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Managing Supply-side Disruption Risks through Dual Sourcing

ABSTRACT: The selection of a sourcing strategy plays a vital role in managing supply disruptions in global supply chains. The choice regarding the number of suppliers is one of the most important decisions in mitigating supply-side risks. Despite the benefits cited in the literature for single sourcing there is enough evidence that provides justification in using dual-sourcing as a risk mitigating policy. In this paper we analyze single versus dual-sourcing strategies of a buying organization in a multi-period setting where each supplier is exposed to disruption risks. We incorporate supplier rating strategies based on the performance of the suppliers and use them in the sourcing decisions. In this paper, we develop a stochastic dynamic programming model to formulate the dual sourcing problem.

***Keywords*:** Dual Sourcing, Supply Chain Risk Management, Vendor Rating, Stochastic Dynamic Programming

1 Introduction

Modern supply chains are complex networks made up of multiple entities spanning the entire globe. In these complex supply chain networks risks exist in every link and managing these risks have become extremely critical in the context of today's globalized supply networks. There have been numerous instances where supply chains have been adversely affected because of unforeseen supply disruptions leading to irreparable damages. A devastating fire broke out due to lightning in March 2000 that shut down the Philips Semiconductor plant in Albuquerque, New Mexico for six weeks. This lead to shortage of components for both Ericsson and Nokia who were procuring from that Phillips plant. Ericsson lost at least $400 million in potential revenues (Simchi-Levi et al. 2007) and its shares also dropped by 14% within an hour of the company's damage revelation. Hurricane Mitch caused widespread devastation to banana production in many parts of Central America in 1998. As a result food companies like Dole and Chiquita faced a prolonged loss of supply. Dole suffered a 4% decline in its revenues (Tomlin, 2006). The catastrophic flooding in Thailand in 2011 affected the production of several key end products, electronic parts and subsystems—most notably semiconductors, cameras and hard disk drives. The disruption to the electronics supply chain had an indirect impact in turn on the production of other devices and systems, including notebook PCs, dynamic random access memory (DRAMs), cameras and set-top boxes. Japan is a vital supplier of parts and equipment for major industries like computers, automobiles and electronics. Thus the tsunami attack which hit Japan in 2011 shook the world economy. The automotive supply chain, especially for Japanese OEMs Toyota and Honda, took the biggest blow, with parts supplies extremely constrained for months, and production and sales levels plunging as a result. In fact, Toyota lost its position as top global car manufacturer in 2011. A number of industries were constrained by shortages of obscure chemicals that represented just a small but vital component of their manufacturing processes, and which turned out to be either only or largely sourced from Japan. As those suppliers lost production capabilities, in some cases for months, manufacturers across the globe were sent scurrying for other sources or to find alternative materials. As companies become more global in scale and dependent on emerging markets, these risks can only escalate. Social and environmental issues create further vulnerability. Another recent example of a supply chain disruption attributed to climate change was the unusually prolonged drought in Russia over the summer of 2010. By early August of that year, over one-fifth of Russia's wheat crop had been destroyed and the government banned all grain exports, contributing to wheat price futures reaching their highest point in nearly two years. General Mills was one of many food manufacturers that faced significant price pressure as a result, announcing increases between 4% and 5% in September 2010.These are just some examples of supply disruptions that have severely impacted the globalized supply chains and have made it extremely important for supply chain managers to come up with strategies to cope with these unforeseen events that lead to huge monetary losses.

