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Integrating financial risk measures into the design and planning of closed-loop supply chains

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ABSTRACT

In this paper, a mixed integer linear programming (MILP) formulation is proposed that integrates financial risk measures into the design and planning of closed-loop supply chains, considering demand uncertainty of final products. The goal is to maximize the supply chain expected net present value (ENPV), while simultaneously minimizing the associated risk. The augmented ε-constraint method is used to generate an approximation to the Pareto-optimal curve for each risk measure. Four different risk measures, most popular measures within the literature, are implemented, compared and directions for their usage by decision makers are discussed. Managerial insights are outlined based in decision makers' risk profile and goal of the risk minimization. A European supply chain case study is explored.

1. Introduction

Nowadays supply chains operate in a very vulnerable environment caused mainly by supply chains globalization where products management is becoming increasingly complex due to market uncertainties and society pressures. Drivers such as sustainability, responsiveness and risk management are today a reality that needs to be accounted for when developing decision supporting tools to inform supply chains activities (Barbosa-Póvoa, 2014). In this context, the traditional supply chains cost minimization design and planning models need to be generalized so as to become more holistic where the above issues need be addressed (Dekker et al., 2004). Such concern is reflected on the study "Global Supply Chain Survey 2013" prepared by Pricewaterhouse Coopers (PwC), where different practices have been identified by companies' leaders as crucial to be followed. Among them, complexity management, risk minimization, sustainability and optimization practices are present apart from the traditional maximum delivery performance, cost minimization, maximum volume flexibility and responsiveness. A deep review on supply chain risk can be accessed in Heckmann et al. (2015).

In this context and in order to capture the truly dynamic nature of most real-life supply chain problems where raw material prices, demand, energy costs, labor costs, exchange rates, among others are uncertain (Cristonal et al., 2009), decision tools should incorporate uncertainty efficiently (Garcia and You, 2015) and should be used to effectively perform risk management. The need for correctly dealing with uncertainty has been identified some years ago by Vidal and Goetschalckx (2000) and later on by Papageorgiou (2009) and Pfohl et al. (2010). In order to respond to such challenge several works appeared in the literature where demand uncertainty has been the mostly widely studied as it is the factor that more often companies have to deal with. In the traditional supply chains the works of Tsiakis et al. (2001), Gupta and Maranas (2003), You and Grossmann (2008) and Georgiadis et al. (2011) have dealt with this problem. Also some recent works have been proposing models to deal with demand uncertainty into reverse chains and in some cases close-loop supply chains, where forward and reserve flows are considered simultaneously, have also been studied. Listes and Dekker (2005) formulated a stochastic programming model for a product recovery network considering uncertainty in demand. Later, Listes (2007) and Salema et al. (2007) studied the design problem taking into account uncertainty in the products demand and returns. Amaro and Barbosa-Póvoa (2009) presented a MILP model for the planning of generalized closed-loop supply chains, where uncertainty on product portfolios demand and prices were accounted for. Francas and Minner (2009) studied the network design of a firm with remanufacturing when both demand and return flows were uncertain. Also El-Sayed et al. (2010) developed a multi-period mathematical model for the design of supply chains that integrate forward and reverse flows

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considering stochastic demands. Pishvaee et al. (2011) proposed a network design model for a reverse supply chain considering three different sources of uncertainty: quantity of returned products, demand and transportation costs. Zeballos et al. (2012), address the uncertain quality and quantity of returns in a closed-loop supply chain but no risk account was considered. Recently, Cardoso et al. (2013) also optimized closed loop supply chains by proposing an optimization model for the design and planning of a supply chain where reverse logistics activities are integrated into the chain. Forward and reverse flows are considered simultaneously and the presence of uncertainty in the product demands was studied.

In the above works risk management was not however treated. The usage of adequate risk measures is still an issue not yet adequately addressed by the academic community (Tang, 2006). When risk measures are considered in the traditional supply chain, no consensus exists on what risk measures should be used to provide information into the decision (Tang and Nurmaya Musa, 2011) or neither on how these risk measures cope with the risk profile of decision makers (Heckmann et al., 2015).

