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Supply Chain Risk Management: Academic Perspective

Abstract

Addressing the challenge of building robust supply chains in an environment of high demand and supply uncertainty, this paper focuses on the research findings in the supply chain risk management process, particularly on i) identifying and mitigating supply side risks related to price and supply chain disruptions, and ii) managing demand side risks through the judicious use of efficient and responsive chains, which would help companies develop effective risk management plans.

Today's enterprise is faced with complex business challenges. Operating in a global environment has resulted in an increased velocity of change in all parts of business. On the one hand customers are demanding lower costs and higher service and on the other hand firms have to grapple with a higher velocity of change in both the demand and the supply side. To attain a high level of supply chain performance, a firm not only has to ensure that the supply chain configuration is aligned with business strategy but also that the supply chain is robust enough to handle demand as well as supply side uncertainties. Hendricks and Singhal[1] report that companies suffering from supply chain disruptions experienced 33–40% lower stock returns relative to their industry benchmarks. Both academicians and practitioners have realised that supply chain management risks, if not managed properly, can have a significant negative impact on business performance. This paper focuses on the robustness of the supply chain and on chains that can handle a high level of demand uncertainty and supply uncertainty. Three areas of academic research in supply chain management are highly relevant for addressing the challenge of supply chain risks. These areas are: *demand side risks*, *supply side risks* and *the supply chain risk management process*. The research findings in these areas can be useful

for managers so we will briefly review extant research and highlight useful conceptualisations and findings.

Managing Supply Side Risks

Unlike the demand side, the firm has a greater control on the supply side and the popular view has been that supply side uncertainty can be handled by choosing appropriate partners in the chain. As a result, the focus has been on supplier selection and supplier development rather than on the management of supply uncertainty. However, certain events in the recent past have underscored the need to consider supply uncertainty. The terrorist attack on the US in September 2001 (9/11) forced firms to look at their supply chain vulnerabilities and firms have realised that they need to focus on both demand uncertainty and supply chain disruptions. Managing supply chain disruptions involves managing events which have low probability of occurrence but high impact on supply chain performance. Similarly, in the last few years, firms have been facing a lot of uncertainty on the supply prices front due to a surge in commodity prices and the volatility observed in foreign exchange markets. In this paper we focus on supply side risks related to supply chain disruptions and price related risks on the supply side of the chain.

Unlike the demand side, the firm has a greater control on the supply side and the popular view has been that supply side uncertainty can be handled by choosing appropriate partners in the chain. However, certain events in the recent past have underscored the need to consider supply uncertainty.

Low levels of supply uncertainty related to supplier delivery uncertainty and supply yield uncertainty can be handled using appropriate levels of safety stocks in the system. Therefore, the paper will not focus on those dimensions of supply side risks.

Managing Supply Chain Disruptions

For large companies the world over, globally distributed chains have become the norm in recent years. In their drive to enter new markets and at the same time cut costs, their supply chains are becoming increasingly long and tenuous. However, with a substantial increase in the number of companies adopting lean manufacturing techniques—a fall back of yesteryear—holding substantial inventory to meet market fluctuations—has fallen out of favour. On the other hand these very lean techniques have created chains with longer paths and shorter clock speeds resulting in more opportunities for disruption and a smaller margin for error for a disruption to take place.

Lengthy supply chains are increasingly proving to be a source of concern in the face of disruptions in sourcing, production and distribution of goods and services. Such disruptions may be caused by natural disasters such as cyclones and tsunamis, industrial accidents or acts of terrorism. These disasters have created greater demands on companies to keep supply chains flexible and integrate disruption risk management into every facet of supply chain operations.