Researchers have divided supply chain risks into two broad categories viz., *operational risks* and *disruption* or *catastrophic risks*. In order to deal with the supply chain risks it is essential to perceive a clear understanding of the types of risks associated with supply chains. The first category, i.e. operational risks refers to the risks due to inherent uncertainties in a supply chain such as coordination issues, sudden decrease of supply, sudden rise in cost, technology fallout, etc. The other category, i.e. disruption risks refer to those which are either man-made or caused due to natural disaster. These refer to terrorist attacks, civil unrest, labor strikes and natural disasters such as floods, hurricanes, droughts and earthquakes. The impact of catastrophic risks is much more than that caused by operational risks (Sawik, 2011). Tomlin (2006) in his work has mentioned about two tactics used to counter disruption risks, viz., mitigation tactics and contingency tactics. Mitigation refers to those tactics where a firm acts way before a disruption occurs while contingency refers to those where a firm reacts after some disruption has already occurred. In many cases a firm may adopt a combination of these risk management strategies. Kleindorfer and Saad (2005) created a supply chain risk framework called SAM, where "S" refers to specifying sources of risk and vulnerabilities, "A" means assessment and "M" stands for mitigation. Berger et al. (2004) points out that there are catastrophic events that affect all suppliers, as well as unique events that affect only one single supplier and developed a decision tree based model which determines the optimal number of buying firm. Ruiz-Torres and Farzad (2007) extended this model to provide better understanding of the effect of the input parameters on the optimal number of suppliers.

The choice regarding the number of suppliers is one of the most important tactical decisions in mitigating supply-side risks. The most frequently used approaches of sourcing can be categorized into two types 1) single sourcing and 2) multiple sourcing. Single sourcing refers to the fulfillment of the purchasing organization's need for a particular product by one selected

Figure 1: Supply Chain Key Issues

Source: Hackett Group's 2012 Key Issue Study

supplier. During the past two decades, driven by the objective of reducing supply chain costs, firms have adopted strategies to rationalize, consolidate and streamline their supplier base. In many cases, this has led to single sourcing strategy for many commodities. The single sourcing strategy has been well proven to realize cost savings and many companies have been able to gain a competitive advantage by utilizing low-cost country sourcing. Larson and Kulchitsk (1998) indicated in a survey that single sourcing ensures higher quality at lower total cost to the buyer and also improved buyer-supplier cooperation. However, at the same time single sourcing exposes the buying firm to a high degree of supply disruption risks.

In the recent past, the emergence of supply chain risk mitigation as a key issue has caused many procurement managers to reassess their reliance on single sourcing strategies. According to a survey conducted in 2012 by the financial consulting firm, The Hackett Group, mitigating supply chain risk has been identified by 77% of supply chain executives as a key issue that must be managed (See Figure 1). One of the key risk mitigation strategies adopted by procurement managers is multiple sourcing. Multiple sourcing has gained immense importance among purchasing organizations because of several advantages it has over single sourcing, the most important being alternative sources of materials in case of delivery disruptions from a supplier. Due to the March 2000 lightning Nokia and Ericksson lost all their essential supplies from the Philips Semiconductor plant. However Nokia's multiple sourcing tactics mitigated the impact. Nokia responded to the disruption by increasing production at its alternate suppliers. In contrast due to an absence of "Plan B" i.e. alternative source Ericsson lost $400 million in potential revenue. Similarly Chiquita was able to mitigate the impact caused by the Hurricane Mitch in 1998 by practicing multiple sourcing strategies. Since Dole was dependent on its only single supplier it suffered a 4% decline in its revenue, while Chiquita increased revenues by 4%.

In this context, research efforts determining the optimal sourcing strategy and supply portfolio and diversification policies are gaining attention. Extant research has analyzed different aspects of the problem such as quantity allocation among suppliers, the trade-off between reliability and higher component costs, and the interplay between supplier diversification and flexible resources. Section 2 provides a detailed review of the relevant research. One key parameter that has not been extensively studied is how the performance of a supplier over multiple time periods affects the supply portfolio selection. Most of the extant research papers focus on single period models and the dynamics of supplier performance over multiple time periods and its interplay with sourcing diversification policies are largely ignored. In this paper we contribute to this stream of research by developing a dynamic stochastic programming model that helps the decision maker develop supplier diversification strategies and split order quantities between two suppliers in a multi-period setting based on various parameters such as supplier performance, procurement costs and probability of local and global supply disruptions.

