

Impact of financial risk on supply chains: A manufacturer-supplier relational perspective

Abstract:

This study aims to analyse the manufacturer-supplier relational perspective under the influence of exogenous financial risk. Following corporate finance theory, a multi-objective decision model for supplier selection and order allocation is developed to maximise the total profit of the manufacturer and minimise the implicit equity stake and financial risks faced by the supplier. A two-echelon supply chain is explored under the influence of foreign exchange risk, default risk, market risk and price fluctuation risk, and solved using an NSGA-III algorithm. Three case scenarios are analysed to explore the impact of a set of financial risks on the manufacturer-supplier relationship and the behaviour of suppliers concerning risk profile, both in the short- and long-term horizon. The study provides insights into the influence of financial risks on the manufacturer-supplier relationship and will be valuable for dealing with scenarios in uncertain economic environments. The research is likely to be of benefit beyond supply chain managers, like investors and financial risk managers in making informed decisions. The need for focus on systemic risk in supply chains is evident from the study.

Keywords: Financial risk; Buyer-supplier relationships; Supply chain risk management; Systemic risk; Corporate finance theory; Systemic risk; NSGA-III

1. Introduction

Supply chains are exposed to a range of risks comprising economic, geopolitical, technological and environmental disturbances (Rangel et al., 2015; Rajagopal et al., 2017). These risks have severe negative consequences on supply chains ranging from financial losses, reduced market share and damage to reputation (Ghadge et al., 2013; Gatzert and Schmit, 2016). Financial risk is a growing global concern since the economic crisis of 2008 that led to the banking insolvencies and business bankruptcies due to profound financial volatility (Blome and Schoenherr, 2011; Zhou and Wang, 2013; Christopher and Holweg, 2017). A survey concerning global risk perception (2018–2019) places financial crisis as the top economic risk in terms of its impact and probability (World Economic Forum, 2019). The recent global pandemic (COVID-19) outbreak is predicted to bring uncertainty to the global economy leading to another recession (Fernandes, 2020; Ivanov, 2020). The growing trend in global financial instability has placed financial risk at centre stage. However, despite its prominence, research on financial risk in supply chain risk management literature is limited (Wandfluh et al., 2016; Osadchiy et al., 2016; Sokolinskiy et al., 2018). Especially, the impact and propagation of financial risk in supply chains are found to be missing (Lian, 2017; Oliveira et al., 2017; Dolgui et al., 2018; Scheibe and Blackhurst, 2018).

In the finance literature, risk is measured as fluctuations around the expected value of financial returns and comprises of market, credit, currency and liquidity related risks (Heckmann et al., 2015). ‘*Financial risk*’ is an umbrella term covering several risk types such as foreign exchange risk, market risk, price fluctuation, inflation risk, etc. (Tang and Musa, 2011; Ghadge et al., 2012; Ho et al., 2015; Scheibe and Blackhurst, 2018). The financial condition and risk exposure levels of individual firms are primary drivers of financial disruptions within supply chain networks (Blome and Schoenherr, 2011; Mizgier et al., 2012). Modern supply chains are highly dispersed

and interdependent in their complex structure. They include a large global supplier base that increases the financial vulnerability of the network. Therefore, investigation of the impact of major financial risks on the manufacturer-supplier relationship is of high importance for the long-term sustainability of businesses. Financial performance between different supply chain stakeholders is well explored (e.g., Shi and Yu, 2013; Kim and Henderson, 2015; Wandfluh et al., 2016); however, the influence of financial risk on supply chain stakeholders is critical for understanding their negative influence on the overall performance of the supply chain (Lanier Jr et al., 2019). Individual stakeholders’ financial circumstances influence supply chain relationships, performance and decisions. This study raises the following research question. *How do financial risks influence the manufacturer-supplier relationship?* The answer to this question is likely to provide useful insights into the impact of financial risks on stakeholders’ relationships in the volatile global environment.

The above research question is addressed by developing a multi-objective problem for supplier selection and order allocation under the influence of different types of financial risk. Capital Asset Pricing Model (CAPM) theory from corporate finance is utilised to develop an optimization model for comprehensive decision-making. The multi-objective decision model has three objective functions: maximise the total profit of the manufacturer; minimise the supplier’s implicit equity stake; and, minimise the overall financial risk faced by the supplier. Justification for the selection of these objectives is provided in section 3.2. Both, the interaction between different financial risks and their impact on inter-firm relationships are incorporated into the model to obtain useful inferences. Following a two-stage approach, first, financial risks are ranked using a Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. Later, the proposed multi-objective optimization problem is solved using the Non-dominated Sorting Genetic

Algorithm (NSGA) III. Introduction and justification for the selection of the VIKOR and NSGA-III method is provided in the literature review. Three case scenarios are analysed to explore the overall impact of combined financial risks on the stakeholder relationship and trends in suppliers’ risk profile both in the short- and long-term. The results of the model are interpreted to develop ideal strategies to mitigate the impact of financial risks for effective supply chain risk management.

The rest of the paper is structured as follows. Section 2 presents the literature on financial risk in supply chains and research approaches to assess them. The VIKOR and NSGA-III method are also introduced in this section. Section 3 describes and formulates the research problem. Section 4 introduces NSGA-III to solve the proposed multi-objective optimisation model. The results are presented and discussed in section 5. Key findings based on the three case scenarios are discussed in section 6. Finally, the paper concludes with a discussion on key inferences, contribution to theory and practice and limitations.

2. Literature Review

2.1. Financial risk modelling in supply chains

Recently, financial risk has become a major concern as a result of growing macroeconomic uncertainty and volatility in international markets (Zhou and Wang, 2013; Osadchiy et al., 2016). In the finance literature, financial risk is measured as fluctuations around the expected value of financial returns (Heckmann et al., 2015). In the Supply Chain Risk Management (SCRM) context, financial risk is a broad term that includes various risk factors associated with financial flows and transactions. These risks include bankruptcy, exchange rate fluctuations, commodity risk, price volatility, low-profit margin, and credit risk, to name a few (Hammami et al., 2014; Ho et al., 2015;

Zhu et al., 2019; Pellegrino et al., 2019). Financial risks can be categorised as exogenous and endogenous risks (Danielsson et al., 2012). While exogenous financial risks are driven by the economic environment such as inflation, interest rates and currency exchange rate, endogenous financial risks are associated with economic transactions such as accounting, cash flow and investments (Rangel et al., 2015). Key exogenous financial risks in the SCRM field can be listed as foreign exchange risk, default risk, market risk and price fluctuation risk (e.g., Mousavi and Ouenniche, 2018; Zhao and Zhu, 2018). In general, exogenous risks have increased both in number and complexity (Hagigi and Sivakumar, 2009; Dolgui et al., 2018) and are difficult to handle, as they are driven by external economic factors. This study contextualises limited financial risks to address the set research question.

- *Foreign-exchange risk*- This occurs while dealing with foreign currency conversion rates leading to a change in supply chain costs (Hammami et al., 2014).
- *Default risk*- This emerges when a firm is unable to meet financial obligations; e.g., inability to pay the contractual interest on credit transactions or the price of the product/material within the agreement period (Tsao, 2019).
- *Market risk*- This is a systematic risk inherent in the market or a market segment and affects the overall market or economy; e.g., interest rates (Rangel et al., 2015) and credit risk (Zhu et al., 2019).
- *Price fluctuation risk*- This involves the risk of a hike in the price of the product or material due to demand fluctuation or commodity price fluctuation within the supply chain network (Hofmann, 2011; Rajagopal et al., 2017; Gaudenzi et al., 2018).

