency (Wieland & Wallenburg, 2012). The logistics and transport risk are proposed as an important risk category in the forest supply chain. The costs of logistics and transport make up a large part of the price of wood.

4.1.5 Environmental Risk

Environmental risk is a common type of SCRs (Jüttner *et al*., 2003; Wang, 2018). Forest sector is strongly influenced by the government policy outputs and natural environment. The experts are often concerned about changing policies and politics. In this paper, we refer to environmental risk as social, natural, and political environmental risk, it may include any potential losses and their likelihood from the social, natural, and political environments. Such as, economic fluctuations, biological risk, wildfires, environmental degradation, weather, pandemic, relegations, politics, public relationships, etc.

Table 1 Supply Chain Risks in the Forest Industry

Type of Risk	Risk elements	Studies
Supply / Source Risk	Supplier-related risks (supplier's Integration, supplier bankruptcy, supplier quality, visibility, collaboration), forest management-related risks (nursey, replanted management, forecast and planning errors) and pre-harvest-related risks.	Ho *et al*. (2015); Kleindorfer and Saad (2005); Steven *et al*. (2010); Wieland and Wallenburg (2012); Zsidisin and Ellram (2003)
Manufacturing Risk	Management and operational risks, (human errors, decision making), process-related risks (capacity, information, process quality, harvesting), inventory risk, production risk, supply degradation, and safety/security risks	Aramyan (2007); Jüttner (2005), Ho *et al.* (2015); Sodhi and Tang (2012); Tang and Nurmaya Musa (2011)
Logistics and Transport Risk	Transport risk-impassable roads, intermittent trucking services, (delivery failure, increased costs) and faulty loading (driver shortage, damage and product loss in transit)	Blackhurst *et al*. (2008); Sanchez-Rodrigues *et al*. (2009); Tang and Nurmaya Musa (2011); Wang (2018)
Demand / Market Risk	Market-related risks, customer-related risks, bullwhip effect, demand uncertainty, competition changes.	Jüttner *et al*. (2003); Manuj and Mentzer (2008); Sodhi and Tang (2012); Steven *et al*. (2010); Tang (2006); Wilding (1998)
Environmental Risk	Weather-related risks, natural disasters, climate change, pests, wildfires, political risks, cultural and ethics, public relationship-related risk, etc.	Jüttner *et al*. (2003); Kleindorfer and Saad (2005); Sodhi and Tang (2012); Steven *et al*. (2010); Tang and Nurmaya Musa (2011); Wang (2018)

4.2 Delphi Study

The aim of the Delphi study is twofold. First, to develop and validate the forest supply chain risk framework. We have presented the forest supply chain risk framework in section 4.1. Second, to understand and identify the major risks in the New Zealand Forest supply chain. The first round of the Delphi study was performed during COVID-19 pandemic in July 2020. At the time, New

Zealand was still under lockdown. The expert's response to the question "What are the major risks/ concerns / issues in the New Zealand forest supply chain?". In Oct 2022, we conducted the second round of Delphi study, the same experts were invited to answer and confirm the major risks in the forest supply chain post COVID-19. **Table 2** summarizes the most common risks and their frequency. The results show that the five types of SCR classification well cover the main risks in the forest supply chain. The word clouds are generated from the analysis.

Table 2 Frequency of Codes

Types of risks	Code	Frequency (references)
Demand / Market Risk	Greater international market competition	15
	Price (i.e. lower log price, fluctuating market prices)	12
	Decreasing China market	10
	Decreasing domestic market demand	7
	Discerning markets and end-users (debarking, log fumigation, etc.)	6
	Losing international customers	5
	Increasing uncertainty in export market	5
	Decreasing demand for the medium and low to medium grade logs (A and K).	4
Environmental Risk	COVID-19 (i.e. Lockdown)	13
	Government policies	12
	Immigration slowdown	7
	Recession / economic crisis / inflation	7
	Decreasing investment	6
	China-US trade war	3
	Climate change / Carbon emission	3
	Russian invasion of Ukraine - war	2
Manufacturing Risk	Insufficient wood processing capability	6
	Reduced harvesting level	5
	Unable to source logs for domestic	5
	Sustainable workflow	3
	Lack of labor (i.e. crews)	3
	New technologies challenges	2
Supply / Source Risk	Planting disruption	5
	Unstable supply flows	4
	Supply disruptions	3
	Infrastructure	3
	High land price	2
Logistics and Transport Risk	Transport, shipping, and port disruption	3
	Increasing shipping cost	3
	International supply chain disruption	2
	Driver shortage	2