It has been noticed in several cases pertaining to the latter that an overcompensating knee jerk government response to such acts generates more loss and for a longer term than the act of terror itself. Delays due to closure of ports and airports, more stringent and time consuming security checks causing longer lead times, a rush to set up duplicative facilities/sources to guard against future attacks, huge insurance premiums and higher costs for emergency sourcing of raw materials are some of the added problems faced by firms. After the 9/11 attack such thinking was seen to directly affect the production of several companies, especially ones working with Just-in-Time (JIT) processes. Ford Motors, for example, was forced to let some of its assembly lines lie idle as trucks full of auto components were stuck at the Canadian and Mexican border, while several others such as Toyota came dangerously near to expending all of their inventories for JIT sourced components and shutting their assembly lines[2]. In their attempts to become lean, several automobile companies in India have reduced raw material inventory significantly. While low inventory levels are a justifiable aim to work towards, they often put supply chains at a huge risk.

Besides terrorism Indian companies may face disruptions in their operations due to several other causes, natural (tsunami, floods, etc) or man made (strikes and riots).

The result of all of these disruptions is similar in its end effects—late order compliance, idle production capacity and in the latter case, loss of future contracts as the supplier country is seen as unreliable and risky. Disruptions in a supplier's operations have caused substantial losses to companies in the past. Consider the losses to Ericsson when it's only microchip supplier Philips suffered a fire in its plant in March 2000 and was unable to manufacture chips. Rival Nokia, which also sourced its chips from the same location, in effect took over almost all the slack capacity available and forced Ericsson to reroute production and lose $1.7 B in FY2000 and almost 4% of the market share to Nokia, according to some estimates[3].

Even though Indian firms may not face a large direct threat, their integration into global markets requires that they address the sourcing concerns of their customers for whom such problems are very real. As more and more of their global customers insist on having backup operations in place, Indian companies must make such policies a part of their offerings. In effect, an Indian supplier would be better able to service a foreign customer and provide a service that would be increasingly valued if he is able to take care of loss-making supply chain disruptions such as delays, loss of opportunity for making a sale, and security concerns.

The dual sourcing concept depends on having two suppliers. The first is a main supplier for fixed volumes with higher efficiency and low transaction costs, catering to the majority of requirements and the second, for flexible quantities, with lower and higher volume limits and who consequently charges a higher price.

Any policy of introducing redundancies goes against the accepted dogma of reducing inventories and slack at every level of operations. While Indian supplier firms have achieved phenomenal gains by adopting lean methodologies, changes in risk levels over the last five years must now force firms to perform a cost-benefit analysis for higher inventory reserves or better still, accept redundant capacities, all of which can be utilised to tide over disruptions. The present phase of incorporating lean manufacturing and other techniques should be followed up by the next one where companies should consider the level of flexibility (in terms of scaling up their operations and holding strategic reserves of inventory) that they can accord to their customers. Dual sourcing is one way of mitigating supply disruptions.

When trying to identify the disruptions which may affect their operations, firms generally focus on the risks that they can see. The supply chain function within the firm would also tend to concentrate on risks that it would be held accountable for. Thus, costs to mitigate a probable natural disaster or a terrorist strike would not typically be factored into risk assessment. Supply chain firms need to enlarge their viewpoints to identify vulnerabilities—from critical processes and equipment to manufacturing and warehousing sites, from technology and transportation to distribution and management.

Dual Sourcing for Mitigating Supply Side Risks

The dual sourcing concept depends on having two (sets of) suppliers. The first is a main supplier for fixed volumes with higher efficiency and low transaction costs, catering to the majority of requirements and the second, for flexible quantities, with lower and higher volume limits and who consequently charges a higher price. The value of this flexibility to choose where to produce/source/transport from, in the face of constant change (change in availability of production facilities, exchange rate fluctuations, demand or a change in raw material costs) has to be matched against negatives such as lowered cost efficiency due to several production locations/vendors, higher transaction and quality control costs and the possible lack of interest on the vendor's side due to the small size of the order.