Today’s global supply chains are complex and interconnected, consisting of multiple layers and stakeholders. Therefore, any financial disruption to a member of the supply chain easily propagates along the network (Ivanov and Dolgui, 2019). Risk propagation is a phenomenon, where disruption caused by a risk at a node in the supply chain cascades across other nodes in the supply chain network (Ghadge et al., 2011; Ojha et al., 2018; Li et al., 2019). It is also referred to as a ‘*ripple effect*’, ‘*snowball/domino effect*’ and ‘*disruption propagation*’ in the SCRM literature. Risk propagation affects multiple stakeholders in the entire supply chain by causing variations in the material, information and financial flows (Jüttner and Maklan, 2011; Blome and Schoenherr, 2011; Ivanov et al., 2017; Dolgui et al., 2020). A good example is Chrysler, the auto company, that had to shut down its four plants and lost millions of dollars in 2008. The reason for this loss was the bankruptcy of one of its suppliers, Plastech, because of poor cash flow and liquidity (Guertler and Spinler, 2015). As can be seen from this example, the poor financial performance of an individual member/stakeholder may have a severe impact on the supply chain’s overall financial performance. It is also evident that endogenous financial risks may transform to exogenous risks following a risk propagation effect (Garvey et al., 2015; Ojha et al., 2018). Past literature is primarily dominated by research on corporate finance (Mousavi and Ouenniche, 2018; Salas-Molina et al., 2018) and seldom linked with core supply chain issues (Zhou and Wang, 2013; Sokolinskiy et al., 2018).

Bandaly et al. (2004) developed a simulation-based, stochastic optimisation model for managing operational and financial risk along the supply chains. Similarly, Hua et al. (2011) developed a multi-agent simulation model to investigate the operational causes that lead to the emergence of bankruptcy risk in supply chains. Liu and Nagurney (2011) studied the impact of foreign exchange risk on supply chain outsourcing following a quantitative modelling and

simulation approach. Liu and Cruz (2012) proposed an analytical framework to investigate the impact of financial risks and economic uncertainty on values and profitability of supply chain firms. Recently, Zhao and Zhu (2018) proposed a risk-averse marketing strategy, modelling and analysing the effect of this strategy on coordination activities in a remanufacturing supply chain under market fluctuation. Azaron et al. (2008) developed a multi-objective stochastic programming model for minimising financial risk, while designing supply chains under uncertainty. Tsai (2017) developed a simulation-driven, analytical model to examine the basic relationship between cost structure and cash flow risk in the supply chain process. Similarly, Sokolinskiy et al. (2018) developed a multi-objective optimisation model to minimise disruption when considering the effect of credit rollover risk.

As observed from the above studies, the current literature mainly focuses on the individual financial risk type; however, modelling of a set of financial risks to draw comprehensive insights is found to be limited. By considering four key exogenous risks, this paper attempts to address the evident research gap on assessing the impact of financial risk in the supply chains.

2.2. Impact of financial risk on supply chain stakeholders

The evident lack of studies investigating the combined impact of financial risk on supply chains encourages us to undertake this quantitative and relational study. In a supply chain, the buyer and supplier often compromise due to power and dependence relationships, while making operational, contractual or financial decisions (Ghadge et al., 2017). For example, buyers intend to extend their payables and benefit from gaining interest off the float. This behaviour can improve their working capital condition by lengthening their suppliers' payment terms (Mizgier et al., 2017); however, it also negatively affects their suppliers' cash flow and leads to an unstable financial situation (Basu

and Nair, 2012). It is obvious that manufacturers need to find a balance between their financial objectives and (long-term) relationships with their stakeholders.

Few researchers have considered financial risks in the supplier selection problem (e.g., Alikhani et al., 2019). Itzkowitz (2015) investigated the impact of buyer-supplier collaboration under the supplier’s financial constraints. Hosseini et al. (2019) explored the resilient supplier selection process under disruption risks. Undoubtedly, the supplier selection stage is a good starting point to model the impact of key financial risks on the supply chain and further explore the relationship between the manufacturer and supplier (Huang et al., 2018). A robust supply chain is of high importance for the financial stability and sustainability of associated businesses. In this context, understanding inter-firm relationship under the influence of critical financial risks will pave the way for valuable insights for improving the overall performance of a supply chain.

2.3 VIKOR and NSGA III Methods

The VIKOR method was first introduced by Opricovic (1998) to solve Multi-Criteria Decision Making (MCDM) problems and is known to provide a compromised rather than optimal solution. VIKOR aims to rank a set of alternatives based on a ranking index, that depends on the closeness of the alternative to the ideal solution (Sayadi et al., 2009). Several researchers have used the VIKOR or extended VIKOR method to rank alternatives and find a compromised solution for MCDM problems (e.g., Opricovic and Tzeng, 2007; Tiwari et al., 2016; Wu et al. 2016; Sharma et al. 2017). The compromise solution is a feasible solution, which is the closest to optimal for a problem with conflicting criteria. MCDM consists of several other methods such as AHP, ANP, TOPSIS and DEMATEL. The VIKOR method was developed for multi-criteria optimization in

complex systems and performs better over TOPSIS and other MCDM methods due to its ability to find alternatives under conflicting and varying units' criteria (Opricovic and Tzeng, 2004).

Genetic Algorithm (GA), a meta-heuristic, is used not just for traditional optimisation (linear, convex) problems, but is also effective for solving distinct and nonlinear issues (Mostafaie et al., 2020). NSGA-III is a Non-dominated sorting genetic algorithm and is a powerful method for overcoming the complexity of constraints faced in multi-objective optimisation problems (Xu et al., 2015). The basic framework of NSGA-III was proposed by Deb and Jain (2014). It can be seen as an improved version of NSGA-II, with a more efficient selection procedure. This algorithm identifies multiple Pareto front regions and is quick for obtaining Pareto optimal sets (Tavana et al., 2016). In general, GA has varying advantages such as high convergence and low computational time and further provides significant reduction in search space to obtain global/near-optimal solutions (Torabi et al., 2006; Mostafaie et al., 2020). It is evident from the above literature that the VIKOR and NSGA-III methods are best suited for the nature of the problem explored in this study.

3. Problem Development

The key focus of this research is to develop an optimisation model that captures the interaction between financial risk and supply chain stakeholder relationships. To build such a mathematical model, where inter-firm financial interactions are considered, the research adopts corporate finance theory. Following this theory, the study models the inter-firm connection between two key stakeholders (manufacturer and suppliers) in a two-echelon supply chain. This inter-firm

relationship is modelled via a multi-objective supplier selection model considering exposure to the four exogenous financial risks earlier discussed.

3.1. Base model

Capital Asset Pricing Model (CAPM) is the theory of asset price determination, considering the risk involved in a particular asset (Fama and French, 2004). The theory is commonly utilised in finance to determine the required rate of return from an asset (Barberis et al., 2015; Zabarankin et al., 2014). The broad notion behind this model is that the lender must be paid back in terms of the time value of the money and risk involved with the borrower.

The following equation provides an expected rate of return corresponding to an asset:

$$R_m - r_{rf} = \beta_m (r_m - r_{rf}) \quad (1)$$

where, R_m =Expected rate of return; r_{rf} =Risk free rate of return; β_m =Volatility to general risk; r_m =Market rate of return.

The risk-free rate of return expresses the time value of money, while the risk of investment is compensated by the volatility of the borrower to the general risk (Bollerslev et al., 1988). The risk-free rate is determined by the earnings from the most stable bonds, such as US Treasury bonds. The risk measure in Eqn. 1 compares the earnings of the investment in the borrower firm, if lent in the market. Beta can take both positive and negative values depending on how the firm's profitability interacts with the economy (Siegel, 1995; Husmann and Andreas, 2007).

A set of indices, parameters and decision variables have been used to formulate the mathematical model, and their notations are represented in Table 1.

