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Optimal apparel supplier selection with forecast updates under carbon emission taxation scheme

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ABSTRACT

Carbon emission tax is an important measure for sustainable supply chain management. This paper studies an optimal supplier selection problem in the fashion apparel supply chain in the presence of carbon emission tax. We consider the scenario in which there are multiple suppliers in the market. In the basic model, each supplier offers a supply lead time and a wholesale pricing contract to the fashion retail buyer. For the fashion retail buyer, the supplier which offers a shorter lead time allows it to postpone the ordering decision with updated and better forecast, and also a smaller carbon tax. However, the wholesale price is usually larger. We propose a two-phase optimal supplier selection scheme in which phase one filters the inferior suppliers and phase two helps to select the best supplier among the set of non-inferior suppliers by multi-stage stochastic dynamic programming. The impacts brought by different formats of carbon emission tax are explored. Finally, we examine an extended model in which there is a local supplier who offers a buyback contract and accepts product returns. Insights from the analysis are discussed.

1. Introduction

Supplier selection problem is an important problem in fashion supply chain management [1]. Traditionally, fashion retail buyers have to consider issues such as wholesale price, product quality, delivery lead time, buyer–seller relationship in making the optimal supplier selection decision. Some companies, such as Bossini, even tried to employ e-procurement scheme in locating the most efficient supplier for fulfilling an order of apparel products. Nowadays, sustainability becomes another important and crucial concern in this optimal supplier selection problem. In fact, to enhance sustainability by reducing carbon footprint, many governing bodies already proposed to implement carbon emission tax on the retail buyers which source from offshore manufacturers located far away [22]. Despite many debates and discussions around the topic, the carbon emission tax will very likely be a common practice imposed all around the world in the foreseeable future.

In light of this, a few important research questions arise: (1) In the presence of carbon emission tax and considering multiple (N) suppliers with different lead times and wholesale price offers, how should a fashion retail buyer make an optimal choice on selecting supplier? (2) How would the carbon emission tax affect the optimal choice of supplier? (3) Suppose that the governing body would like to use carbon emission tax as a way to encourage local sourcing, how effective is the simple linear (in distance) carbon taxation scheme? Will the nonlinear carbon taxation scheme, such as a quadratic one, performs more effectively? (4) If there exists a local supplier which offers a buyback contract to accept physical product returns from the retailer by the end of the retail selling season, how would it affect the optimal supplier selection scheme? The above questions are all practical and important in sustainable supply chain management with carbon emission tax. To derive scientifically sound answers to them, we conduct an analytical study and develop the optimal solution algorithm by multi-stage stochastic dynamic programming. To be specific, we consider the case in which there exist multiple qualified suppliers in the market. Each supplier has a publicly announced supply lead time and wholesale price offer. For the fashion retail buyer, employing a supplier with a shorter lead time not only reduces the carbon footprint (and hence the corresponding carbon emission tax), but also allows it to have more time to improve demand forecast and make a better final ordering decision. However, the wholesale price associated with a short lead time supplier is usually larger. To derive the optimal supplier selection decision, we propose a two-phase scheme in which phase one is devoted to filtering the set of suppliers by eliminating the inferior suppliers and phase two is employed to determine the best supplier among the filtered set of non-inferior suppliers by solving a multi-stage stochastic dynamic program. After deriving the optimal dynamic programming algorithm for the two-phase solution scheme, we

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conduct analysis on the impacts brought by different formats of the carbon emission tax on the optimal supplier selection problem. As we will show in the subsequent sections, our analysis reveals that the linear carbon emission taxation scheme is not the best scheme in encouraging local sourcing, and is outperformed by a simple nonlinear quadratic carbon taxation scheme. An extended model with a local supplier which offers a buyback contract is further investigated and some more insights from the analysis are discussed. To the best of our knowledge, this paper is the first which examines the optimal supplier selection scheme with multiple suppliers under different kinds of carbon emission taxation schemes. It is also the first one which considers the situation when there is a local manufacturer among the set of suppliers, which offers a buyback contract.

The organization of the rest of this paper is as follows. In Section 2, we review the related literature. In Section 3, we define the basic model and the uncertainty structure of the problem. In Section 4, we explore the first "filtering" phase of the two-phase optimal supplier selection scheme. In Section 5, we employ dynamic programming to derive the algorithm for the second phase of the optimal scheme. In Section 6, we conduct analysis with both the linear and nonlinear carbon emission taxation schemes. In Section 7, we investigate an extended model in which a local supplier offering a buyback contract is present. In Section 8, we conclude with a discussion of future research directions. To enhance presentation, all technical proofs are placed in Appendix.