In the first round of Delphi study, most major risks were outside New Zealand and related to markets and external environments. There is "no doubt" that the COVID-19 pandemic caused many disruptions across the New Zealand Forest supply chain. Such as: supply disruptions, production disruptions, and transport disruptions. The results support our risk classifications. **Figure 3** shows a word cloud for the first round of Delphi study. The most prominent words highlighted were 'market', 'logs', 'supply', 'demand', and 'China'. The findings were consistent with our coding results. Most risks were from markets including both international and domestic markets. China is the New Zealand's top log importer. Many experts expressed concern about the Chinese market. One of the experts suggested that strong rely on China market was a risk. COVID-19 has a huge impact on prices and demand for international markets. Several experts mentioned that this had implications for both growers and processors in New Zealand. Our results show that government plays a vital role in the New Zealand Forest sector, some experts suggested that government policies (i.e. subsidies) would have profound effects on the industry. One of experts explained: "*In particular overseas investment in the industry will stagnate, overseas investors will look to other more investment friendly countries instead of NZ and plantation owners will reduce the harvest level in anticipation that a future government might recognize the folly of forcing forest owners to supply logs to less profitable markets."*

As shown in the **Figure 4**, the second round of Delphi study was conducted in Oct 2022. We attached the previous round results in the email and asked the experts the same questions "*what are the top risks or uncertainties of New Zealand forest business post COVID-19?*" via emails. Most experts confirm that the concerns or risks are still much the same or similar to previous results. For example "*demand for logs (K & A grades especially) from China remaining low due to reduced construction activity from historic overbuild and ongoing Covid issues – this could lead to the NZ domestic log supply problems in other log grades as outlined last time"… "Volatile log prices leading to uncertainty of employment for logging crews and imposition of production quotas – we could see logging capacity decline"… "Shortage of seasonal workers for nursery work and planting; this is not so much at the moment as we are coming out of the planting season, but this may become a problem again next winter"… "Volatility in exchange rates and shipping prices; recent movements in both these have propped up at wharf gate prices for logs, but if the NZ$ strengthens and shipping rates rise then we could see significant drops in at wharf gate prices, as prices in China have dropped"…* "*With*

climate change fire is increasing as a risk but is still not high."

Some experts stress that *"labour shortages is also going to be big as it is on our industry already" ... "log pricing is quite stable locally but has some clouds on the export market" ... "increasing demand for carbon forest planting as the prices of CO2 goes up," ... "this has changed land use patterns with forestry out competing beef and sheep farming which is leading to backlashes from farm lobby groups. This risks government intervention which is already happening in some areas"...* An expert added "*things are getting more complicated because of the inflation and the war"*.

