Assessing Supply Chain Risk and Performance Simultaneously via Multiple Tiers DEA Efficiency

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ABSTRACT

For years, researchers and practitioners have primary investigated the various technologies and strategies to measure and improve supply chain performance. Recently, there has been increasing attention placed on the supply chain risk management to assess and mitigate risks. The purpose of this paper is to examine the constructs of performance and risk matched together, and to evaluate the supply chain potential outcomes in terms of benefits, costs, and risks. The paper explains the interaction between risk and performance in a supply chain context, explores the real-world application of multiple tiers DEA joint efficiency, and develops an approach of quantitatively assessing supply chain risk management and performance simultaneously.

INTRODUCTION

Supply chain risk management (SCRM) can be viewed as a strategic management activity in firms. It may affect operational, market and financial performance of firms. Organizational performance is enhanced when the strategy to reduce uncertainty takes into account ‘‘context’’ and ‘‘environmental realities’’ (Duncan, 1972). In the case of SCRM, context can be interpreted to refer to sources of risk, magnitude of risk and its relationship to business objectives, and threat of disruption in supply chains. Environmental realities can be interpreted to mean the degree of exposure to adverse events, scope of extended supply chains, supplier management practices, etc. Similarly, Christopher and Lee (2004) recognize the increasing risks in the supply chain context and the need for new responses to manage these. Underlying these developments in SCRM is the imperative to devise and develop appropriate performance measures and metrics to evaluate, educate and direct the operational and strategic decisions. Therefore, the essence of SCRM is to make decisions that optimally align organizational processes and decisions to exploit opportunities while simultaneously minimizing risk.

The growth and development of Supply Chain Management (SCM) is not driven only by internal motives, but by a number of external factors such as increasing globalization, reduced barriers to international trade, improvements in information availability, and environmental concerns. Furthermore, computer generated production schedules, increasing importance of
controlling inventory, and government regulations and actions have provided the stimulus for the development of SCM. The uncertainty toward which RFID technology is focused results both from internal processes and firms’ relationships with suppliers and buyers (Cannon et al., 2008). To meet objectives, the output of the processes enabled by the supply chain must be measured and compared with a set of standards. In order to be controlled, the process parameter values need to be kept within a set limit and remain relatively constant. This will allow comparison of planned and actual parameter values, and once done, the parameter values can be influenced through certain reactive measures in order to improve the performance or re-align the monitored value to the defined value.

Data Envelopment Analysis (DEA), first introduced in Charnes et al. (1978), has been proved to be a useful tool in evaluating relative efficiency of homogeneous Decision-Making Units (DMUs) in a multiple-input multiple-output setting. Some measures linked to supply chain members cannot be simply classified as outputs or inputs of the supply chain. For example, the supplier’s revenue is an output for the supplier, and it is in the supplier’s interest to maximize it; at the same time it is also an input to the manufacturer who wishes to minimize it. Simply minimizing the total supply chain cost or maximizing the total supply chain revenue (profit) does not properly model and resolve the inherent conflicts. Cook et al. (2007) developed a DEA model for evaluating the joint efficiency of supply chains with multiple tiers or members. However, Cook et al. didn’t specify what are the supply chain inputs and outputs in DEA model, and didn’t mention supply chain risk.

There are number of conceptual frameworks and discussions on supply chain performance measurements or supply chain risk assessments; however, there is a lack of evaluation of the associated potential performance in terms of benefits, costs and risks. Performance and risk are interconnected and require deliberate and robust implementation of supplier management tools and controls to maximize performance whilst controlling the consequential risks. The aims of this paper are to: firstly, explain the interaction between risk and performance in a supply chain context; secondly, explore the application of multiple tiers DEA joint efficiency which is modeled as the average of the seller’s and buyer’s efficiency scores, and develop an approach of quantitatively measuring supply chain risk management and performance simultaneously.