There is no doubt however that flexible sourcing allows a company to get over temporary disruptions. For example, in 2002 during the US East Coast longshoremen strike, Dell Computers followed two procedures to maintain its supply to customers[4]. Firstly as was its usual practice, it changed the price structure of its models so that customers were more inclined to buy those which were easier to produce (due to relatively greater ease in sourcing of components). Secondly it flew in components, effectively setting up a parallel transport chain for its sourcing.

Similarly, an Indian company which is a major player in the consumer goods sector has been following the concept of multi-location production and has built up what is effectively a mobile production capability. In the face of disruptions in production in one of its fixed plants, it is able to pack up and move its mobile factory to another area and tide over the problem.

The requirement from firms is however, *to put such options in place before they face such problems*. This requires the firm to perform a cost-benefit analysis of introducing a redundancy in any of their processes. Doing this includes estimating the probability of the disruption, a process that is extremely difficult. By assuming a value for the probability (preferably erring on the higher side), and using real options to place a value on the flexibility accorded, firms can have sound financial grounds to opt for flexibility in their operations.

Location of Secondary Source to Mitigate Supply Side Risks

The decision to go in for a redundant sourcing/production operation is closely dependent on the location of the secondary source. For example it may not make much sense for a manufacturer in the US to locate both its sources in a single country or region from the point of view of maintaining steady supplies. In such a case, any disruption in the inbound freight processes (such as closure of borders due to another terrorist strike) would lead to the US firm being cut off from both its sources. Another concern may be the stability of the country where the vendor is located. A third issue is the spreading out of suppliers geographically so that a natural calamity does not have the same debilitating effect on all.

The risk assessment of a supplier from the point of view of its location needs to be carried out in a much more detailed manner. Some of the associated risks that would be included are: transport risk (relative ease of disruption in transportation); country risk (risk from internal troubles) which includes economic and political risk; and risk arising from the location of suppliers further upstream which supply to the immediate suppliers.

What firms must look for is a negative correlation between these parameters. For this companies must develop a correlation matrix to evaluate the outsourcing location vis-à-vis the domestic location in terms of the above parameters. Consider the example of weather or currency fluctuations. Monsoon months in India are sure to affect transportation, particularly in the southern and western states. This implies that on the basis of the parameter 'weather', an alternate location which does not experience such disruptive effects (by virtue of its location in a relatively drier place that is unaffected by the monsoons) would be negatively correlated with the original locations in the southern and western states. Similarly for exchange rate fluctuations, setting up facilities in countries whose exchange rates are negatively correlated provides a way of hedging currency risk. Obviously a much more detailed set of parameters will be required to be looked into, for which firms should refer to country risk assessment documents such as the Political Risk Services' International Country Risk Guide (ICRG)[5].

There is a need to incorporate redundancies into all the segments of supply chain operations in the face of new uncertainties brought about by operating in the global markets. International suppliers such as those in India must adopt policies on issues that are very important to foreign markets. The perspectives of suppliers and customers may often be opposite, with customers looking at increasing security, hedging and introducing redundancies into operations (especially sourcing) at every level and suppliers looking at consolidated orders and lowering costs of transportation. Common ground has to be sought by which incentivised suppliers adopt new practices incorporating flexibility at crucial stages that will be required when catering to foreign markets.

Methodologies for Handling Disruptions

Handling disruptions in the supply chain requires the combination of two different kinds of actions. The first consists of putting in place physical backup facilities to which production/sourcing can be shifted in times of disruption. The second consists of being able to map and standardise the knowledge of the processes of a company to enable quick replication when the firm is faced with the loss of its key people or facilities.

Supply Cost Uncertainty

In the recent past firms have been facing pressure on the cost front because of the surge in commodity prices. Crude oil prices moved from $40 a barrel to $147 over just two years and just when firms were trying to prepare themselves for the $200 a barrel price mark, crude prices crashed to $40 a barrel in just six months. All the major commodities like steel, copper, and aluminium have seen

significant price volatility over the last few years. Further, sourcing managers also had to worry about exchange rate fluctuations. For example firms such as EADS whose revenues are in US dollars and costs are in Euros have been facing tremendous pressure on the business performance front.

