Int J Adv Manuf Technol (2013) 68:835–847
DOI 10.1007/s00170-013-4947-4

ORIGINAL ARTICLE

Carbon footprint tax on fashion supply chain systems

Tsan-Ming Choi

Received: 3 August 2012 / Accepted: 1 March 2013 / Published online: 17 April 2013

Abstract In this paper, the impacts brought by the carbon footprint tax on fashion supply chain systems are analytically examined. First, based on various industrial practices in fashion apparel, we construct the two-echelon manufacturer–retailer analytical fashion supply chain model. Second, by exploring the fashion supply chain with a highly fashionable product, we study how the carbon footprint tax can affect the retailer's optimal choice of sourcing. We further investigate the significance of carbon footprint tax on fashion supply chain management under two commonly adopted contracts, namely the pure wholesale pricing (WP) contract and the markdown money (MM) contract. Our analytical findings illustrate that: (1) under the WP contract case: A properly set carbon footprint tax, which depends on the product's manufacturing and shipping costs, and manufacturer's profit margin, can successfully entice the retailer to source locally. (2) Under the MM contract case where the MM contract is set in a way that the supply chain is coordinated: (a) If the carbon footprint tax is equal to the difference between the product costs from the local and offshore sourcing, then the optimal MM rates and the optimal supply chain product quantities from the local and offshore sourcing modes are the same. (b) Similar to the WP contract case, we prove analytically that a properly determined carbon footprint tax can always entice the retailer to source locally. Further analysis with extended models under the consideration of having a stochastically larger demand with the local sourcing mode is conducted.

Keywords Local sourcing · Carbon footprint tax · Sustainability · Fashion supply chain management

T.-M. Choi (✉)
Business Division, Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Room ST740, Hung Hom, Kowloon, Hong Kong
e-mail: Jason.choi@polyu.edu.hk

1 Introduction

Green supply chain management is a hot topic in production and operations management [1, 2]. Empirical reports and cases all reveal the fact that green supply chain management is critical to the sustainability of many industries which include fashion apparel [3, 4]. Actually, green manufacturing and supply chain management practices are known to be an especially pertinent issue in the fashion apparel industry. This fact is driven by the consumers' increasing level of awareness and concerns on environmental protection. Many consumers are now willing to pay more for green apparel products from environmentally friendly retailers (produced by environmentally sustainable manufacturers). This trend in consumer preference and attitude highly affects the green supply chain management practices in fashion apparel and leads to a new sustainability mindset (such as the 5R model [2] and the use of environmental management systems [11]). In addition, the traditional fashion apparel supply chains are notorious for producing a lot of wastes and scraps, releasing pollutants such as dyeing chemicals and toxic gases, involving excessive packaging especially in retail operations, and employing environmentally unfriendly electricity power supplies [14]. As a result, imposing green supply chain management-related measures is crucial in order to dampen the harmful effects brought by fashion supply chain operations. As a remark, some renowned fashion-related companies have already imposed a formal program to measure and reduce carbon footprint. For example, Marks and Spencer has its formal "Plan A" program. Under this program, the company reported in its official 2010/2011 report that the company has decreased 13 % of its total carbon emissions which is equivalent to a reduction of over 90,000 tonnes of CO2 emission from the figure in 2006/2007 [24, p.2]. The Marks and Spencer's case has shown how significant the carbon emission reduction can be in the fashion industry and there are big rooms for improvement.

Recently, some nations are discussing to place the fashion apparel industry as one of the focal industries for further exploration of the respective green manufacturing-related policies, and various measures are proposed. One measure that is commonly discussed is the carbon footprint [28, 29] taxation scheme [3, 9, 17]. To be specific, carbon footprint tax is an environmental protection tax imposed on companies with respect to the amount of carbon footprint involved [30]. It relates to the amount of carbon emission from the business operations, and covers various aspects which include sourcing and distribution [6]. This carbon footprint taxation scheme is still in its early development, and there are some concerns over its implementation [15, 25, 27]. One specific application of using the carbon footprint tax is to encourage retailers to source locally by penalizing product purchasing from a source far away from the market (because this act is harmful to the environment) [3].

Motivated by the importance of green supply chain management in the fashion industry and the applicability of carbon footprint tax, this paper analytically studies the significance of imposing carbon footprint tax on fashion supply chain systems. First, formal analytical fashion supply chain optimization model is constructed with reference to the industrial norm and practice in fashion apparel. Second, by examining the optimal decision in the fashion supply chains, we investigate how the carbon footprint tax can affect the retailer's optimal sourcing choice. Third, we further explore the impacts brought by carbon footprint tax on fashion supply chains and their supply chain agents, under the pure wholesale pricing (WP) contract and the markdown money (MM) contract, respectively. As we will show later on in the subsequent sections, this paper analytically reveals a few important insights. For example, we find that: (1) Under the WP contract case: A properly set carbon footprint tax, which relates to the product's manufacturing and shipping costs, and manufacturer's profit margin, can successfully entice the retailer to source from a local manufacturer. (2) Under the MM contract case where the contract is set in a way that the supply chain is coordinated: (a) If the carbon footprint tax is equal to the positive difference between the product costs from the local and offshore sourcing, then the optimal MM rates of partial refund and the optimal supply chain product quantities from the local and offshore sourcing modes are the same. (b) Similar to the WP contract case, we prove analytically that a carefully set carbon footprint tax can always entice the retailer to source locally. In the extended model, under the assumption that the demand with local supply is stochastically bigger than the demand with offshore supply, the retailer's profit with local supply is proven to be stochastically larger than the retailer's profit with offshore supply if the carbon footprint tax is set as the difference between the wholesale prices offered by the local and offshore manufacturers under the WP contract case. We further illustrate how to properly set the carbon footprint tax under the extended model when the demands are normally distributed. Based on the research results, some managerial implications and insights are discussed.