SUPPLY CHAIN RISK AND PERFORMANCE

Supply chain risk and supply chain risk management have, along with financial risk and risk management, become dominant features in management. Managers are continuously being challenged, because there are many unexpected and unpredictable disruptions that add to the risks of a supply chain, and therefore, an important measure of management performance is the ability to successfully manage such risks. In practice the principal may seek to specify the performance criteria and identify the associated risks in relation to its portfolio of individual suppliers or distributors. Consequently, each agent will seek to negotiate an agreement (i.e. contract) in terms of performance, risk sharing and reward outcomes.
The risks being addressed here are those that potentially influence the ongoing performance of the business in terms of effectiveness and/or efficiency and not just those that may result in a crisis or the failure of the enterprise. The nature of risk assessments can be formal to informal, as well as quantitative or qualitative. The first step in their supply risk assessment approach is determining the probability of a risk event occurring, which can be classified as high, medium, and low chance. The second step consists of estimating the likely problem duration, which can be based on past experience. The third step is investigating the business performance impact of the risk event. Use of a multi-functional team is recommended to quantify the size of the potential problem and its effect on business profitability and performance.

Decisions relating to changes in the supply chain structure and relationships should involve the analysis and evaluation of the associated potential outcomes in terms of performance and risks. Performance and risk are interconnected and require deliberate and robust implementation of supplier management tools and controls to maximize performance while controlling the consequential risks. Conventional wisdom suggests that risk and performance are directly related, such that higher risk taking will typically generate higher potential returns. This relationship, although initiated within the context of financial markets relating to equity transactions, is generally held to apply more widely within business decision-making.

Members of the supply chain are becoming increasingly inter-dependent, suggesting an inter-locking of interests. They involve a chain of decision nodes, networked together; each node plays some role in adding value to the performance of every member of the chain, although this may be indirect and often minimal; each node has the potential to contribute to the risk profile of the decision to be taken, both positively and negatively; and correspondingly, each node exerts some influence on the successful implementation of the management decisions and risk resolution. This is interesting, because it clearly illustrates that decisions taken at the individual node have potential chain-wide implications, more often than not these implications are unseen in the immediate vicinity of the node, but may resurface further up or down the supply chain.

There are potentially an infinite number of factors exposing the business to undesirable consequences in terms of performance and risk. The term driver has been introduced to differentiate those factors likely to have a significant impact on the exposure (i.e. likelihood and consequences) to undesirable performance and risk outcomes, or possibly providing the opportunity to improve performance, albeit with increased risk. For example, the decision to develop a new direct channel to the consumer, bypassing existing distribution channel members, would expose the business to new risks both from the reaction of the consumer and the retaliatory actions of the other channel members, although possibly improving potential performance outcomes. Ritchie and Brindley (2007) developed a model linking supply chain business performance as

\[
\text{Aggregate Business Performance} = f \{(\text{Profit}), (\text{Risk}), (\text{Time})\}
\]

We may illustrate the possible range of outcomes between perceived risk and performance as the following:
The range between “high” and “low” risk perceived may incorporate an infinite number of intermediate risk perceptions or a scale. Similarly, performance outcomes may prove equally diverse within the range. Conventional wisdom suggests that risk and performance are directly related, such that higher risk taking will typically generate higher potential returns, but that doesn’t mean higher risk taking will typically generate higher performance. Only four out of this infinite set of potential risk-performance outcomes are illustrated as exemplars. Cell A demonstrates the relationship of high risk taking resulting in potentially high rewards/performance, the impetus for risk taking. The very presence of risk also suggests that the outcome may prove less rewarding as displayed in Cell B. Correspondingly, low risk situations and opportunities may typically be perceived as generating low levels of performance as in Cell D, although high levels of performance outcomes may also be achieved as in Cell C situation.

AN APPROACH OF ASSESSING SUPPLY CHAIN RISK AND PERFORMANCE

Ritchie and Brindley (2007) proposed some challenges and questions: can risk reduction only effectively be achieved by the deterioration in some aspects of performance? What extent do organizations recognize the interaction between performance and risk? In this paper, we think that risk and performance measurement can be defined as the process of quantifying the efficiency and effectiveness of an action.