Rating suppliers based on performance measures is an important component of production and logistics management that plays a key role in shaping supplier selection decisions and sourcing strategies of a firm. Selecting the right supplier is a complicated task as it involves considering different criteria. In today's complex supply chains, the performance of a firm does not depend solely on itself but is closely tied with the performance of its suppliers. Thus understanding a supplier's capabilities and performance potential is crucial to the buying firm's success. Starting from Dickson's (1966) vendor selection model, researchers have focused on various critical criteria such quality, reliability, delivery, performance history etc. However, how supplier performance affects the sourcing decisions and risk mitigation strategies of a firm have not been thoroughly studied in the literature. Supplier selection, in a way, is one of the key risk management strategies used to shield against potential supply disruptions. The various factors affecting a supplier's performance and its interplay with supply risk mitigation as well as contingency tactics is an important and potential area of research in management science. One of the primary contributions of this paper is to analyze different supplier selection criteria in evaluating supplier performance and its role in shaping sourcing decisions in view of managing possible disruption risks.

In this paper we focus on the dynamics between single versus dual-sourcing in the context of supply-side disruptions. The paper considers the presence of two suppliers whose performances are judged based on two criteria - *reliability* and *quality*. One is a local supplier which is reliable and without any quality issues but at the same time highly expensive (high-cost supplier). The other is a supplier from a low-cost country which is much cheaper but at the same time whose reliability and technical capability fluctuates (low-cost supplier). We develop a stochastic dynamic programming model to formulate the dual sourcing problem in a multi-period setting where each time-period the performance of the suppliers are evaluated based on reliability and quality parameters in order to derive the optimal sourcing decisions.

2 Literature Review

In this paper we touch upon two streams of literature viz., single versus dual sourcing methods, and supplier/vendor rating. Next we review the relevant papers in these two streams.

(i) Single vs. Dual sourcing Methods

Single versus dual sourcing strategies have been studied mostly in a single-period setting in the extant literature. Pochard (2003) uses real options theory to compare single sourcing with dual sourcing and examines how buying firms should prepare for disruptions in their supply chain. Burke et al. (2007) found that when the supplier capacity is large in comparison to product demand and the firm does not enjoy any diversification benefits, single sourcing is more dominant than dual sourcing. In all other cases dual sourcing is an optimal sourcing strategy. Empirical studies indicate that dual or multiple sourcing dominates most business areas (Goffin et al., 1997; De Toni and Nassimben, 1999; Shin et al., 2000). A review done by Stefan Minner (2003) identifies inventory models with multiple supply options and discusses their contribution to supply chain management. Purchasing managers favor multiple sourcing over single supplier as dependence over single supplier invites several kinds of risk. According to the study lead by Minner the risk of increasing prices in global sourcing due to exchange rate volatility, supply disruptions due to machine breakdowns, labor strikes or political instability, capacity limitations, lead time variability can be mitigated if multiple suppliers are available. Depending on single supplier invites agency problems like opportunistic behavior and information asymmetries with respect to true manufacturing costs and dynamic cost development. However these can be overcome by introducing supplier competition through multiple sourcing. Tomlin and Wang (2005) identifies that in comparing a single-source dedicated strategy with a single-source flexible strategy, a flexible strategy is strictly preferred to a dedicated strategy when the dedicated resources are costlier than the flexible resource. It has been proved that this intuition is correct if the firm is risk neutral or if the resource investments are reliable. If both these conditions fail to hold, the intuition can be wrong. Anupindi and Akelle (1993) points out various reasons for a buyer not to single source. The reasons being uncertainty in both quality and quantity of supply, price variations due to exchange rate fluctuations when sourcing from international suppliers, the habit of a single supplier to hold the buyer to “ransom” etc. Thus industries are increasingly moving towards a smaller supplier base of two or three suppliers. Further in single-sourcing the buyer often has to provide concession and encourage effort in work to the supplier to ensure improved performance Kumar et al (1990). According to Whittier (1990) and McMillan (1990) performance is improved by creating quality competition through quantity allocations and/or price renegotiations with two/three suppliers. Costatino and Pellegrino (2010) focus on developing a quantitative model for examining the economic advantages of adopting multiple sourcing versus single sourcing in risky environments. They show that in risky environments the trade-off between single and multiple sourcing depends on deterministic and probabilistic factors. Another major area of research is focused on how to split orders between different suppliers. Lau and Zhao (1994) minimizes the sum of annual holding and ordering costs subject to maximum allowable stock-out risk to find the optimal ratio of split between two suppliers. They further concluded that the split between two suppliers depend on their mean lead times. Kelle and Miller (2001) on the other hand show that large demand and lead time uncertainty favor multiple sourcing. Sawik (2011) uses a portfolio approach in a make-to-order environment to optimize the allocation of orders of custom parts among suppliers. Their research points out that the decision is based on price, quality, and reliability. These factors are self-conflicting as the supplier offering lowest price may not be reliable or provide the best quality while the supplier providing the best quality may not be cheap. In another research effort by Berger and Zeng (2006) a study has been done on the optimal supply size depending on financial loss function, the operating cost and the chance of all the suppliers being down. Burk et al. (2007) suggests that one should choose single sourcing over multiple sourcing when the supplier capacity is large relative to the product demand and when there are no diversification benefits available for the buying firm.