Firms have been struggling with the following three issues:

- Appropriate hedging strategy to handle price volatility
  - Southwest Airlines has entered into a contract for crude at $50 for the period 2007-2009, reporting a savings of $1.5 billion till July 2008[6].
  - Ford entered into a long term contract for the supply of palladium at a fixed price, and reported a write off[7].
- Appropriate price contract with suppliers
  - Who should take the commodity and exchange rate related risks? Should the supplier be protected from these risks or should they be shared fairly across buyers and suppliers?
- Designing robust networks

Global facility network design decisions are strategic in nature and a firm will have to live with facility location and capacity decisions for several years. Most of the data used in the network design model are likely to change over a period of time. For example, in international network design, foreign exchange rates affect relative cost structures significantly and predicting the same is extremely difficult, if not impossible. There are several ways in which firms handle these issues. Firms try and use scenario building through which they try and generate large numbers of likely future scenarios and select an option which performs reasonably well across the projected scenarios. So the focus shifts to selecting a robust solution rather than on picking a solution which is optimal for one scenario.

Over a period of time Toyota has introduced greater flexibility in its plants worldwide[8]. That is, a plant should be able to produce models which are required in the domestic market but must also be able to produce models for a few export markets. On the whole the network would have excess capacity, so based on the movement of exchange rates, volume would be allocated to the respective plants in the network. For example, Toyota might look at its Indian and Thai plants as the supply source for the South Asian market and keep excess capacity at both places. If the baht is cheaper than the rupee, it can allocate more volume to the Thailand facility and if the rupee is cheaper, it can allocate a higher share of the export market to India. This excess capacity in the network provides the luxury of options to the Toyota network. This is known as 'real option' because it provides a firm flexibility similar to financial options in financial markets. But unlike financial options, real options are difficult to trade. Firms which have focused their global manufacturing facilities excessively have realised that any significant change in the rate of the currency can change the cost structures in a significant way. For example, currently LG uses its China facility as an export base and exports 70% of its production from China. Given the uncertainty of the Chinese yuan, LG has decided to build excess capacity in India so that there is another hub available as an option for export[8]

Based on the nature of demand uncertainty, products can be classified as functional or innovative. For functional products, the focus is on meeting predictable demand cost effectively, while for innovative products the focus is on meeting unpredictable demand cost. So, for functional products one needs to design efficient supply chains, while for innovative products one needs responsive chains.

The idea of excess capacity in global networks may go against the current logic of a lean supply chain design. It would be tempting to cut capacities so that one can show short term profits; but then in the process, the firms would lose their flexibility.

Managing Demand Risks

Based on the nature of demand uncertainty, products can be classified as functional products or innovative products. In case of functional products, the focus is on meeting predictable demand cost effectively, while for innovative products the focus is on meeting unpredictable demand cost effectively. So, for functional products one needs to design efficient supply chains, while for innovative products one needs responsive chains. Low levels of demand and supply uncertainty can be handled using appropriate levels of safety stocks in the system. In this

paper we focus on supply chains which have to deal with either a high level of demand uncertainty or a high level of supply uncertainty or both.

The demand for several product categories in the fashion industry and in the high technology industry is inherently unpredictable. Firms usually work with inaccurate forecasts and end up with risks related to high obsolescence and lost sales costs. They suffer from poor forecast accuracy as they offer a large variety and usually have product life cycles of a few months.