A generic and well-established definition of performance is used, dividing this construct into efficiency and effectiveness. Efficiency is regarded in a resource input-output sense such that the greater volume of outputs for a given volume of inputs then the greater the efficiency. Effectiveness relates to the degree to which the planned outcomes are achieved. Achievement of the target market share may be seen as highly effective although the use of advertising expenditure in doing so may be regarded as inefficient in performance terms.

DEA estimates the efficiency index by calculating the ratio of weighted outputs to weighted inputs, and the input and output weights are decided according to the best interests of the DMU being evaluated. DEA has proven to be an effective approach in estimating empirical tradeoff curves (efficient frontiers), and in measuring the relative efficiency of peer units when multiple performance measures are present (Zhu, 2003). Evaluation of single tier manufactory or warehouse efficiency, using DEA, has its advantages. In particular, it eliminates the need for unrealistic assumptions inherent in typical supply chain optimization models and probabilistic models; e.g., a typical EOQ model assumes constant and known demand rate and lead-time for delivery.
Note that an effective management of the supply chain requires knowing the risk and performance of the overall chain rather than simply the risk and performance of the individual supply chain members. Each supply chain member has his own strategy to achieve his efficiency; however, what is best for one member may not work in favor of another member. Sometimes, because of the possible conflicts between supply chain members, one member’s inefficiency may be caused by another’s efficient operations. For example, the supplier may increase its raw material price to enhance its revenue and to achieve an efficient performance. This increased revenue means increased cost to the manufacturer. Consequently, the manufacturer may become inefficient unless it adjusts its current operating policy. Measuring supply chain performance becomes a difficult and challenging task because of the need to deal with the multiple performance measures related to the supply chain members, and to integrate and coordinate the performance of those members. As noted in Zhu, although DEA is an effective tool for measuring efficiencies of peer decision making units (DMUs), it cannot be applied directly to the problem of evaluating the efficiency of supply chains. This is because some measures linked to supply chain members cannot be simply classified as “outputs” or “inputs” of the supply chain. In fact, with respect to those measures, conflicts between supply chain members are likely present.

Cook et al. (2007) developed a DEA model for evaluating the joint efficiency of supply chains with multiple tiers or members. Suppose there are N similar supply chains or N observations on one supply chain, and each supply chain has P supply chain members or tiers as describe in the figure Cook et al. (2007).

![Diagram of supply chain](image)

In the j-th supply chain, S_dj means the d-th member, X^d_j means inputs of member d, Y^d_j are outputs of member d and also inputs of member d+1.
Here, X has I dimensions, Y has S dimensions; and X^d_j = (x^d_ji , i = 1, ..., I_d ), Y^d_j = (y^d_js , s = 1, ..., S_d ), d = 1, ..., P, j = 1,..., N. Suppose the weight of x^d_ji is v_i^d and the weight of y^d_s is u_s^d , then Cook’s model is:
The first part of the objective function is the efficiency of first DMU $S_1$, and it means $d=1$; the second part of the objective function is the sum of efficiency from DMU $S_2$ to DMU $S_p$. Then the sum of the $P$ DMUs efficiencies is divided by $P$, so that the value of the objective function is greater than 0 and less than or equal 1.

Cook et al. didn’t specify what are the supply chain inputs and outputs in the above DEA model, and didn’t mention risk assessment in supply chain efficiency evaluation. We start here to implement the DEA model.

The risk associated with all commodities are evaluated for their impact on “earnings before interest and taxes” (EBIT) and reported on a quarterly basis to the coordinator of the risk assessment process. There are 13 categories that are evaluated within the supply risk assessment and measurement process:

1. Additional costs for cancellation due to lack of planning.
2. Additional costs for transportation due to lack of planning.
3. Additional costs for material obsolescence.
4. Unexpected material price increase due to allocation.
5. Unexpected material price increase due to yield problems.
6. Unexpected material price increase due to change of specification.
7. Missing parts due to late delivery.
8. Missing parts due to supplier quality defects.
9. Missing parts due to instability of supplier’s country.
Each supply risk category is assessed using an 11-step process:

1. What is the impact on EBIT in millions dollars (before management implementation) for the current fiscal year?
2. What is the probability of occurrence before risk management implementation (in percent) during the current fiscal year?
3. What is the impact on EBIT in millions dollars for the next fiscal year?
4. What is the probability of occurrence before risk management implementation (in percent) for the next fiscal year?
5. Insert explanations for the key risk factors.
6. List risk handling measures to avoid the risk.
7. Rate the implementation status of risk management: very low (0-20 percent); low (20-40 percent); medium (40-60 percent); high (60-80 percent); very high (80-100 percent).
8. What is the impact on EBIT in millions dollars (after risk management implementation) for the current fiscal year?
9. What is the probability of occurrence after risk management implementation (in percent) during the current fiscal year?
10. What is the impact on EBIT in millions dollars for the next fiscal year?
11. What is the probability of occurrence after risk management implementation (in percent) for the next fiscal year?

Commodity managers assess their suppliers based on past experience and anticipated supply trends. The eleven steps focus on estimating the expected impact on EBIT, the probabilities of risk events occurring, and the measures or activities to be implemented for reducing risk. Estimates are made for both the current and upcoming fiscal year. Within the process there is a trade-off between accuracy and speed. More accurate probabilities and the effects on earnings can be derived if additional information is obtained. However, deriving more exact data means that a significant degree of managerial effort would be required by commodity managers that may not be offset by the benefits from engaging in supply risk assessment and measurement processes. In addition, the purpose of estimating supply risk is not to determine exact probabilities or effects on earnings. Instead, the process facilitates the communication of possible supply failures between the commodity and supply line managers, and the risk manager. In addition, the process prioritizes supply risk that warrants managerial attention and provides guidance for proactively reducing the chance that risk events transpire. The commodity and supply line managers are responsible for managing supply risk, and headquarters are responsible for reporting incidents and provide additional resources when required.

Traditionally supply chain performance measures were based on price variation, rejects on receipt and on time delivery. For many years, the selection of suppliers and product choice were mainly based on price competition with less attention afforded to other criteria like quality, reliability, etc. More recently, the whole approach to evaluating suppliers has undergone drastic change. The evaluation of suppliers in the context of the supply chain (efficiency, flow,
integration, responsiveness and customer satisfaction) involves measures important at the strategic, operational and tactical level. Strategic level measures include lead time against industry norm, Quality level, Cost saving initiatives, and supplier pricing against market. Tactical level measures include the efficiency of purchase order cycle time, booking in procedures, cash flow, quality assurance methodology and capacity flexibility. Operational level measures include ability in day to day technical representation, adherence to developed schedule, ability to avoid complaints and achievement of defect free deliveries. Suitable metrics are as follows:

(1) Range of product and services: A plant that manufactures a broad product range is likely to introduce new products more slowly than plants with a narrow product range. Plants that can manufacture a wide range of products are likely to perform less well in the areas of value added per employee, speed and delivery reliability. This clearly suggests that product range affects supply chain performance.

(2) Capacity utilization: From the above assertion, it is clear that the role-played by capacity in determining the level of activities in a supply chain is quite important. Capacity utilization directly affects the speed of response to customer demand through its impact on flexibility, lead time and deliverability.

(3) Number of faultless notes invoiced: An invoice shows the delivery date, time and condition under which goods were received. By comparing these with the previously made agreement, it can be determined whether perfect delivery has taken place or not, and areas of discrepancy can be identified so that improvements can be made.

(4) Flexibility of delivery systems to meet particular customer needs: This refers to flexibility in meeting a particular customer delivery requirement at an agreed place, agreed mode of delivery and with agreed upon customized packaging. This type of flexibility can influence the decision of customers to place orders, and thus can be regarded as important in enchanting and retaining customers. Flexibility of the factors by which supply chains compete, flexibility can be rightly regarded as a critical one. Being flexible means having the capability to provide products/services that meet the individual demands of customers. Some flexibility measures include: (i) product development cycle time, (ii) machine/toolset up time, (iii) economies of scope.