Table 1. Notations of the indices, parameters and decision variables

Set of indices:	
S	Supplier
m	Manufacturer
p	Product
f	Risk factor
n	Total number of risk factor
TR	Total risk
Parameters:	
I_f	Impact of risk factor f
DR	Percentage of default risk measure
PF	Percentage of price fluctuation risk measure
FE	Percentage of foreign exchange risk measure
EC_{mr}	Percentage of economic crisis in market
w_m	Weight of market risk calculated by VIKOR
w_{dr}	Weight of default risk calculated by VIKOR
w_{pf}	Weight of price fluctuation risk calculated by VIKOR
w_{fe}	Weight of foreign exchange risk calculated by VIKOR
W_f	Weight of risk factor f
β_{seq}	Equivalent volatility at supplier s
β_{meq}	Equivalent volatility at manufacturer m
β_m	Sensitivity to market risk
β_{dr}	Sensitivity to default risk
β_{pf}	Sensitivity to price fluctuation risk
β_{fe}	Sensitivity to foreign exchange risk
EQ_{sm}	Value of supplier s equity in manufacturer m
CF_{sm}	Net cash flow from manufacturer m to supplier s
g_m	Growth estimate of manufacturer m
$\omega \in (0,1)$	Probability that manufacturer m can be retained for next period

γ_{sm}	0, if supplier s and manufacturer m are in the same country 1, if supplier s and manufacturer m are in different countries
sp_{mp}	Selling price of product p at manufacturer m
p_{smp1}	Price of product p from supplier s to manufacturer m transacted through cash
p_{smp2}	Price of product p from supplier s to manufacturer m transacted through credit
d_{mp}	Production cost at manufacturer m of product p
d_{sp}	Production cost at supplier s of product p
t_{smp1}	Cost of transaction from supplier s to manufacturer m for product p transacted through cash
t_{smp2}	Cost of transaction from supplier s to manufacturer m for product p transacted through credit
i_{mp}	cost of inventory for per unit product p at manufacturer m
l_{sm}	Distance from supplier s to manufacturer m
s_{smp}	Transportation cost per kg unit distance from supplier s to manufacturer m
w_p	Weight of product p
cap_{sp}	Capacity of product p at supplier s
dem_{mp}	Demand for product p at manufacturer m

Decision variable:

x_{smp1}	Quantity of product p from supplier s to manufacturer m transacted through cash
x_{smp2}	Quantity of product p from supplier s to manufacturer m transacted through credit
y_{sm}	0, if supplier s is not selected by manufacturer m 1, if supplier s is selected by manufacturer m

The overall risk index (total risk) is calculated by summing up the product of the weight of each risk factor and the impact of each risk factor over a total number of risk factors involved (Zayed et al., 2008).

$$TR = \sum_f^n W_f I_f \quad (2)$$

Using Ordinary Least Squares (OLS), Chan-Lau (2006) estimated a time-regression as shown in the equation:

$$R_{mt} - r_{rft} = \beta_m(EC_{mr} - r_{rft}) + \beta_{mDr}DR_t + \beta_{SMB}SMB_t + \beta_{HML}HML_t$$

where, *SMB* represents small-minus-big factor, *HML* represents high-minus-low factor and *t* represents the time period. OLS chooses the parameters of a linear function during regression, thus it is commonly used to form prediction equations (Garthwaite, 1994). Adopting a time regression equation (2) and by considering four major financial risks faced by the two-echelon supply chain, equation 3 can be obtained.

$$R_m - r_{rf} = w_m \beta_m (EC_{mr} - r_{rf}) + w_{Dr} \beta_{Dr} DR + w_{Pf} \beta_{Pf} PF + w_{Fe} \beta_{Fe} FE \quad (3)$$

A manufacturer can select a supplier (from a set of suppliers) having minimum risk and minimum implicit equity stake to the supplier to maximise their total profit. The implicit equity stake is the revenue generated from the supply chain under trade credit (Liu, 2013). Supplier and buyer (manufacturer) build a repeat transaction relationship; thus, the supplier holds an implicit equity stake in the manufacturer (Ng et al., 1999). Suppliers build this implicit equity stake through

potential for future business opportunities (Petersen and Rajan, 1997). This equity stake considers current and future profits, including long-term intangible benefits.

3.2. Multi-objective model

The multi-objective optimisation model developed considers three objective functions namely: i) maximise the total profit of the manufacturer, ii) minimise the implicit equity stake of the supplier in the manufacturer's business, and iii) minimise the overall financial risks faced by the selected suppliers. The first objective is consistent with the general agenda of the inter-firm relationship, i.e., to maximise individual profit. This function helps the manufacturer to choose the best supplier (from a pool of suppliers) offering products at a lower overall price. Firms do not want to share a major portion of equity in order to prevent the chance of acquisition (Greve and Zhang, 2017). The other two objectives are considered to ensure financial security to the manufacturer from supply chain disruptions and surviving in the volatile market. The second objective minimises the implicit equity stake of the supplier at the manufacturer; this enables the maximum ownership of the manufacturer firm to stay with itself. As explained by Liu and Cruz (2012), equity is calculated by discounting the future cash flows of the supplier from a manufacturer to the present value, where the rate of return is calculated by Eqn. (3). The cash flow from the manufacturer to the supplier is given by the difference in purchasing cost of products from the supplier and the production cost at the supplier including transaction cost in cash and credit as shown in Eqn. (4). Equity is determined by Eqn. (5) in the model.

$$CF_{sm} = \sum_p \left[x_{smp1} P_{smp1} + \frac{x_{smp2} P_{smp2} (1 + PF)}{1 + R_m} - d_{sp} (x_{smp1} + x_{smp2}) - x_{smp1} t_{smp1} - x_{smp2} t_{smp2} \right] \quad (4)$$

$$EQ_{sm} = \frac{CF_{sm}}{\frac{1+R_m}{(1+g_m)\omega} - 1} \quad (5)$$

The third objective function minimises the total risk involved concerning the suppliers, which are selected by the manufacturer. The aim of this function is to ensure that the manufacturer selects a less risky supplier in order to maintain a steady flow of products and manage steady demand requirements. If a manufacturer selects a supplier which is vulnerable to economic uncertainty, they may face difficulty in fulfilling demand. Therefore, the equivalent sensitivity of supplier s to major financial risk factors is calculated in Eqn. (6). The equivalent sensitivity of the supplier considers key financial risks identified earlier. The model does not consider the price fluctuation risk faced by the supplier, as the supplier selection decision by the manufacturer is independent of the tendency of the supplier's supplier (Tier II supplier) to change the price of the raw materials.

$$\beta_{seq} = \frac{w_m \beta_m + w_{dr} \beta_{dr} + w_{fe} \beta_{fe} \gamma_{sm}}{w_m + w_{dr} + w_{fe}} \quad (6)$$

The model has two main assumptions to reduce the complexity of the problem: i) Demand is deterministic for a given period and is the same for product p at the supplier as well as manufacturer; ii) Since inventory cost and production cost are independent of supplier selection, here we consider $i_{mp} = 0$ and $d_{mp} = 0$. The formulation of the multi-objective problem is provided by Eqn. (7), Eqn. (8) and Eqn. (9). Eqn. (10) is a capacity constraint and ensures that manufacturer m cannot order more than the capacity of supplier s for p . Eqn. (11) assures that manufacturer m selects at least one supplier. Eqn. (12) fulfils the demand constraint such that the

quantity of orders across all the selected suppliers is less than or equal to the demand requirements.

Eqn. (13) to (15) are the non-negativity constraints.