In this paper we extend the single versus dual sourcing problem in a multi-period setting and incorporate supplier-ratings in the sourcing strategies. Next we look at the literature on supplier ratings.

(ii). Supplier/Vendor Ratings

Supplier selection plays an important role in mitigating supply disruption risks and thus over the past four decades supplier rating has evolved as an important area in industrial marketing research (Dickson, 1966). According to Ishikwan (1990) quality evaluation of a supplier can be done by considering the following criteria: quality, cost, delivery, and service. A study by Weber et al. (1991) reveals that traditionally vendors focused on criteria like quality, delivery speed, reliability, price offered. In case of a relationship which is longer and closer, vendors are selected on the basis of their global performances. Global evaluations, on the other hand, ranges from total cost analysis (Roodhooft and Konings, 1996; Ellram, 1996; Tagara and Lee, 1996), supplier's capacity in production planning (Ho and Carter, 1988), their future manufacturing capability (Ellarm, 1990) and continuous improvement capabilities (Choi and Hartley, 1996). Rao and Kiser (1980) and Bache et al (1987) have identified over fifty criteria for supplier selection. Gaballa (1974) formulated a single-objective, mixed-integer programming to minimize the sum of purchasing, transportation and inventory costs by considering qualitative criteria like vendor's quality of material, delivery and capacity. Weber and Current (1993) used a multi-objective approach to analyze the trade-offs between conflicting criteria in supplier selection problems. Masella (1995) and Merli (1991) have divided important supplier selection criteria under different levels-Level 1-Price and quality; Level 2-Supplier's logistical performance such as Reliability, flexibility, supply lots and lead time.; Level 3-Supplier's process capability such as Set up time, Lot size, Lead time.; Level 4- Supplier's human resource from several points of view-design involvement, management ability, culture etc.; Level 5-Strategic performance like business partnership. Muralidharan and Anantharaman (2001), Deshmukh (2001) describe the importance group decision making in vendor evaluation. They also discuss how Analytical Hierarchy Process (AHP) and a multi-criteria decision-making (MCDM) tools are useful in such evaluation. An attempt has been made by Mandal and Deshmukh (1993) to study the problem of documenting the two factors for vendor selection using MCDM methods. A trade off among quality, cost and delivery performance measures have been studied by Kraljic (1983), Burton (1988) and Benton and Krajewski (1990). The relative importance of supplier attributes like quality, cost and delivery performance have been studied by various researchers such as Wagner et al (1989), Chapman (1993) and Chapman and Cartar (1990). Yu and Tsai (2008) conducted a case study on a semiconductor industry to rate supplier's performance. In our dynamic stochastic programming model we incorporate quality and reliability as the performance measures of the suppliers in the sourcing framework.

Next we explain the stochastic dynamic programming model for single verses dual sourcing.