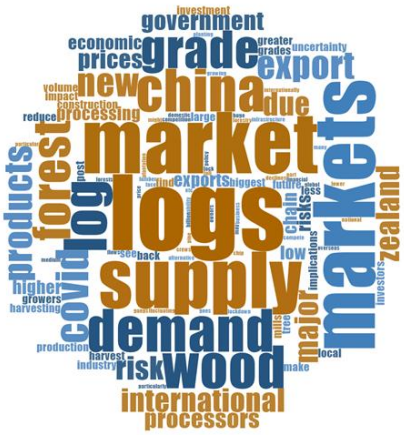

Figure 3 A Word Cloud for the First Round of Delphi Study

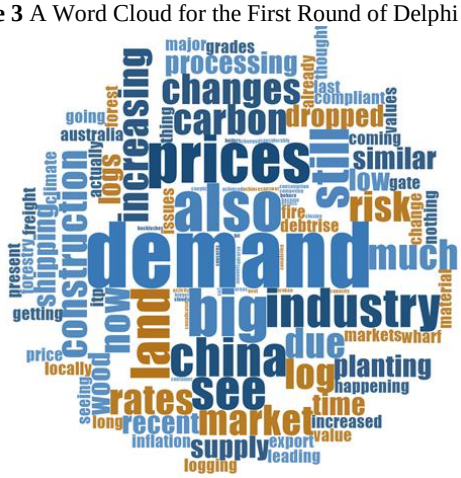

Figure 4 A Word Cloud for the Second Round of Delphi Study

5. DISCUSSION

In this paper, we have developed the classification of the forest SCR. The SCR inherent in system, the risk may arise from various events and sources, types of SCR may have different severity of their impact, such as likelihood of adverse events, and the regularity of occurrence, even the same SCR may have different effects with different time periods. In addition, risk may occur from broken processes and unexpected events within a company, from transactions of supply chain partners or could occur at a higher industry or environment level that impacts supply chain performance (Gaonkar & Viswanadham, 2007). It is important to identify the key SCRs and manage them to improve the performance (Wang, 2018). Moreover, policy makers can leverage the framework to assess the specific risks in supply chains.

Supply risk is a significant problem discussed in previous SCR studies (Ganguly & Kumar, 2019; Ho *et al*., 2015; Wieland & Wallenburg, 2012; Zsidisin, 2003). For example, manufacturing depends on numerous suppliers, the outcomes of clients are reliant on their suppliers' performance outcomes, and suppliers' performance ultimately impacted the end customer (Krause *et al*., 2007). Demand risk is often discussed together with supply risk. The demand risk can be caused by unpredictable events, external environment or customers (Wagner & Bode, 2008; Zsidisin & Ritchie, 2009). For instance, in 2019, New Zealand's export log prices dropped more by 20% due to the high volumes of logs from beetle-damaged forests from Europe to China (MPI, 2019). The lower log prices led to lower harvest and export volumes, and harvesting crews experienced redundancies first. Manufacture, logistics and transport are important functional areas in the forest industry. Various facilities, resources and capabilities are required to process and convert the trees to finished wood products, such as, mills, transport vehicles, vessels, infrastructure, etc. subgroups of risk may be further developed in term of different context and/or purposes. Environmental risk includes both supply chain environment among the supply chain partners and external environmental factors. Forest supply chain has its unique characteristics, for example, pests, forests can survive pests. It can reduce the yearly growth and affect quality (grades). The new thing is that due to the climate change beetles can

harm trees are not prepared to survive that. They move to the colder climate. In forests, because of the large areas and 1-100 yo stands, the damage is way more serious than in agriculture. Also, it is hard to use any prevention or spraying.

Climate change has significant impacts on the forest supply chain. None of the annual or short living crops are affected like forestry since the production sites could be moved or irrigation can be used. The forest stand rotation period is 15-200 years the average is around 80. Climate change could kill high value stands and eliminate revenue and supply. At the same time, it can flood the market by low value (pulp and paper) logs and destroy the market. It happened in the US, Canada and the EU. In 2019 NZ forestry suffered because China was supplied by low-value beetle-infested wood from the EU. Therefore, it is not just a supply problem for the mills but a demand issue for some. Moreover, wildfires can destroy 100 yo old stands and all the accumulated value. They are more frequent due to climate change.

COVID-19 caused many disruptions in the New Zealand Forest supply chain. A Delphi study is conducted to validate the forest SCR classification and identify the major forest supply chain risks in New Zealand post COVID-19. In the first round, most significant impacts were from downstream supply chains and markets, they were outside New Zealand. In the second round, the results of the first round were sent via email to the same experts, we found that the main risks remained the same, but impacts of risks have expanded from outside New Zealand, downstream supply chain to upstream supply chain within New Zealand. The experts affirm the major risks and reach a consensus.

While the focus in this paper is on forest SCR classification, the concept of SCR mitigation should be also considered in forest supply chain. Contemporary risk management is a cross-disciplinary process (Mullai *et al*., 2009). SCR mitigation is one of the fastest growing areas in business research (Andreas & Carl Marcus, 2012; Sodhi & Tang, 2012). SCR mitigation is defined as the applying tactics to manage regular and unique risks of the supply chain by risk assessments targeting vulnerability reduction and continuity (Andreas & Carl Marcus, 2012). In addition, risk management is all coordinated activities to direct and control an organization with regard to risk (Aven, 2011). Tang (2006) define SCR mitigation is the management of SCRs by coordination and collaboration among the supply chain partners to ensure profit ability and continuity. The aim of SCRM is to identify the potential risks and implement appropriate coordination activities to reduce supply chain supply chain vulnerability (Jüttner *et al*., 2003).