- First objective - Maximize total profit at manufacturer m due to supplier s

$$f_1 = \text{Max} \left(\sum_p s p_{mp} (x_{smp1} + x_{smp2}) - \sum_s y_{sm} \sum_p \left(\begin{aligned} & x_{smp1} p_{smp1} + \frac{x_{smp2} p_{smp2} (1 + PF)}{1 + R_m} + d_{mp} (x_{smp1} + x_{smp2}) + \\ & (s_{smp} l_{sm} (x_{smp1} + x_{smp2}) + i_{mp} \frac{(x_{smp1} + x_{smp2})}{2} - x_{smp1} t_{smp1} - x_{smp2} t_{smp2}) \end{aligned} \right) \right) \quad (7)$$

where,

- 1st term = selling price of product at manufacturer
- 2nd and 3rd term = cost of buying from supplier s at cash and credit
- 4th term = production cost at manufacturer m
- 5th term = transportation cost from supplier s to manufacturer m
- 6th term = inventory holding cost
- 7th and 8th term = transaction cost for cash and credit payments
- Second objective - Minimise equity stake of manufacturer m at supplier s

$$f_2 = \text{Min} \sum_s y_{sm} EQ_{smp} \quad (8)$$

- Third Objective - Minimise risk due to all suppliers $s \in S$

$$f_3 = \text{Min} \sum_s y_{sm} \beta_{seq} \quad (9)$$

Such that,

Capacity constraint:

$$\sum_m (x_{smp1} + x_{smp2}) \leq \text{cap}_{sp} \quad \forall s, p \quad (10)$$

Selection of at least 1 supplier:

$$\sum_s y_{sm} \geq 1 \quad \forall m \quad (11)$$

Demand satisfaction:

$$\sum_s (x_{smp1} + x_{smp2}) \leq \text{dem}_{mp} \quad \forall m, p \quad (12)$$

Non-negativity constraints:

$$x_{smp1} \geq 0 \quad \forall s, m, p \quad (13)$$

$$x_{smp2} \geq 0 \quad \forall s, m, p \quad (14)$$

$$y_{sm} = \{0,1\} \quad \forall s, m \quad (15)$$

4. Research Methodology

Due to the inherent complexity in modelling, the study employs a two-stage solution approach. First, the VIKOR method (Opricovic, 1998) is adopted to weigh the financial risks. Then, NSGA-III (Deb and Jain, 2014) is utilised to solve the proposed multi-objective optimisation model.

4.1. VIKOR approach

Consider there are m alternatives and n criteria. Then, alternative X_m , y_{ij} represents the actual value of the i^{th} alternative for the j^{th} criteria; for $i=1, 2, \dots, m$ and $j=1, 2, \dots, n$. The step-wise procedure is as follows:

- a) Determine the decision matrix, $y_{m \times n}$
- b) Determine the values of y_j^+ and y_j^- where $y_j^+ = \max_i y_{ij}$ and $y_j^- = \min_i y_{ij}$ for all $j=1, 2, \dots, n$.
- c) Calculate the utility measure U_i and regret measure R_i for $i=1, 2, \dots, m$ with the following equations:

$$U_i = \sum_j^n \left(\frac{w_j (y_j^+ - y_{ij})}{(y_j^+ - y_j^-)} \right), R_i = \max_j \frac{w_j (y_j^+ - y_{ij})}{(y_j^+ - y_j^-)}$$

where w_j is the relative importance of criteria j .

- d) Estimate the VIKOR index Q_i for $i=1, 2, \dots, m$ as

$$Q_i = \frac{v(U_i - U^+)}{(U^- - U^+)} + \frac{(1-v)(R_i - R^+)}{(R^- - R^+)}$$

where, $U^+ = \min_i U_i$ and $U^- = \max_i U_i$ and v is the weight of maximum group utility and is assumed to be 0.5. When v is larger ($v > 0.5$), the index of Q_i will tend to majority rule (Ju and Wang, 2013).

The alternatives are ranked according to the decreasing order of U, R and Q , which gives three rank lists. This procedure provides a solution which is proportionate with the maximum group utility of the ‘majority’ and minimum individual regret of the ‘opponent’ (Kim and Ahn, 2019). The VIKOR method is adapted due to its unique approach to accommodate complex interactions and interdependencies (Wu et al., 2017). It is well suited for the given problem comprising of four different type of financial risks.

4.2. NSGA III

NSGA-III is highly efficient and performs best when there are several objectives to optimise, and thus preferred over other algorithms and exact optimisation methods. Taking the population size to be p , the stepwise procedure of NSGA-III, adopted from Deb and Jain (2014), is briefly explained in Figure 1.

- *Definition of reference points:* Unlike NSGA-II, diversity of the obtained solutions in NSGA-III is ensured by defining reference points. We define a set of reference points, R_p on a hyper-plane with equal orientation along all the axes. The number of reference points

R_p is defined by the following formula
$$R_p = \binom{O+d-1}{d}$$
, where O is the number of objective

functions and d is the number of divisions to be taken on each axis of the objection function.

- *Normalising the population:* We have to determine the minimum value of all the objective functions, f_i^{\min} to identify an ideal point in the current population. Then, we determine $F_{\min} = f_1^{\min}, f_2^{\min}, f_3^{\min} \dots f_o^{\min}$ and subtract F_{\min} from each objective function, as explained in Deb and Jain (2014). This is to generate a hyper-plane from the ideal points and objective function values having an identical range.
- *Associating solutions with the generated reference points:* After normalising the population, we need to correlate each chromosome with a reference point. To achieve this, we define a reference line that joins the origin with a reference point. We next calculate the perpendicular distance between each chromosome and reference line. Therefore, a reference point with a minimum perpendicular distance is associated with the chromosome.
- *Niche preservation:* The solution with the smallest perpendicular distance to reference point has to be selected, irrespective of the number of reference points associated with one solution.
- *Genetic control operators:* The next set of chromosomes is generated as obtained in NSGA-II. As suggested by Deb and Jain (2014), taking a number of reference points R_p close to the number of a chromosome P gives equal weightage to all chromosomes. The children generation is made by applying the genetic operators used in the NSGA II algorithm.

- 1:Determine number of reference points (Rp) on the hyper-plan
 - 2:Initialise population
 - 3:Perform Non Dominated Sorting on the population
 - 4:**while** stopping criteria
 - 5: Select two chromosome C_1 and C_2 by tournament selection
 - 6: Apply simulated binary crossover, with crossover probability p_c
 - 7: Perform Non Dominated Sorting on the population
 - 8: Normalise the population
 - 9: Associate each chromosome with reference points
 - 10: Apply niche preservation
 - 11: Keep the niche obtained solutions for the next generation
 - 12:**end while**
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Figure 1. Stepwise procedure of NSGA-III

5. Findings

5.1. Analytical results

The results obtained by solving the proposed multi-objective model are presented in this section. The four types of financial risk identified were evaluated based on their likelihood, impact, detectability and speed of onset. A scale of 1-9, provided in the Appendix, was used for rating each risk type. Primary ratings (that is input of the VIKOR method) as shown in Table 2 were identified with the help of an expert panel from academia and the financial industry. This panel comprised of three academics from the areas of accounting & finance, risk management and economics. Five financial industry experts came from: banking (two), insurance (one), investment (one) and consultancy (one). A panel comprising eight experts from multi-disciplinary areas met in late 2018 to brainstorm risk ranking and to identify a range of key financial variables. Expert opinion is a preferred option for model development when empirical or formal experimentation is impractical

(Lummus et al., 2005). There are no set guidelines on the size of expert panel, and it tends to vary for each study (e.g., Melnyk et al., 2005; Rostamzadeh et al., 2018; Yadav and Singh, 2020). Due to the lack of an established ranking system for the financial risks and availability of financial data, the expert panel were asked to, first, rank risks and, second, identify a range of values for key financial parameters during brainstorming sessions.

According to the expert panel, the most frequent financial risk was foreign exchange risk followed by price fluctuation, as their detection was identified to be more difficult than the other two risks. The default risk and market risk were identified as extreme-impact risks. Speed of onset was rated as moderate for the foreign exchange, default and market fluctuation risks; while speed of onset of the price fluctuation risk was assessed as being fast by the panel members. Ranking of the four risks was identified following the VIKOR method as explained in the previous section. Table 3 and Table 4 provide the decision matrices for the problem and ranking of the risks, respectively. Based on the weights obtained by the VIKOR method, the risks were ranked as market risk, default risk, price fluctuation risk, and foreign-exchange risk.