Starting from the supply chain risk definitions several ones have been proposed. March and Shapira (1987) defined risk as the variation in the distribution of possible outcomes, their likelihoods and subjective values. Cavinato (2004), Spekman and Davis (2004) and Juttner (2005) divide the supply chain risks into four categories: physical if they have impact in the logistics activities, such as transportation, warehousing and manufacturing; financial if they are related to the flow of money and the investment made in the network; informational if they involve the processes and electronic systems of the network; and relational if they have impact on the linkages amongst the several stakeholders of the supply chain. Tang (2006), in his review of supply chain risk management states that there are two types of risks within a supply chain: operational risks and disruption risks. Operational risks are related to inherent uncertainties such as in products demand, supply and all types of costs. Disruption risks are referred to natural disasters such as earthquakes, floods, hurricanes and also terrorist attacks. Bogataj and Bogataj (2007) defined risk as the potential variation of outcomes that influence the decrease of value added of any activity in a supply chain. Goh et al. (2007) classified supply chain risks into two different types: internal risks that encompass supply, demand and trade credit risks, and external risks that arise from the interactions amongst the supply chain and the environment, including international terrorism and natural disasters. In their work, the authors tried to develop a methodology for minimizing risks and maximizing profit of a global supply chain, but in the risk analysis they basically studied the presence of uncertainty in the demand, exchange rates, country tax rates and import tariffs through the use of different scenarios.

When a quantitative approach is used, the most common way of managing risk is by including in the model formulation the minimization of a risk measure term (Conejo et al., 2010). Several risk measures exist where the most used were identified as: variance (Mirzapour Al-e-hashem et al., 2011); variability index (Ahmed and Sahinidis, 1998); probabilistic financial risk (Barbaro and Bagajewicz, 2004); downside risk (You et al., 2009); risk premium (Applequist et al., 2000) and value-at-risk and conditional value-at-risk (Nickel et al., 2012).

In the literature, there are several examples of the application of the above different risk measures mainly in the financial area, but few studies have been published in the area of supply chain management. Guillén et al. (2005) formulated a supply chain design problem as a multi-objective stochastic MILP model for a three-echelon supply chain considering uncertainty in the demand. The model considered three objective functions: maximization of the expected net present value, maximization of the demand satisfaction and minimization of the financial risk using the downside risk measure. Azaron et al. (2008) developed a multi-objective stochastic programming model for a supply chain design under uncertainty but with the goal of minimizing costs, the variance of the total cost and the financial risk were considered, where the probabilistic financial risk measure was used. The model was applied to a supply chain example that only considers the forward flow amongst suppliers, plants and customers centers in a single time period. You et al. (2009) applied risk management to a planning problem of a global forward supply chain under demand and freight rates uncertainty. They implemented four different risk measures: variance, variability index, probabilistic financial risk and downside risk and concluded that the last two measures appear to be more effective in reducing high cost risk when compared to the others. Carneiro et al. (2010) and Tometzki and Engell (2011) implemented conditional value-at-risk for managing risk in planning problems and attested the importance of considering risk in optimization problems in the presence of uncertainty. Khor et al. (2011) used two risk measures, value-at-risk and conditional value-at-risk for the midterm process planning of a petroleum refinery under uncertainty. However, they gave a specific weight to the risk measures instead of exploring all possible values for the trade-off amongst profit and risk. More recently, Nickel et al. (2012) defined a design model for a two echelon supply chain where they account the risk of falling below a given target established for the return on investment using the downside risk. Gebreslassie et al. (2012) compare the use of downside risk and CVaR in the design of biorefinery supply chains under uncertainty. A multicut L-Shaped method was implemented so as to address complexity in this stochastic problem addressed. The authors conclude that even when CVaR is reduced, the chance of low cost scenarios is still high, which is not achieved when using downside risk. Thus a CVaR approach results more adequate.

In a recent supply chain risk review Tang and Nurmaya Musa (2011) stated there is still a lacking of quantitative models for supply chain risk management, since the majority of the literature is based on qualitative approaches. Another identified gap in Heckmann et al. (2015) is that works addressing risk modeled within a time scale are scarce and hence more work has to be developed so as to study how the affected supply chain evolves under risk and being controlled by different risk measures. Additionally, to the best of the authors' knowledge, there are no papers that study risk on closed-loop supply chains, complex systems whose importance has been increasing considerably (Barbosa-Póvoa, 2014).

Following these needs, we consider, in this work, the design and planning of generic closed-loop supply chains that integrate simultaneously forward and reverse flows and where risk measures optimization is contemplated against the expected net present value maximization. A bi-objective model that maximizes the expected net present value (ENPV) and minimizes risk using four different kinds of risk measures is formulated. The augmented ε-constraint method is used to generate an approximation to the Pareto-optimal curve for each risk measure and the obtained results are compared. The application of the developed model is demonstrated through a European supply chain case study.

The remaining of this paper is organized as follows. In Section 2 the model definition and the respective mathematical formulation are given. Section 3 presents a real case study of a European supply chain network and the supply chain design and planning results when considering the risk neutral problem and the risk measures are presented and discussed. A sensitivity analysis in some critical parameters is also performed in Section 3. Finally, in Section 4, some conclusions are drawn and directions for future developments identified.