2. Literature review

We concisely review some representative papers related to this paper in three areas as follows.

First, this paper relates to the green supply chain operations management literature [25,32], especially the ones exploring carbon emission tax.[1] To the best of our knowledge, the pioneering analytical study on inventory management with carbon emission tax is conducted by Hua et al. in [18] in which they build analytical models and examine the inventory optimization problem when there are carbon emission rules. They reveal how different carbon trading rules affect the optimal inventory decisions. After that, Song and Leng [30] study in the newsvendor problem context the impacts brought by different commonly observed carbon trading rules. They study both the scenarios with carbon trading quota and carbon footprint tax. They characterize the optimal inventory decisions under each case and generate very important insights on how carbon trading rules affect the newsvendor problem's optimal inventory control policy. Other recently published studies related to green/sustainable supply chain operations management include (i) an empirical study of environmental sustainability in fashion supply chains [4], (ii) an examination of the environmental tax in the pulp and paper industry [13], (iii) an exploration of closed loop supply chain by using genetic algorithm [15], (iv) a case study on carbon footprint analysis in the auto company's supply chain [23], (v) an analysis of the impacts of environmental management systems on fashion companies' financial performance [25], (vi) an analytical study on sustainable supply chain management under oligopolistic competition [28], (vii) a proposed framework for modeling carbon footprint across a supply chain [32], and (ix) a study on the supply chain coordination mechanism in a three-level green supply chain [36]. Note that in all of the above reviewed papers, none of them focus on the optimal supplier selection problem and are hence very different from this paper.

Second, this paper relates to the optimal supplier selection problem. We concisely review some recently published papers in this area and readers can refer to [1] for an excellent review of the supplier selection literature. Motivated by various industrial practices, Mendoza and Ventura [26] explore a serial supply chain in which an optimal control on inventory and an optimal decision on the supplier choice need to be determined. They build a formal model to derive the optimal inventory control policy that can well coordinate the transfer of products. They also derive the lower bound of the minimum total cost. Huang and Keskar [19] study the supplier selection problem for original equipment manufacturers. They present an integration framework with which the company's senior management can configure a set of proper metrics to measure individual supplier's performance. They argue that an optimal decision on supplier selection can hence be made with their proposed framework and metrics. Li and Zabinsky [24] develop a two-stage stochastic programming model and a chance-constrained programming model to help determine the optimal set of suppliers. They consider the presence of business volume discounts and obtain the Pareto-optimal solutions for a sample problem. They further describe the tradeoffs between cost and risk in their model by employing a multi-parametric programming technique to further evaluate the alternative Pareto-optimal supplier selection solutions. Che and Wang [5] study the optimal supplier selection scheme in the manufacturing environment. They consider the scenario when there are multiple types of products and producing them require the procurement of both common and non-common parts. They formulate an analytical model to capture the detailed bill of material requirements of the practical problem. Under the assumption that the suppliers have production capacity constraints, they derive the "recommended" supplier selection scheme for having suppliers of both common and non-common parts by a genetic algorithm. Kheljani et al. [21] analytically discuss the coordination issue in the context of the optimal supplier selection problem. They study the supply chain in which there are multiple supplier candidates and one retailer. They apply a mixed-integer nonlinear programming approach to determine the optimal supplier with which the supply chain is also coordinated. Recently, Hajji et al. [17] investigate a stochastic supplier selection problem, together with optimal controls on inventory replenishment and manufacturing. They focus on studying the important supply chain issues related to coordination and information sharing. By building a stochastic dynamic programming model, they successfully derive the optimal policy and argue that it is always important to have multiple suppliers in helping with replenishment and production. They further comment that the replenishment lead time is a very important measure in the optimal supplier selection process. Similar to the above reviewed papers, this paper explores the optimal supplier selection scheme (and also jointly determines the corresponding optimal ordering quantity). However, this paper is different from all of them because we consider the presence of carbon emission tax as well as the importance of forecast updating in the context of apparel sourcing.

Third, this paper employs the forecast updating process under a Bayesian approach which relates to the vast research area on inventory management with forecast updating. The pioneering papers on this area include Azoury [2] and Murray and Silver [27]. The idea behind this well-established area is to employ market information to improve forecast and ultimately lead to better inventory decision in both the single echelon and the multi-echelon settings. For example, Choi et al. [6] examine the optimal ordering policy in light of different delivery options. They employ the Bayesian conjugate pair approach in modeling the forecast

[1] Note that there are several other related research areas such as reverse logistics [14,15] and social responsibility related operations [34]. Owing to space limitation, we will not review them in this paper.