In recent times some firms have realised that even though forecasting before the start of the season is difficult, data obtained from initial sales in the early part of the season can help firms in updating forecasts which are likely to have reasonably high forecast accuracy. Essentially one would find that the standard deviation of demand for an updated forecast would be of a much lower order of magnitude compared to the standard error associated with initial forecasts. That is if one defines a parameter called forecast correction factor, one would observe the following:

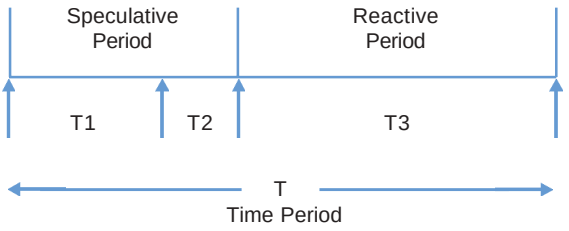
Updated standard deviation of demand for the season= Forecast correction factor * Initial standard deviation of demand for the season

The forecast correction factor is likely to be in the range of 0.1 to 0.4 in the context of new products.

The responsive supply chain approach manages demand related risks by taking advantage of lower variability of demand observed in the updated forecasts. Based on the revised forecast, the latter part of the season can be serviced from a responsive manufacturing facility which can be located close to the market. Further, the firm can use a faster mode of transport so that time taken in transportation can be cut down significantly. In the responsive approach to demand risk management, the firm divides the season into two components—speculative time and responsive time. The speculative part of the season is managed using a long but efficient chain based on the speculative forecast available before the start of the season. Demand for the latter part of the season is serviced using a responsive supply chain based on updated forecasts derived from observation of initial sales.

To take an example from the garment industry, let us say we have a season of time period T (Exhibit 1). This is divided into reactive time period T3 and the balance is the speculative time period. Demand during the speculative

Exhibit 1 Responsive Approach to Demand Risk Management



period is serviced from a cheaper source of supply requiring long lead times. Admittedly, forecast accuracy is very poor at this stage. The speculative time period is further divided into T1 and T2 as shown above. Time period T1 is used for observing the initial sales pattern and at the end of time period T1, forecasts are updated and orders are placed on the responsive manufacturing facility for manufacturing the required garments with the appropriate product mix for the likely demand in time period T3. Time period T2 is used for manufacturing the garment from fabric and transporting the same to the markets using a faster mode of transport.

Thus demand during the speculative period (T1+T2) is managed using the speculative approach and demand during reactive period T3 is managed using the responsive supply chain. The responsive chain is more expensive because it usually involves manufacturing facilities located close to markets and these facilities generally work with smaller batches. Further, a faster mode of transport also results in additional cost. Essentially expensive manufacturing and transportation would be traded off against lower lost sales and markdown costs. Much before the start of the season, orders are placed with the cheaper source of supply for the speculative period.

Supply Chain Risk Management Process

A structured process-oriented approach to supply chain risk management includes the following steps:

- Identification of supply chain risks
- Analysis and assessment of supply chain risks
- Constructing probability and impact matrix
- Developing risk management plan

These tasks have to be seen as the necessary support processes function of an integral, cross functional supply

process—from the source of demand to the fulfilment of the internal customers needs—and not the sole responsibility of the purchasing function.

Supply Chain Risk Identification

The identification of risks of supply includes a complete coverage of all sources of possible damage or loss to the company. One needs to examine which of the firm's operational events are affected by supply risks. The supply risks can be classified according to the nature and extent of the damage or loss and the degree to which they can be influenced.

Risk identification helps in setting up early warning systems which help in detecting the latent risks. Early warning indicators should be identified for the various environments in which a firm operates such as the economic, social, political, technological, ecological, supply, production and competitive environments. The firm needs to not only specify the early warning indicators but also stipulate how the events which cross the threshold values should be communicated to trigger appropriate response.

Supply Chain Risk Analysis and Assessment

Supply risk assessment evaluates the effect of risks on the company's performance. It takes into consideration at least two factors: the likelihood or probability that an unfavourable event will occur, and the consequences for the firm. The simplest measure of risk is the product of probability and estimated damage.