The rest of this paper is organized as follows. Section 2 presents a brief literature review related to green supply chain management and supply chain contracts. Section 3 illustrates the analytical fashion supply chain model in the presence of carbon footprint tax. Sections 4 and 5 show the findings and analytical results for the cases with the WP contract and the MM contract, respectively. Section 6 presents some further analysis based on the assumption that the demand with local supply is stochastically higher than the demand with offshore supply. Section 7 concludes the paper with a discussion on research implications and insights. To enhance exposition, all technical proofs are placed in the Appendix.

2 Literature review

This paper relates to two major research areas in supply chain management, namely green supply chain management practices and supply chain coordination contracts. We review some recent representative works in the literature as follows.

Green supply chain management is a hot topic nowadays [12]. The earlier literature which relates to green supply chain management focuses a lot on closed loop supply chain management with practices such as remanufacturing [24]. In this scope, recently, Hossein et al. [7] studied a closed loop supply chain distribution network optimization problem. Their model incorporated the concept of having the reverse flows imported into the forward model. They proposed a fuzzy goal programming method to solve the network optimization problem in their proposed closed loop supply chain. They presented some computational results to demonstrate that their proposed solution approach can effectively solve the network design problem. Other than the "classic" topic of closed loop supply chain management, the recent green supply chain management literature also extensively examined some timely measures such as carbon footprint[1] taxation schemes. To be specific, Sundarakani et al. [18] investigated the modelling of carbon footprint in green supply chain systems. By focusing on an analytical model formulation, they proposed various important methods on establishing transport-related carbon footprint models. In the context of inventory management, Hua et al. [8] pioneered an influential study on how firms can optimize their inventory decisions in the presence of carbon footprint

---

[1] For more details on carbon footprint and its estimation, readers can refer to [25, 27].

trading rules. They analytically developed the optimal inventory control scheme. They further studied how the carbon pricing scheme and carbon quota system can affect the optimal inventory control rules. Based on a case study in the pulp and paper industry, Gemechu et al. [6] explored the imposition of environmental tax on products and services with respect to the corresponding "carbon footprint." They employed the commonly adopted life cycle and environmentally extended input–output analyses to estimate the amount of carbon emission. Most recently, Choi [3] analytically examined how a properly designed carbon footprint taxation system can help enhance the level of environmental sustainability on "a quick response system based retailer." He considered Bayesian information updating process as a part of the quick response system and the retailer has an inventory service objective. He built a stochastic fashion supply chain model in which a local supplier and an offshore supplier are present with different lead times. He demonstrated analytically how the carbon footprint taxation scheme affects the choice on the retailer's sourcing decision in the presence of probable information updating. He argued that the carbon taxation scheme can lead to a mean-risk improving scenario where the fashion retailer enjoys both an improved profit and a lower level of risk under quick response when the carbon footprint taxation scheme is properly applied. For a recent review and case study on carbon footprint in supply chain management, refer to [30].

In the supply chain management literature, channel coordination is a big topic [21]. Essentially, it is well known that a supply chain, no matter it is green or not, will naturally be only suboptimal when it is operated under a decentralized setting. The major reasons explaining this fact come from the presence of the bullwhip effect [20] and the double marginalization phenomenon (see [13, 21]). As a result, the use of incentive alignment scheme in the form of supply chain contracts is widely proposed as a means to coordinate the supply chain channel (see [22] for a recent development of more sophisticated contracts). Among the supply chain contracts explored in the literature, the WP contract and the MM contract are two forms commonly adopted in the fashion industry [16, 26]. In fact, the WP contract is usually termed as the fundamental supply contract because the supplier only needs to announce a unit wholesale price to the buyer, and the buyer reacts by deciding the order quantity. In the MM contract, in addition to the unit wholesale price, the supplier also lets the buyer know that by the end of the selling season, the supplier will sponsor the buyer to "markdown (and clear)" inventory by offering a unit markdown price which can be treated as a "partial refund" (for the product leftover). In the literature, it is known that the WP contract cannot coordinate the supply chain (P.S.: Coordination here means maximizing the whole supply chain system's (expected) profitability [21]) even under a very simple supply chain setting (see [13]). However, different from the WP contract, the MM contract can coordinate the supply chain. As a result, the MM contract becomes a very important measure in supply chain management. In the literature, the MM contract has been widely explored. For instance, Whang [19] studied a supply chain with markdown competition. He modelled the case when there are two retailers in the supply chain and they compete for market share. He generated many important analytical insights on how the MM contract affects the optimal inventory decisions for the competing retailers. Elmaghraby et al. [5] examined the optimal design of pre-announced markdowns in the presence of fully rational consumers. They explored the case when the retailer can subtly employ a pre-announced markdown price to optimally enhance profitability. Yin et al. [20] investigated the optimal markdown pricing scheme in the presence of strategic consumers. They focused their analysis on the inventory display formats. They revealed analytically how a limited displayed inventory affects the strategic consumers' optimal decisions and hence the retailer's profit. Most recently, Shen et al. [16] studied the supply chain optimization problem with the use of the MM contract in the fashion industry. They showed analytically how the MM contract can achieve coordination in the presence of risk averse suppliers. They also illustrated how the MM contract affects the fashion supply chain system with real data analysis.