Table 2. Primary rating based on expert opinion

Risk criteria	Likelihood	Impact	Detectability	Speed of onset
Foreign-exchange risk	7	7	9	5
Default risk	3	9	3	5
Market risk	1	9	3	5
Price fluctuation risk	5	5	7	3

Table 3. VIKOR Decision Matrix

		Likelihood	Impact	Detectability	Speed of onset
	Weight of the criteria	0.29	0.38	0.13	0.21
	Foreign-exchange risk	0.25	0.25	0.32	0.18
Risk factors	Default risk	0.15	0.45	0.15	0.25
	Market risk	0.06	0.50	0.17	0.28
	Price fluctuation risk	0.25	0.25	0.35	0.15

Table 4. Rankings obtained by the VIKOR method

	Rankings						
Risk factors	Ui	Ri	Qi	U	R	Q	Weight
Foreign-exchange risk	0.55	0.38	1.00	4	3	4	0.171467
Default risk	0.40	0.15	0.16	2	1	2	0.316153
Market risk	0.32	0.21	0.13	1	2	1	0.320707
Price fluctuation risk	0.50	0.38	0.88	3	3	3	0.191673

Due to the lack of suitable, primary financial data (involving transactions, equity stake and risk levels) for the considered problem, members of the expert panel were asked to identify a range

of values for key financial parameters captured in Table 5. After identification of the weights of four key financial risks, NGSa-III was applied to the representative data to solve the developed multi-objective model. The parameters of the algorithm were tuned in MATLAB R2015b, in order to improve the performance of the algorithm. Following an iterative process, the final (adjusted) values of the parameters for NGSa-III were obtained and are presented in Table 6. The concept behind parameter tuning is to obtain a near-optimal solution in the shortest possible time.

Table 5. Range of values for model parameters

Parameter	Range	Parameter	Range
P_{smp1}	~U[\$10, \$1000]	PF	~U[0, 0.25]
P_{smp2}	~U[\$10.5, \$1050]	FE	~U[-0.025, 0.5]
d_{sp}	~U[\$1, \$20]	EC_{mr}	~U[0.5, 1.5]
t_{smp1}	~U[\$.25, \$2.50]	β_m	~U[-2, 3]
t_{smp2}	~U[\$.45, \$4.50]	β_{dr}	~U[-0.001, 0.002]
s_{smp}	\$1 per KM per KG	β_{pf}	~U[0.02, 0.5]
w_p	~U[20, 350]	β_{fe}	~U[-0.05, 0.02]
cap_{sp}	~U[1000, 5000]	w_{fe}	0.171467
dem_{mp}	~U[500, 5500]	w_{dr}	0.316153
g_m	~U[0.2, 0.4]	w_m	0.320707
ω	0.9	w_{pf}	0.191673

r_f	$\sim U[0.04, 0.05]$	g_m	$\sim U[-0.05, 0.05]$
DR	$\sim U[-0.05, 0.15]$	l_{sm}	$\sim U[5000, 15000]$

For analytical purposes, we considered that a manufacturer has a choice of 10 suppliers, with equivalent volatility (β_{seq}) ranging from 0.5 to 1.4. Solving the model using NSGA-III, the pareto optimal front between total profit gained and implicit equity stake of the suppliers in the manufacturer was obtained (Figure 2). Analysing this result from a relational perspective, it is observed that although the manufacturer needs to have maximum ownership to increase profit, the implicit equity stake cannot be decreased beyond a certain level. Such a business relationship will not be of interest to supplier(s), as it leads to a relational breakdown.

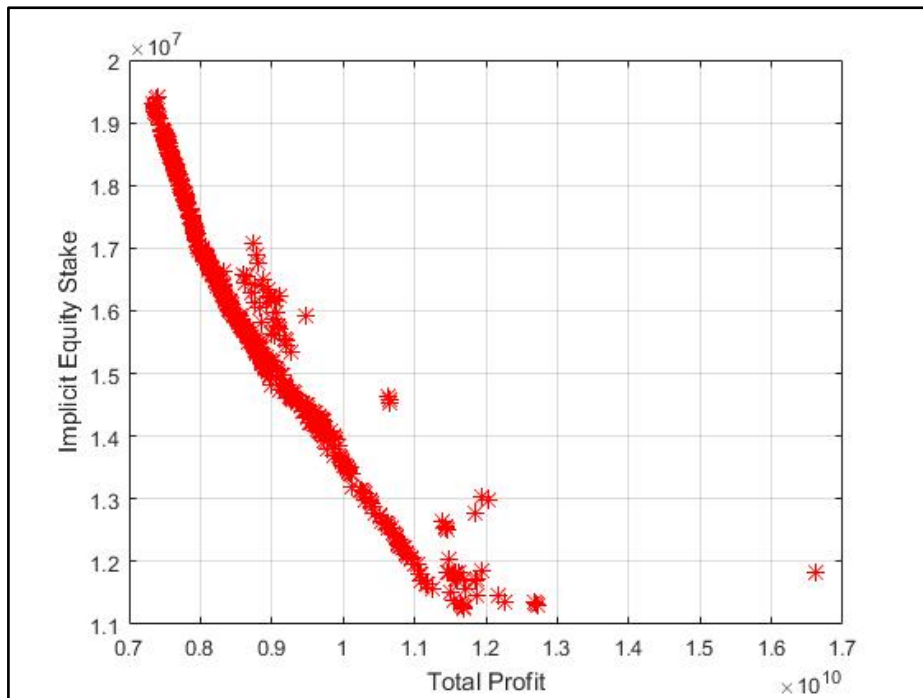


Figure 2. Total profit vs supplier’s implicit equity stake

Table 6. Tuned parameter values for the NSGA III algorithm

Parameter	Value
Population size	150
Number of divisions	10
Crossover probability	0.5
Mutation probability	0.5
Mutation rate	0.02

Since there is no direct relation between supplier sensitivity (vulnerability) with total profit obtained by the manufacturer and the implicit equity of the supplier, Figure 3 and Figure 4 illustrate the frequency of choosing a set of suppliers, which has minimum sensitivity to major financial risk factors. Figure 5 also shows the frequency of supplier selection in 150 instances. The results show that suppliers with a higher sensitivity to different financial risks are not preferred by the manufacturer. This is an anticipated result; however, a more detailed analysis is necessary to reveal the effects of different financial risks on the relational preferences between manufacturer and suppliers. The next section attempts to find answers to such questions following a scenario-based approach.