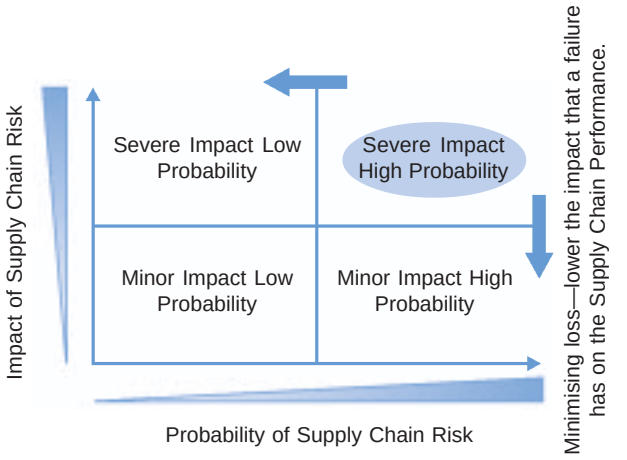
Decisions on supply risks can be taken only when the impact of risks on the company's business can be evaluated. To enable supply managers to enhance the efficiency and effectiveness of supply management through managerial actions, measures like the supply risk value have to be incorporated into the decision making process. Supply managers have to focus their attention on reducing the effect that risk can have on the organisation's success and profitability.

Constructing Probability and Impact Matrix

The firm must take appropriate measures for supply risks in accordance with its corporate risk management policies.

Classification of supply risks according to their probability and expected impact clearly shows the nature of different risks and helps in developing appropriate response strategies (Exhibit 2).

Exhibit 2 Supply Chain Risk Probability and Impact Matrix



Source: Supply Management Institute, EBS, Germany

For example, supply risks can also be classified into three categories: high risks that pose a serious threat to the company, medium risks that are critical but not life threatening, and low risks that have to be watched carefully since they can evolve into medium risks or even high risks.

Risk Management Plan Development

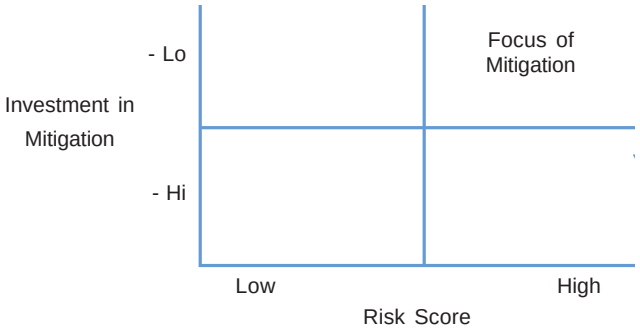
Understanding supply risks through assessments can permit purchasing organisations to take appropriate action.

The different possibilities for managerial action in supply risk management are:

- Avoidance (eliminate): Not performing an activity that could carry risk. Avoiding risks also means losing out on the potential gain that accepting (retaining) the risk may have allowed. For example, supplier selection, change management, continuous improvement process, early supplier involvement and quality control.
- Reduction (mitigate): Involves methods that reduce the severity of the loss or the likelihood of the loss from occurring. For example, multiple sourcing, risk and revenue sharing and buffer-oriented management.
- Transference (outsource or insure): Insurance, hedging, contracts and risk sharing plans.
- Retention (accept and budget): Acceptance of risks through reserves for contingencies.

Clearly high score risk items requiring lower investments

Exhibit 3 Risk Management Plan Development



in mitigation should be the focus of risk mitigation efforts while high score risks which require high investments require a different approach such as transference or even avoidance (Exhibit 3).

Risk Management Plan Implementation

A firm should keep the following in mind while implementing its risk management plan:

- Supply chain risk management needs to be integrated with enterprise risk management.
- Supply chain risk management is not the sole responsibility of the supply chain risk officer; it should become a line function.
- A structured process-oriented approach of supply risk management should be adopted.
- Not all potential uncertainties can be identified; there are 'unknown unknowns' which business continuity planning should develop capabilities to handle.