Previous studies have addressed the generic SCR mitigation strategies. Christopher and Lee (2004) stated that supply chain confidence effects of mitigating SCR, both transparency and control are keys for reestablishing supply chain confidence. Guo *et al*. (2006) studied information sharing for managing SCRs. Manuj and Mentzer (2008) proposed a comprehensive risk management and mitigation model for global supply chain. Wang *et al*. (2018b) elaborated a capability theory for SCR mitigation in the third-party logistics providers. We suggested that SCRM strategies could be further developed to better suit the forest businesses. Further research may be conducted to investigate specific problems associated with types of SCRs and develop relevant SCRM strategies in context. Conventional risk analysis including the two types of approaches, both reactive and proactive approaches should be considered simultaneously in the forest SCRM.

From a managerial perspective, early studies find that most business managers tried to avoid risk, rather than take it. For example, the uncertainty-absorbing contracts are used to avoid the external environmental risk (Cyert & March, 1963), and using third party companies (Wang *et al*., 2018b). However, most managers believe that SCR is controllable and manageable (March & Shapira, 1987). Risk management targets should be included among corporate goals, and major corporate initiatives should incorporate risk assessment and risk mitigation strategies (Lam, 2003). Moreover, beyond sound theory, risk management is driven by comprehensive practice. Best practices in risk management can only emerge when sound theories and models are tested in the confines of the real world (Lam, 2003; Wang *et al*., 2015). Heckmann *et al*. (2015) stress that many researchers have felt the need to capture risk in supply chain management. This study identified the main SCR in forest industry and provided insights on forest supply chain management.

6. CONCLUSIONS AND FUTURE RESEARCH

This study presents a conceptual framework of forest SCRs. A review is conducted on the SCR and supply chain management. SCR is an important topic in supply chain management (Mullai *et al*., 2009; Zsidisin & Ritchie, 2009). In some areas such as financial management, manufacturing, pharmaceutical, transport etc. (Heckmann *et al*., 2015; Tang & Nurmaya Musa, 2011; Wang *et al*., 2015; Zsidisin, 2003), the importance of considering SCR is recognized. However, very few SCR studies have been conducted in an entire forest supply chain. The review and the classification proposed supports the forest SCR mitigation research. To support sustainable development, resilient forests, and high-value timber manufacturing and products in forest sector, it is significant to understand and identify these risks in the forest supply chain.

This paper makes the following contributions, we revisit SCR conceptualization, the forest SCR framework is developed, and types of forest SCRs are defined. Forest SCR studies were rarely found in both supply chain and forest literature. The major types of SCRs including supply risk, manufacturing risk, logistics and transport risk, demand risk and environmental risk are derived mainly from previous SCR studies in different industries (Ho *et al*., 2015; Manuj & Mentzer, 2008; Sodhi & Tang, 2012; Wang *et al*., 2018b). We map a typical forest supply chain from forest to final customer, the simple forest supply chain system comprises all important stakeholders, e.g. growers, harvesting, mills, traders and end users. The studies take a holistic approach to view the SCRs in forest sector (Mullai *et al*., 2009; Zsidisin & Ritchie, 2009). This sheds light on most forest SCRs. Furthermore, forest SCR studies were rarely found in previous studies, this paper contributes to the forest supply chain literature.

Some of limitations of the present study included as follows. First, only papers in English were included in our literature review. In addition, the types of forest SCR were based on previous SCR studies and subjective judgment. The New Zealand forest supply chain risks may be unable to represent all countries. The conceptual framework may be empirically validated in different contexts. Finally, SCRM is discussed in the paper, the generic SCRM strategies may be adopted in the forest industry. However, forest industry differs from other industries, Zsidisin and Ritchie (2009) suggest that both the operational and strategic levels should be considered in the SCRM. Operationally, the focus would be towards the operational risks and operational issues on the functional areas, strategic developments will impact at the operational level. It is significant to investigate specific problems associated with types of forest SCRs to develop appropriate risk management strategies in the forest industry.

Previous risks studies tend to focus on the negative impacts of SCRs in firms (Tang, 2006; Wang, 2018). However, SCRs often associated with both negative and positive impacts. Although positive impacts do not often harm supply chain performance, for example, delivery earlier than scheduled time, in extreme cases, it still may cause other potential cost such as additional storage fee. Moreover, researchers and managers may exploit the positive risk impacts for various purposes. Therefore, further studies may investigate positive impacts which are originated from forest SCRs, and the interrelationships among the types of forest SCRs.

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