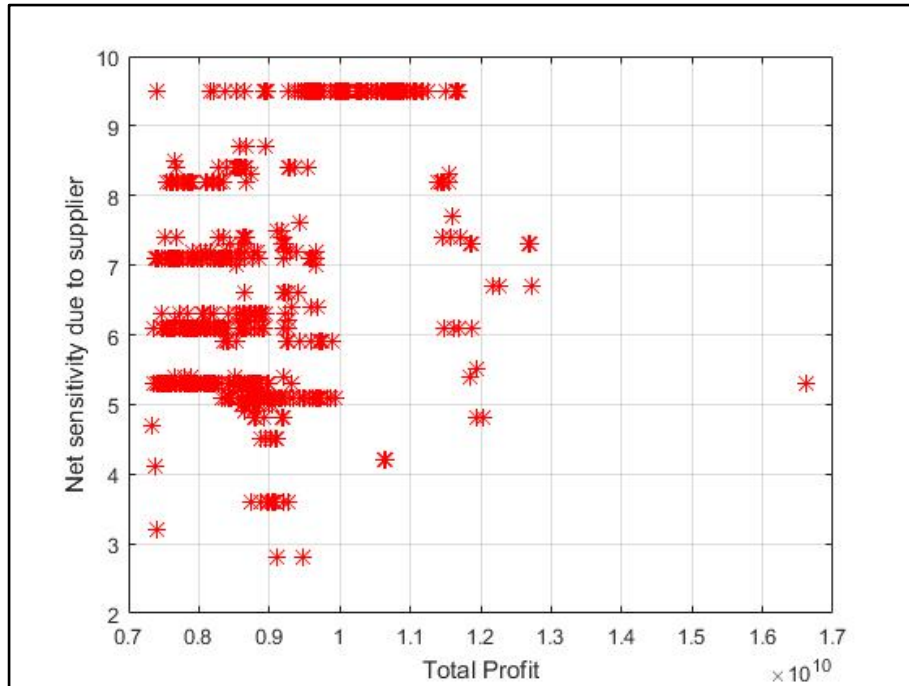


Figure 3. Total profit vs net sensitivity due to supplier

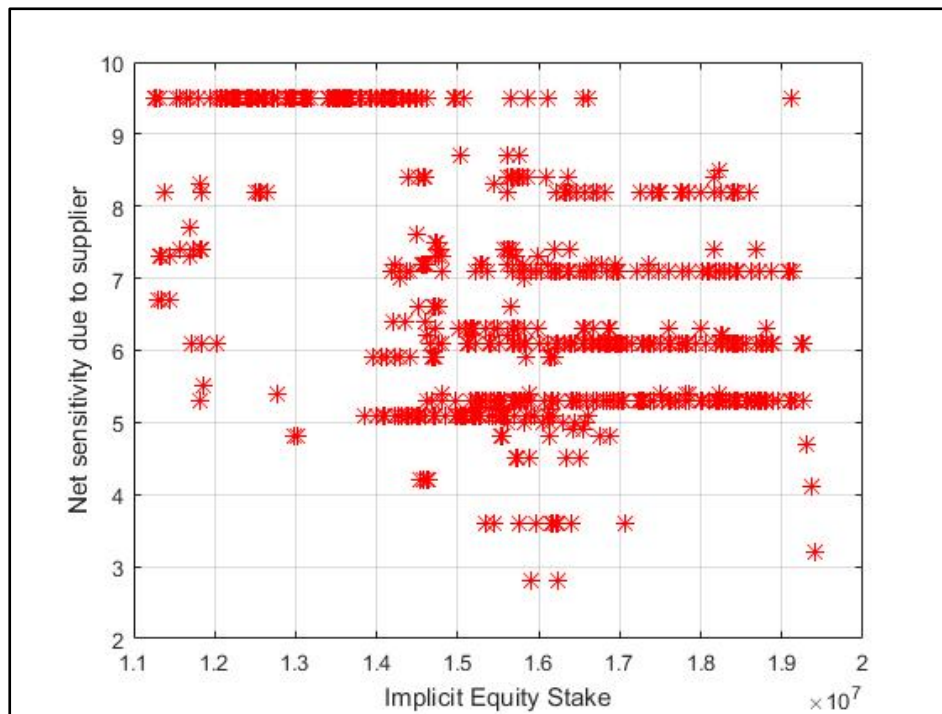


Figure 4. Supplier’s implicit equity stake vs net sensitivity due to supplier

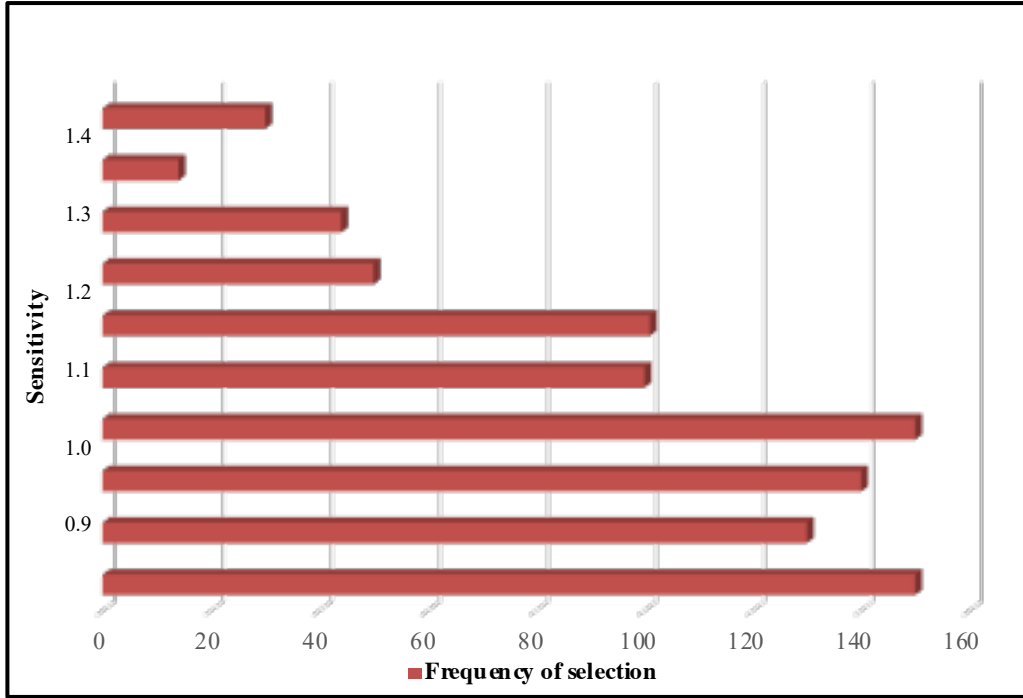


Figure 5. Frequency of supplier selection

5.2. Scenario analysis for changing risk profiles

It is observed that the financial risks impact both total profit and the relationship between supply chain stakeholders. Three case scenarios are proposed and analysed to explore the overall impact of different financial risks on the manufacturer-supplier relationship and the behaviour of suppliers concerning risk profile, both in the short- and long-term horizon.

Case 1: Impact of market risk on supply chain

Considering a two-echelon supply chain with a manufacturer and three suppliers, and assuming that equivalent volatility of supplier 1 (β_{1eq}) is 0.4, β_{2eq} is 0.8 and β_{3eq} is 0.6; it is obvious that supplier 2 is found to be more vulnerable to market fluctuations. Solving this problem by varying $R_m - r_{rf}$ between 0 - 0.10, Figure 6 shows that, as the market risk premium increases, the overall

implicit stake owned by the supplier exponentially decreases. This implies that as the market conditions worsen, the relationship between key stakeholders (manufacturer-supplier) becomes less beneficial to the supplier. Meanwhile, the ownership of the manufacturer increases. Suppliers have an implicit equity stake in the manufacturer that makes them dependent on future business and implies a long-term relationship.

On lowering the economic conditions further, the implicit equity of the supplier may go as low as 0, which implies that no supplier would be interested in building a long-term relationship with the manufacturer. As the risk premium increases, both profit and implicit equity decline, which is consistent with the corporate finance theory. As the market risk increases, the cost of credit payment increases, which diminishes the percentage profit. Meanwhile, in spite of the increase in cash flow from manufacturer to supplier, the implicit equity continues to decline due to an increasing rate of return on investment. The manufacturer has to choose between implicit equity and profit based on its priorities and business strategies. Decreasing implicit equity beyond a certain point will lead to the manufacturer losing their relationship with the supplier.

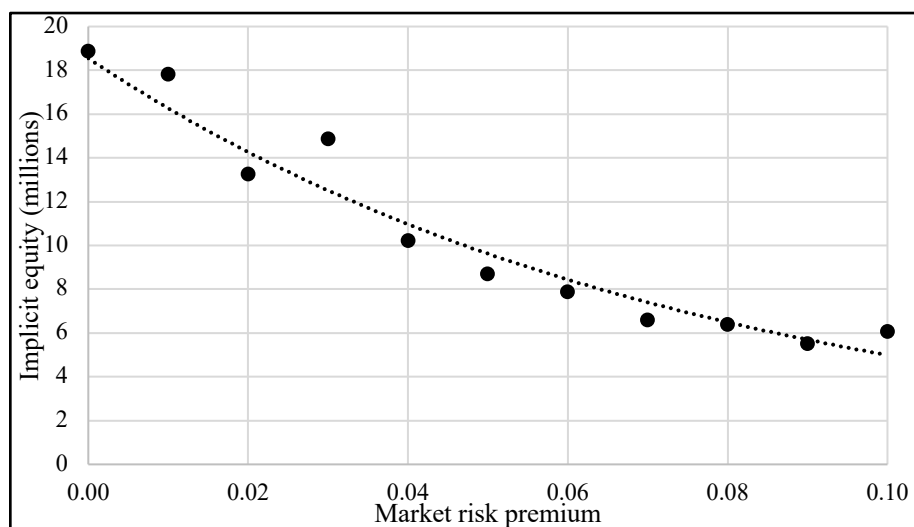


Figure 6. Market risk premium vs implicit equity stake of supplier

Case 2: Impact of price and currency fluctuation risk on supply chain

This case is divided into two parts to examine the impact of a financial crisis (price and currency fluctuation risks) on the supplier’s and manufacturer’s region.