Review and Evaluating

With the shift of purchasing to supply management and its development to a strategic management function, the development of performance measurement systems to facilitate the coordination and alignment of purchasing and supply management activities with corporate strategy gains importance. Incorporation of supply risk metrics into the supply balanced scorecard seems to be the logical consequence of the fact that risks are an integral part of entrepreneurial decision making.

Conclusion

Supply risk management will continue to be a subject of research as companies still have enormous need for better identification, analysis, assessment and management of supply risks. Impulses for further study and research will be given through the regulations of the Sarbanes-Oxley Act of 2002 that demands sustainable management including a company-wide risk management system and through the Enterprise Risk Management (ERM) Framework that has been introduced by the Committee of Sponsoring Organisations of the Treadway Commission (COSO) in 2004. The ERM framework supports the implementation of the directives set forth in the Sarbanes-Oxley Act and enhances the necessity for companies to assess and improve their enterprise risk management processes including the supply risk management processes.

The discussion that follows this academic perspective illustrates how the challenges of supply chain risk management, including the identification of supply and demand side risks in an environment of high uncertainty, and how the development and implementation of an effective risk management plan are being addressed by companies in the field with the view to constructing robust supply chains.

References and Notes

1 Hendricks, K, and V Singhal, 2005, 'An Empirical Analysis of the Effect of Supply Chain Disruptions on Long Run Stock Price Performance and Equity Risk of the Firm', *Production and Operations Management*, pp 25–53.

2 'September 11: When Just-In-Time Becomes Just-In-Case', http://www.drjimmirabella.com/mgt570/Sep11.htm.

3 Latour, A, 2001, 'Trial by Fire: A Blaze in Albuquerque Sets off Major Crisis for Cell-Phone Giants', *Wall Street Journal*, Jan 29.

4 Breen, Bill, 2004, 'Living in Dell Time', *Fast Company*, Nov, http://www.fastcompany.com/magazine/88/dell.html.

5 http://www.prsgroup.com/ICRG_Methodology.aspx.

6 Southwest Airlines Co, Annual Report, 1996. http://www.southwest.com/investor_relations/swaar06.pdf.

7 White, G L, 2002, 'Precious Commodity: How Ford's Big Batch of Rare Metals Led to a $1 Billion Write-Off', *Wall Street Journal*, Feb 6, A1.

8 Shuchman, Lisa, 1998, 'Toyota Retools to Lift Export Flexibility', *The Asian Wall Street Journal Weekly*; Gratton, Ken, 2009, 'Flexibility the Key to ForEx Fluctuations: Toyota', http://www.carpoint.com.au/news/2009/large-passenger/flexibility-the-key-to-forex-fluctuations-toyota-11300.

9 Winters, L Alan, and Shahid Yusuf, (Eds), 2007, *Dancing with the Giants: China, India, and the Global Economy*, Washington

D C: The World Bank, and Singapore: The Institute for Policy Studies.

Other Works

'Flexibility in the Face of Disaster: Managing the Risk of Supply Chain Disruption', *Knowledge@Wharton*, Sep 6, 2006.

Agrawal, V, and S Seshadri, 2000, 'Risk Intermediation in Supply Chains', *IIE Transactions*, Vol 32, No 9, pp 819–831.

Chopra, Sunil, and Sodhi S Manmohan, 2004, 'Managing Risk to Avoid Supply Chain Breakdown, *MIT Sloan Management Review*, Fall, p 53.

Claude, B E, R H Campbell, and E V Tadas, 1996, 'Political Risk, Economic Risk, and Financial Risk', Report on International Country Risk Guide, *Financial Analysts Journal*, Nov/Dec.

Cohen, M A, and A Huchzermeier, 1999, 'Global Supply Chain Network Management under Price/Exchange Rate Risk and Demand Uncertainty', in M Muffato, and K S Pawar, (Eds), *Logistics in the Information Age*, SGE Ditorali, pp 219–234.