3 Stochastic Dynamic Programming Model for Dual Sourcing

In order to model the choice between dual sourcing and single sourcing we develop a stochastic dynamic programming model in a multi period setting. We start by considering the availability of two suppliers (geographically apart from each other) to a firm. Both the suppliers possess the capability of supplying a certain required component needed by the firm, though at different prices and with varying reliability. We assume that the first supplier, say S_1, is very reliable yet costly (domestic high-cost supplier) while the second supplier, say S_2, is cheap but at the same time not that reliable (foreign low-cost supplier). Thus the amount demanded from S_2 is not received completely and only a fraction of it is delivered to the firm. The fraction of a particular order that S_2 actually delivers depends on two criteria namely *reliability* and *technical capability*. Reliability and technical capability of the second supplier, S_2 may increase or decrease from one time-period to another based on internal process improvements or decline in technological prowess. The current level of reliability and technical capability of S_2 depends upon its level in the previous time-period. The buying organization needs to order *Q* every period. c_1 and c_2 denote the cost per unit of the product from S_1 and S_2 respectively. We also consider the availability of spot market from where the buying organization can get the remaining product quantity in case there is some shortfall due to supplier's delivery disruptions. The spot market charges c_s per unit. ($c_s > c_1 > c_2$).

Local disruptions may occur at any of the supplier's locations at any time-period making that particular supplier completely unable to deliver the required amount of product. Let p_1 denote the probability of no disruption at S_1. Thus $1-p_1$ is the probability of disruption at S_1.

Again let p_2 denote the probability of no disruption at S_2. Thus $1-p_2$ is probability of disruption at S_2.The state of any particular period of the dynamic programming model is the reliability and technical Capability score of S_2.

The table below lists the variables used in the dynamic programming model.

TABLE 1*:* Notations used in the stochastic dynamic programming model for dual-sourcing

Q	Amount ordered every time-period
c_1	Cost per unit of supplier 1
c_2	Cost per unit of supplier 2
c_S	Cost per unit of spot market
x_t	Amount ordered from supplier 2
K_t	Fraction of order received from supplier 2
R_t	Reliability score of supplier 2 at time-period *t*
Y_t	Technical capability score of supplier 2 at time-period *t*
p_1	Probability of no disruption at supplier 1
p_2	Probability of no disruption at supplier 2
$p(R_t, Y_t \mid R_{t-1}, Y_{t-1})$	Probability of reliability and technical capability being R_t and Y_t at time-period *t* given the reliability and technical probability was R_{t-1} and Y_{t-1} at *t-1*
f_t	Function calculating the minimum cost of procurement for the buying organization

The following recursive functional equation specifies the multi-period dual sourcing model:

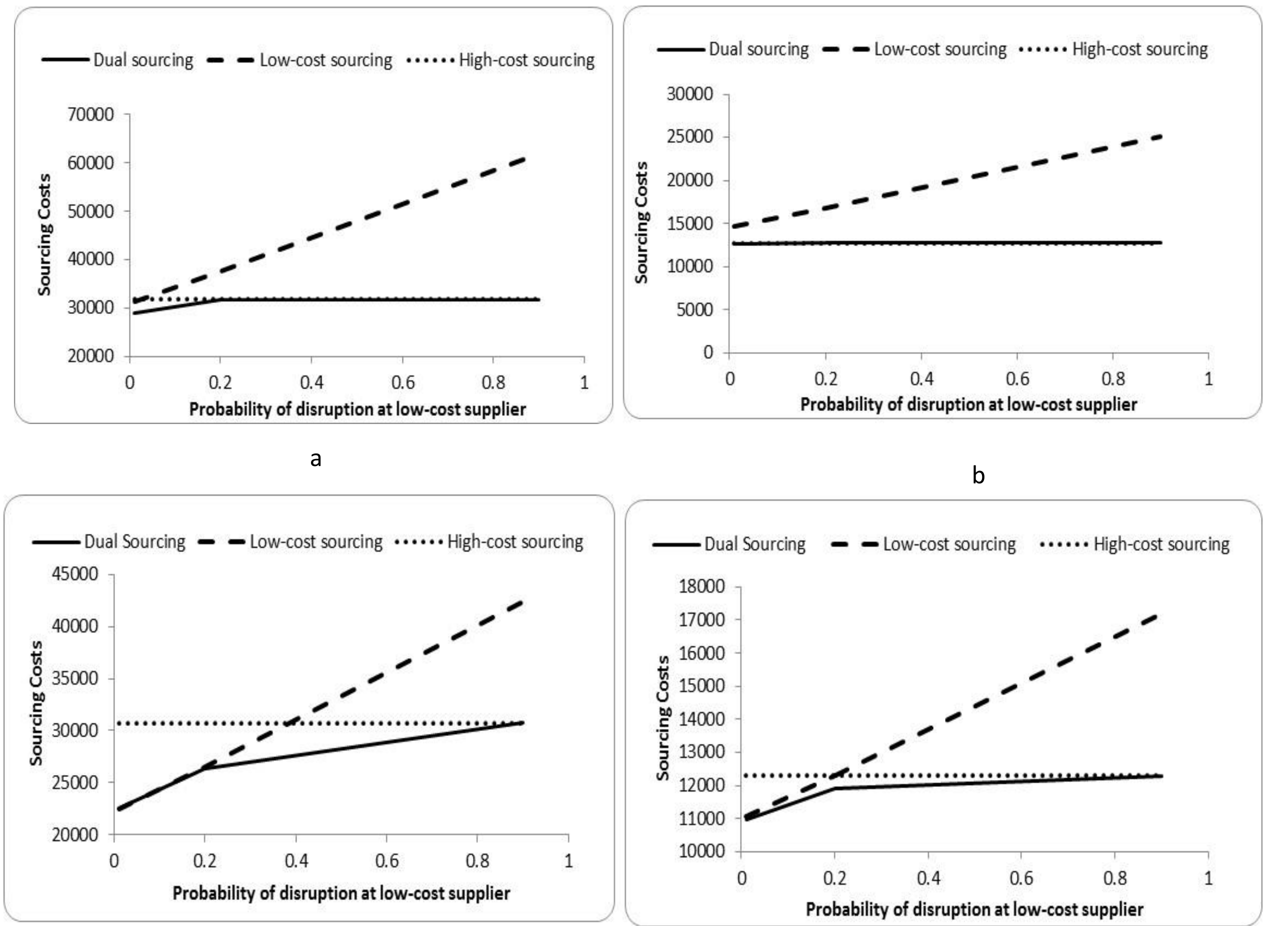
$$f_t(R_{t-1}, Y_{t-1}) = \underset{x_t}{Min} \; p_2 \sum_{R_t, Y_t} p(R_t, Y_t \mid R_{t-1}, Y_{t-1})[p_1 c_1 (Q - x_t) + (1-p_1)c_s(Q-x_t) + c_2 K_t x_t + x_t(1-K_t)c_S$$

$$+ f_{t+1}(R_t, Y_t)] + (1-p_2)[p_1(c_1(Q-x_t) + c_S x_t) + (1-p_1)c_S Q + f_{t+1}(R_t, Y_t)]$$

The boundary condition is given by: $f_T(R_T, Y_T) = 0$

Next we run the above sourcing model for various numerical inputs and derive critical managerial insights.

Figure 2: Sourcing costs at different levels of supply disruption of the low-cost supplier under varying conditions of low versus high-cost sourcing and spot price differentials



c

d

4 Numerical Insights and Managerial Implications

For the numerical analysis, we assume that the local supplier could be in any of the following five levels of reliability and technical capability states: “very high”, “high”, “medium”, “low”, “and very low”. The buying firm could derive the current state of reliability and technical capability of the supplier based on the performance in the previous time-period. The transition probabilities for going from any one of the five states in the current time-period to a future state in the next time-period can be determined based on past performance of the supplier. In the first set of numerical analysis we focus on the sourcing strategies under varying levels of supply disruptions from the foreign supplier at different values of local versus foreign sourcing costs and varying spot price conditions. We assume that the local supplier is a reliable but costly supplier whose chances of disruption are almost zero whereas the foreign supplier is a “low-cost” supplier with certain probability of supply disruption.