(a) When economic crisis hits a supplier’s country/region

Companies have to track and consider the condition of the industry or region of their suppliers while making financial decisions as shocks propagate along the supply chain (Kale and Meneghetti, 2014). When a country/region is hit by an economic crisis, the GDP of the country decreases, which diminishes the price of the final products manufactured by that country (Bems et al., 2010). This unique case considers price and currency fluctuation risk.

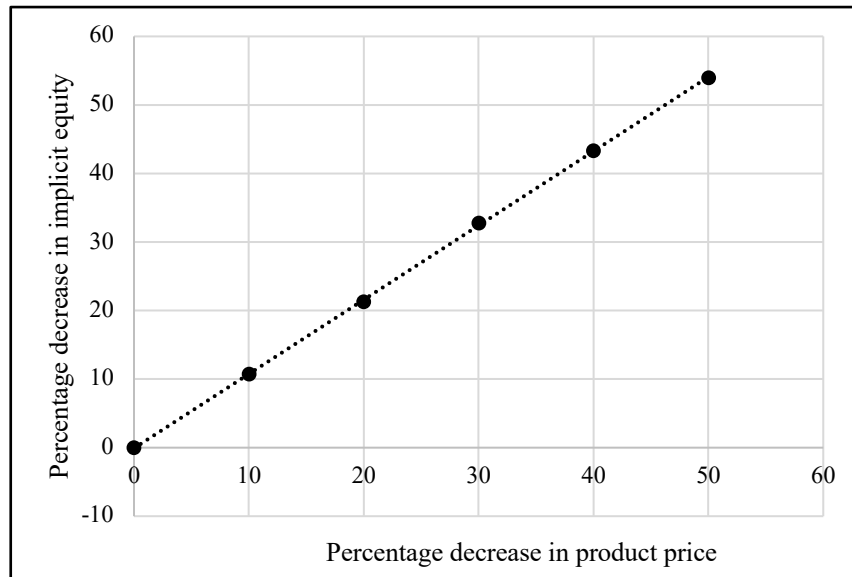


Figure 7. Percentage decrease in product price vs percentage decrease in implicit equity of supplier

Assuming that the price of the product sold by the supplier decreases up to 50% of the original price, the result will be a decrease in total cash flow from the manufacturer to the supplier,

reducing the implicit equity stake of the supplier at the manufacturer firm. Figure 7 depicts that the decrease in the price of the product at the supplier side is directly proportional to the decrease in implicit equity of the manufacturer owned by the supplier. Therefore, as the economic crisis worsens and prices fall, the supplier struck by the economic crisis will also lose their relationship with the manufacturer which, in turn, leads to the manufacturer searching for alternative suppliers with lower prices in order to protect their profit level.

(b) When economic crisis hits a manufacturer's country/region

During a financial crisis, sales and profits of financially distressed manufacturers will decrease over time due to lower demand potential and higher financing costs (Liu, 2013). When an economic crisis hits a manufacturer's country and the conditions worsen, the market risk in this region will increase due to the decline in the potential market demand, making the implicit investment by the supplier more volatile. To measure this, the market sensitivity is varied from 0 to 0.7. In the short term the market risk fluctuation might yield a higher implicit equity. However, in long term, as the market worsens, the implicit equity owned by the supplier will decrease, as illustrated in Figure 8. Finally, the financial distress will propagate to suppliers and the supplier will no longer receive dividend payments and will have to cancel their contract with the manufacturer.

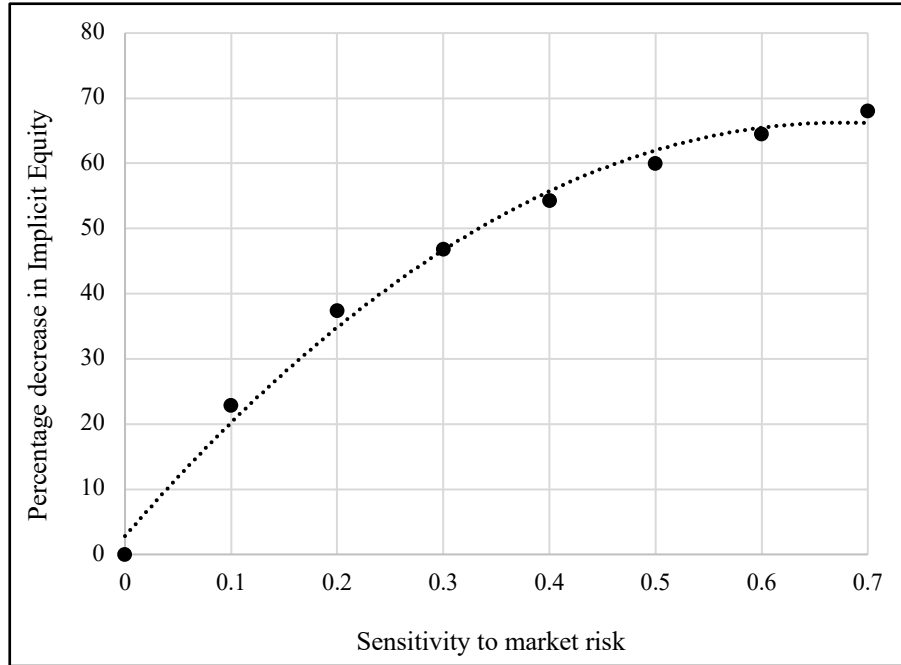


Figure 8. Sensitivity to market risk vs percentage decrease implicit equity stake

Case 3: Impact of default risk on supply chain

When the manufacturer files for bankruptcy, the supplier loses its future dividend payment equal to the implicit equity. However, the manufacturer will have to pay the unsettled dividends regarding the supplier's uncleared debts, after liquidation of all its assets. Unlike market risk, default risk is not a systematic risk and, hence, not rewarding. Therefore, during an increasing default risk of a manufacturer, the supplier is heading toward sales loss over the short term. As the bankruptcy risk of the manufacturer increases the implicit equity owned by the supplier decreases (as shown in Figure 9). Also, it is interesting to note that payment failure from the downstream customer to upstream supplier would lead to poor solvency of the supplier. The supplier will then have difficulty in making payments to its own supplier(s). As the failure escalates along the network, the whole supply chain may incur a bankruptcy avalanche (Kale and Meneghetti, 2014).