Gaur, V, and S Seshadri, 2005, 'Hedging Inventory Risk through Market Instruments', *Manufacturing & Service Operations Management*, Vol 7, No 2, pp 103–120.

Hallikas, J, I Karvonen, U Pulkkinen, V M Virolainen, and M Tuominen, 2004, 'Risk Management Processes in Supplier Networks', *International Journal of Production Economics*, Vol 90, No 1, pp 47–58.

Hallikas, J, V M Virolainen, and M Tuominen, 2002, 'Risk Analysis and Assessment in Network Environments: A Dyadic Case Study', *International Journal of Production Economics*, Vol 78, No 1, pp 45–55.

Hendricks, K, and V Singhal, 2005, 'An Empirical Analysis of the Effect of Supply Chain Disruptions on Long Run Stock Price Performance and Equity Risk of the Firm', *Production and Operations Management*, pp 25–53.

Huchzermeier, A, and M A Cohen, 1996, ,Valuing Operational Flexibility under Exchange Rate Risk', *Operations Research*, Vol 44, No 1, pp 100–113.

Johnson, M E, 2001, 'Learning from Toys: Lessons in Managing Supply Chain Risk from the Toy Industry', *California Management Review*, Vol 43, No 3, pp 106–124.

Jüttner, U, H Peck, and M Christopher, 2003, 'Supply Chain Risk Management: Outlining an Agenda for Future Research', *International Journal of Logistics*, Vol 6, No 4, pp 197–210.

Kogut, B, and N Kulatilaka, 1994, 'Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network', *Management Science*, Vol 40, No 1, pp 123–139.

Kulkarni, S S, M J Magazine, and A S Raturi, 2004, 'Risk Pooling Advantages of Manufacturing Network Configuration', *Production and Operations Management*, Vol 13, No 2, pp 186–199.

Lee, H L, 2002, 'Aligning Supply Chain Strategies with Product Uncertainties', *California Management Review*, Vol 44, No 3, pp 105–119.

Lewis, M A, 2003, 'Cause, Consequence and Control: Towards a Theoretical and Practical Model of Operational Risk', *Journal of Operations Management*, Vol 21, No 2, pp 205–224.

Li, Qing, 2007, 'Risk, Risk Aversion and the Optimal Time to Produce', *IIE Transactions*, Vol 39, pp 145–15.

Li, C L, and P Kouvelis, 1999, 'Flexible and Risk-Sharing Supply Contracts under Price Uncertainty', *Management Science*, Vol 45, No 10, pp 1378–1398.

Lonsdale, C, 1999, 'Effectively Managing Vertical Supply Relationships: A Risk Management Model for Outsourcing', *Supply Chain Management: An International Journal*, Vol 4, No 4, pp 176–183.

Reitman, Valerie, 1997, 'Toyota Motor Shows its Mettle after Fire Destroys Parts Plant', *Wall Street Journal*, May 8.

Sheffi, Y, 2001, 'Supply Chain Management under the Threat of International Terrorism', *International Journal of Logistics*, Vol 12, No 2, pp 1–11.

Snyder, L V, 2006, 'Facility Location under Uncertainty: A Review', *IIE Transactions*, Vol 38, No 7, pp 537–554.

Sodhi, M S, 2005, 'Managing Demand Risk in Tactical Supply Chain Planning for a Global Consumer Electronic Company', *Production and Operations Management*, Vol 14, No 1, pp 69–79.

Tomlin, B, and Y Wang, 2005, 'On the Value of Mix Flexibility and Dual Sourcing in Unreliable Newsvendor Networks', *Manufacturing & Service Operations Management*, Vol 7, No 1, pp 37–57.

Zsidisin, G A, 2003, 'A Grounded Definition of Supply Risk', *Journal of Purchasing and Supply Management*, Vol 9, No 5, pp 217–224.

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