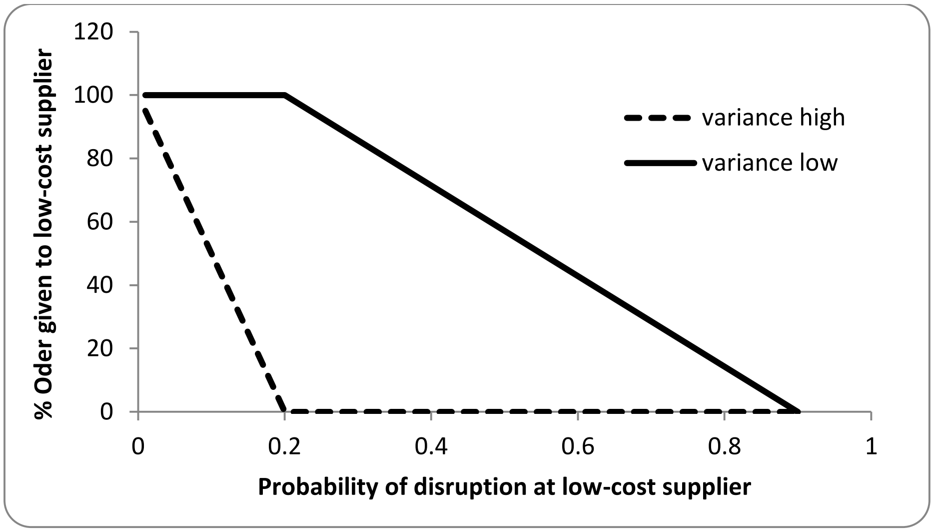
Table 2: Percentage Increase in costs if Low-Cost or High-Cost Single Sourcing is used compared to Dual Sourcing

			Spot Price			
			High		Low	
			Cost Differential			
			High	Low	High	Low
Prob. Of Disruption at Low-Cost Supplier	High	Low Cost Sourcing	42%	43%	18%	21%
		High Cost Sourcing	0%	0%	0%	0%
	Low	Low Cost Sourcing	10%	19%	0.40%	2.00%
		High Cost Sourcing	3%	0	21%	7%

We study three possible sourcing strategies, viz., low-cost, high-cost and dual sourcing. As mentioned earlier, local sourcing corresponds to high-cost sourcing and foreign sourcing corresponds to low-cost sourcing. The results of the above numerical study are provided in Figure 2(a)-(d). In Figure 2(a) and 2(b) we analyze the sourcing costs when the spot price of the component is high and in Figure 2(c) and 2(d) we study the sourcing costs when the spot price of the component is relatively low. In Figure 2(a) and 2(b) we highlight the sourcing costs for the three sourcing strategies when the cost differential between the local and foreign supplier is high and low respectively. We find that when the spot price of the component is high and the cost differential between low-cost and high-cost sourcing is also high then at low probabilities of supply disruption of the low-cost supplier, dual sourcing clearly is the best strategy. However as the probability of supply disruption of the low-cost supplier increases then high-cost sourcing and dual sourcing are both optimal. Implicitly the above result means that as the probability of disruption of the low-cost supplier increases then the entire sourcing should take place from the high-cost supplier. Similar results hold when the cost differential between the low-cost and the high-cost supplier is low.

When the spot price of the component is low and the cost differential between low and high cost sourcing is high then at low probabilities of disruption at the low-cost supplier, low-cost sourcing and dual sourcing provide the best options. However as the probability of disruption

Figure 3: % Order given to low-cost supplier under varying levels of reliability and technical capability conditions and probabilities of supply disruption



increases then dual sourcing clearly is the best strategy. When the cost differential between low and high cost supplier is low then dual sourcing dominates the two strategies. Based on the results obtained above we construct Table 2 that identifies the percentage increase in costs if low-cost or high-cost sourcing strategy is used compared to dual sourcing under different market conditions.

From Table 2, we conclude that when the probability of disruption at the low-cost supplier is high and the spot price of the component is also high then the increase in costs if a firm goes for low-cost sourcing compared to dual sourcing is the highest. On the other hand, if the probability of disruption at the low-cost supplier is low and the spot price of the component is also low then adopting high-cost sourcing leads to significant increase in costs compared to dual sourcing. We also observe that high cost sourcing and dual sourcing provide similar cost benefits when the probability of supply disruption increases for the low cost supplier. In a similar vein, low-cost sourcing and dual sourcing provide similar cost advantages when the probability of disruption of the low-cost supplier is low and the spot price of the component is low. The above analysis can be used by the buying firm to identify optimal sourcing strategies based on the different business scenarios.