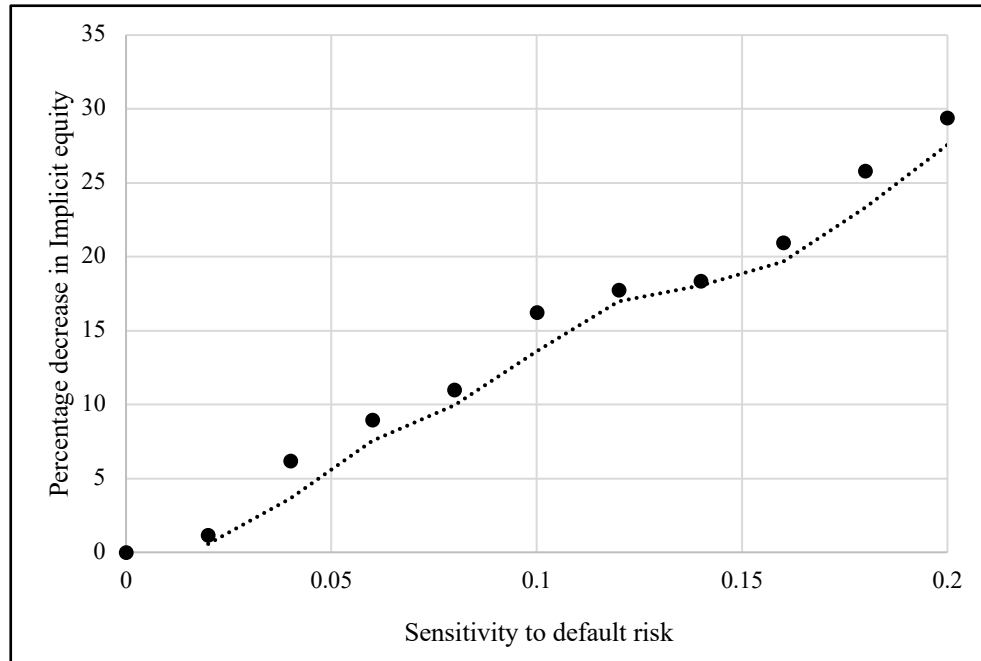


Figure 9. Sensitivity to default risk vs percentage decrease implicit equity stake

6. Discussion and conclusion

6.1. Conclusion

This study aimed to analyse the manufacturer-supplier relational perspective under the influence of key financial risks. As a result, a multi-objective mathematical model was developed for supplier selection and order allocation following corporate finance theory. While considering four exogenous financial risks, the proposed multi-objective decision-making model targeted to achieve three objectives: maximise the total profit of the manufacturer, minimise the supplier’s implicit equity stake and minimise the overall financial risk faced by the supplier. Considering the context of supplier selection and order allocation, manufacturer-supplier relational perspectives were explored following a scenario-based approach. Financial risks were first ranked using a VIKOR method and later used to develop and solve a multi-objective optimisation model

following the NSGA-III approach. Three case scenarios were investigated to capture the impact of changing risk circumstances on the relationship between manufacturer and suppliers, in short and long-term horizon. The model quantified the implicit equity stake as well as financial risks observed in the supplier selection process. The results were analysed from both the manufacturer as well as supplier perspective; and the optimality conditions were discussed for these two stakeholders under changing risk circumstances.

The following conclusions can be drawn, while attempting to answer the research question *How do financial risks influence the manufacturer-supplier relationship?*

- i) Financial risks impact not only the profits, but also affect the long-term relationship between supply chain stakeholders.
- ii) Suppliers with higher sensitivity are not preferred by the manufacturer.
- iii) As the market risk premium increases, the overall implicit equity stake owned by the supplier exponentially decreases. This implies that the relationship between supplier and manufacturer becomes less beneficial for the supplier as market conditions worsen.
- iv) When an economic crisis hits a supplier’s country, the implicit equity stake of the manufacturer owned by the supplier will decrease proportionally to the decrease in the price at the supplier side; this means that the supplier will lose their relationship with the manufacturer as the economic crisis worsens.
- v) When an economic crisis hits a manufacturer’s region, the market risk in this region will increase, making the implicit investment by the supplier more volatile. While the market risk fluctuation may lead to higher implicit equity in the short term, the implicit equity stake owned by the supplier will decrease in the long term as the market continues to worsen. Ultimately, the financial distress will propagate to the suppliers and result in the termination of the contract with the manufacturer due to payment problems.
- vi) Increasing default risk of a manufacturer leads to sales loss for suppliers in the short term and, as the risk continues to increase, the implicit equity owned by the supplier

decreases. vii) Furthermore, cash flow problems would propagate to the suppliers and their tier II & III suppliers; and this escalation of the solvency problems may affect the whole network and cause a bankruptcy avalanche. All of these remarks emphasise the sensitivity of the manufacturer-supplier relationship to multiple financial risks.

6.2. Contribution to research and practice

This study provides several theoretical and managerial insights based on a two-stage empirical analysis. Lack of understanding concerning the complex behaviour of financial risks and their impact on supply chain stakeholders is apparent in the literature (Sokolinskiy et al., 2018). In particular, modelling of a set of financial risks together, in order to understand the relational perspective, is a unique research contribution. The study contributes to the SCRM literature by understanding the complex interaction between a set of financial risks and inter-firm relationships within the supply chain following corporate finance theory. A scenario-based approach to understand supply chain dynamics for different exogenous risks and actors in a two-echelon supply chain is unique and contributes to a growing interest in systemic risk in the supply chain. It is anticipated that the significant disruptions brought in by the COVID-19 pandemic will give rise to systemic risk. Systemic risk was a major contributor of the global meltdown in 2008 and is defined as a financial breakdown of an entire system (economy or industry), caused by a cascading impact of an event at the micro/firm level, triggering severe instability in the financial sector (Kaufman and Scott, 2003). Evidently, exogenous financial risks are indirect, cascading drivers for systemic risk. The results were interpreted from both the manufacturer and supplier perspective by considering the perceptions, benefits and possible mitigation approaches followed by each stakeholder. Thus, the research contributes to a growing interest on systemic risk in the context of the supply chain.

It is inferred that increasing market risk can be rewarding in the short term for supply chain players. However, in the long term, it is wiser to create relationships with supply chain actors that have stable profits and are less exposed to financial risks. It is also found that the default risk is a dangerous risk and it is difficult to absorb and cope with, within the supply chain. This empirical study derives multiple inferences presented in the previous section on the impact of financial risks on the manufacturer-supplier relationship in a two-echelon supply chain.

The study provides several managerial implications. The developed model would help manufacturers in making supplier selection and order allocation decisions based on the financial situation of suppliers. Similarly, suppliers will benefit by understanding the value of their ‘implicit equity stake’ for sustainability of the supply network. Supply chain practitioners generally focus on financial risks and the profits of their firm (Caniato et al., 2016); however, examining the impacts of these risks on supply chain decisions and stakeholder relationships will guide managers in making informed decisions associated with foreign exchange risk, default risk, market risk and price fluctuation risk. Most importantly, the findings made through the scenario cases are expected to benefit investors, financial institutions and risk managers in enabling effective decision-making in the post COVID-19 era. This study will also contribute to the growing field of SCRM by providing critical insights into managing ‘financial’ relationships between different supply chain stakeholders, while collaboratively managing different exogenous financial risks.

6.3. Limitations and future research avenues

Like any other research, this study has several limitations in terms of the availability of suitable real case data to test and validate the developed model. Expert panel opinions were utilised along with the authors’ experience in SCRM to identify a range of parameters and establish the representative data to analyse the model. Measurement error associated with the judgements made

by the expert panel was not considered. Additionally, only four key exogenous financial risk types were considered in the analysis and other risks (such as endogenous risks) remained unexplored. The study did not compare the solution of the developed model with any established approaches in order to check the effectiveness of the model or algorithm. Since complete information regarding the sensitivity of a security to microeconomic risks was not available, CAPM was adopted over Arbitrage Pricing Theory (APT). Only the positive values of volatility measure, Beta, were considered in the study. It would be interesting to observe variations in the results for negative values of Beta. Future research can attempt to address some of the identified shortcomings, following the use of real financial data from Bloomberg or other suitable data sources. Future research may also focus on quantifying how different financial risks shape the competitive scenario in multi-tier and multi-commodity supply chains. The influence of supply chain risk mitigation strategies on the financial risks in volatile environments is another interesting avenue for future research. The study can also be extended to multi-echelon supply chains to capture intricacies in a wider network.

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APPENDIX

Rating	Likelihood	Impact	Detectability	Speed of onset
9	Very High	Extreme	Very difficult	Very slow
7	High	Major	Difficult	Slow
5	Moderate	Moderate	Moderate	Moderate
3	Low	Minor	Easy	Fast
1	Very low	Incidental	Very easy	Very fast

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