(5) Customer query time: Customer query time relates to the time it takes for a firm to respond to a customer query with the required information. It is not unusual for a customer to enquire about the status of order, potential problems on stock availability, or delivery. A fast and accurate response to those requests is essential in keeping customers satisfied.

(6) Information processing cost: This includes costs such as those associated with order entry, order follow/updating, discounts, and invoicing. On the basis of survey results from various industries, Stewart (1995) identified information processing cost as the largest contributor to total logistics cost. The role of information technology is shifting from a general passive management enabler through databases, to a highly advanced process controller that can monitor activities and decide upon an appropriate route for information.

Based on the above analysis on the supply chain risk and performance evaluation, we explore the real-world application of the DEA model, and develop an approach of quantitatively assessing supply chain risk management and performance simultaneously. We have I = 25 in the above DEA model, meaning the input variable X has 25 dimensions. The indicators of X are:
Additional costs for cancellation due to lack of planning.
(2) Additional costs for transportation due to lack of planning.
(3) Additional costs for material obsolescence.
(4) Unexpected material price increase due to allocation.
(5) Unexpected material price increase due to yield problems.
(6) Unexpected material price increase due to change of specification.
(7) Missing parts due to late delivery.
(8) Missing parts due to supplier quality defects.
(9) Missing parts due to instability of supplier’s country.
(10) Additional material costs due to single sourcing during ramp-up phase.
(11) Contractual risk.
(12) Investing in supplier improvement.
(13) Currency risk.
(14) Bid management cycle time.
(15) Inventory costs.
(16) Lead time for procurement.
(17) Lead time manufacturing.
(18) Obsolescence cost.
(19) Overhead cost.
(20) Process cycle time.
(21) Product development time.
(22) Product service variety.
(23) Stock out cost.
(24) Transportation cost.
(25) Warranty cost.

We have S = 14 in the above DEA model, meaning the output Y has 14 dimensions. The indicators of Y are:

(1) Supply chain response time
(2) Accuracy of scheduling.
(3) Capacity utilization.
(4) Compliance to regulations.
(5) Conformance to specifications.
(6) Delivery reliability.
(7) Forecasting accuracy.
(8) Labor efficiency.
(9) Perceived quality.
(10) Perceived value of product.
(11) Production flexibility.
(12) Return on investment.
(13) Selling Price.
(14) Value added.

The first 13 indicators in input X are related to supply chain risk; the remaining 12 indictors, which are from number 14 to 25, are related to traditional supply chain (not considering risk).
performance. After we put the 25 input variables and 14 output variables into the Cook’s DEA model, we get the supply chain risk and performance efficiency computation model. If the objective function value is 1, then the supply chain is DEA efficient in both risk and performance simultaneously.

CONCLUSION AND FURTHER RESEARCH

The aim of exploring the interaction between risk and performance in a supply chain context is addressed initially through consideration of the more generic links between risk and performance prior to focusing attention on the supply chain decisions and the associated performance measures and metrics. The current study develops an approach base on DEA model aimed at: (i) correctly characterizing risk and performance interaction in multi-member supply chain operations, and (ii) calculating the joint efficiency of the supply chain and its members. The model tries to maximize the joint efficiency of the seller and buyer, and imposes weights on the intermediate measures that are the same when applied to the measures as outputs of the supplier as when applied to those measures as inputs of the buyer. Although the models are nonlinear programming problems, they can be solved as parametric linear programming problems, and a best solution can be found using a heuristic technique.

We point out that although the DEA model has 25 indicators in input X and 14 indicators in output Y, it does not try to examine whether the members of a specific supply chain are behaving in a cooperative or non-cooperative manner. Specifically, identification, categorization and evaluation of different risk sources and causal pathways will aid the wider understanding of the nature and scale of risks and their impact on aggregate performance. These are topics for further research. Other useful further theoretical developments include the idea that one echelon can use knowledge about another echelons (supplier or customer), to improve its own performance or the mutual performance of the members.

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