In the next set of results, we analyze the sourcing problem under different scenarios where the reliability and the technical capability of the low-cost supplier changes from one state to another. In one scenario we assumed that the low-cost supplier's reliability and the technical capability changes drastically from one state to another. We call this the high-variance condition because the variance of the states in the transition matrix for this scenario is high. In the other scenario we assumed that the variance between the different states is low i.e., the reliability and the technical capability of the supplier does not change drastically. We compare the sizes of the order that the firm places to the low-cost supplier when variance between the future states of reliability and technical capability is high and when variance is low under different probabilities of supply disruption. The results are highlighted in Figure 3.

We observe that when variance is low the firm orders everything from the low-cost supplier at low probabilities of supply disruption. As the probability of disruption increases the percentage of total order given to the low-cost supplier gradually decreases. When variance is high the percentage of total order given to the low-cost supplier shows a much steeper fall and becomes zero at low probability of supply disruption. The above analysis leads to the conclusion that when the performance of the low-cost supplier is stable in terms of reliability and technical capability then even at relatively higher probabilities of supply disruption percentage of sourcing from the low cost supplier is significant. However if the performance of the low-cost supplier drastically changes form one state to another then the percentage of sourcing from the low-cost supplier under dual-sourcing falls strikingly.

5 Conclusions and Future Research Directions

Modern supply chains are complex networks made up of multiple entities spanning the entire globe. In these complex supply chain networks risks exist in every link and managing these risks have become extremely critical in the context of today's globalized supply networks. There have been numerous instances where supply chains have been adversely affected because of unforeseen supply disruptions leading to irreparable damages. The selection of a sourcing strategy plays a vital role in managing supply disruptions in global supply chains. The choice regarding the number of suppliers is one of the most important decisions in mitigating supply-side risks. In the recent past, the emergence of supply chain risk mitigation as a key issue has caused many procurement managers to reassess their reliance on single sourcing strategies. Despite the benefits cited in the literature for single sourcing there is enough evidence that provides justification in using dual-sourcing as a risk mitigating policy. Supplier rating based on performance measures is an important component for shaping supplier selection decisions and sourcing strategies of a firm. Selecting the right supplier is a complicated task as it involves considering different criteria. In this paper we analyze single versus dual-sourcing strategies of a buying organization in a multi-period setting where each supplier is exposed to disruption risks. We integrate the supplier rating mechanisms in our supplier selection and sourcing choice problem. We develop a stochastic dynamic programming model to formulate the sourcing problem and derive various managerial insights under different scenarios of supply disruptions. We find that when the spot price of the component is high and the cost differential between low-cost and high-cost sourcing is also high then at low probabilities of supply disruption of the low-cost supplier dual sourcing clearly is the best strategy. However as the probability of supply disruption of the low-cost supplier increases then high-cost sourcing and dual sourcing are both optimal. When the spot price of the component is low and the cost differential between low and high cost sourcing is high then at low probabilities of disruption at the low-cost supplier low cost sourcing and dual sourcing provide the best options. However as the probability of disruption increases then dual sourcing clearly is the best strategy. When the cost differential between low and high cost supplier is low then dual sourcing dominates the two strategies. We also derive the optimal split of the order size between the low-cost and the high-cost supplier under dual sourcing and analyze the ordering decisions as the market as well as the performance of the low-cost supplier varies. We measure performance of the supplier in terms of reliability and technical capability.

In the present paper we have not considered any capacity constraints at the supplier end. In the future we would like to analyze the sourcing problem in a dynamic setting with supplier capacity constraints. Here we have only looked at the problem from the buying organization's perspective. In a future research project the supply chain implications under a game theoretic setting may be analyzed where the suppliers can be strategic and can determine their selling prices under dual-sourcing mechanisms. Incorporating learning into the dual-sourcing decisions based on the order fulfillment at each time-period can be another interesting future research endeavor.

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