As reviewed above, even though the existing literature has examined various important aspects of green supply chain management with carbon footprint, how the imposition of carbon footprint affects the fashion retailer and the whole fashion supply chain under different supply chain contracts is not yet fully known. In addition, given that the MM contract can coordinate a fashion supply chain, it is important to know how the carbon footprint taxation scheme affects the coordination mechanism of the fashion supply chains as well as the performances of the coordinated fashion supply chains and their agents. *To the best of my knowledge, the above important research issues have not yet been explored in the literature. Addressing these open research questions hence outlines the contribution of this paper.* Table 1 shows the literature positioning of this paper.

3 Basic model

We construct the basic fashion supply chain model in this section. We consider a fashion supply chain in which there is a fashion retailer who has to decide the order quantity for an apparel product before the selling season starts. This fashion retailer sells the fashionable apparel product in a short selling season, and demand is known to be highly volatile. As widely observed in the fashion industry, we study the situation when the fashion retailer (e.g., located in Australia) can get supply of the needed apparel product

Table 1 This paper's literature positioning

	Carbon footprint considerations	Supply chain contracts	Local sourcing considerations	Larger demand case under local sourcing
[3]	Yes	No	Yes	No
[5]	No	Yes	No	No
[6]	Yes	No	No	No
[8]	Yes	No	No	No
[9]	Yes	No	No	No
[10]	Yes	No	No	No
[13]	No	Yes	No	No
[16]	No	Yes	No	No
[17]	Yes	No	No	No
[18]	Yes	No	No	No
[19]	No	Yes	No	No
[22]	No	Yes	No	No
[23]	No	Yes	No	No
This paper	Yes	Yes	Yes	Yes

from two sources: One is located far away from the retail market (e.g., in India) and one is located locally (e.g., in Australia). The main reason for getting supply from the far-away place (via "offshore production") is the much lower production cost compared to the "local supply." For a notational purpose, we use "*O*" and "*L*" to represent "Offshore" and "Local," respectively.

We assume that the product demand D is an independently and identically distributed (*iid*) random variable following a cumulative distribution function $F(D)$. For manufacturer $i\in\{O,L\}$, the unit manufacturing cost is denoted by ϖ_i, and the unit delivery cost (shipping the product to the retailer) is represented by d_i. We define the per unit product cost m_i (i.e., the cost of getting one unit of product ready and shipped to the retail place) as follows,

$$m_i = \varpi_i + d_i, \quad \text{for } i \in \{O, L\}. \tag{3.1}$$

We define:

$$\Delta m = m_L - m_O. \tag{3.2}$$

To avoid trivial cases from happening, we consider the case with $\Delta m>0$ throughout this paper because the product cost from the local supply is commonly larger than the one from the offshore supply; otherwise, the retailer will not consider this offshore production option at all. With this assumption, we will naturally have the case that in the absence of the carbon footprint tax, the retailer will prefer to source from the offshore manufacturer because of a lower product cost (which is the commonly observed industrial practice and norm). This problem feature will be assumed throughout this paper (or else the whole problem on the need of carbon footprint tax becomes meaningless).

In the fashion apparel industry, it is an industrial norm that most garment manufacturers for the same kind of products will employ a standard mark-up to determine the wholesale price of their products. This standard mark-up also relates to the concept of fairness, and both manufacturers and retailer buyers usually know about it. Following this industrial practice, the unit wholesale price of the product for manufacturer $i\in\{O,L\}$ (w_i) in our model is hence given as follows,

$$w_i = (1 + \beta)m_i, \tag{3.3}$$

where $\beta>0$ and it represents the *manufacturer percentage profit margin*, as determined by the industrial norm.

After receiving the product, the retailer sells the product to consumers at a unit retail selling price p. By the end of the respective period, any leftover can be cleared at a market clearance price v. To avoid trivial cases, we have: $v<m_i<w_i<p$. Under the WP contract, the manufacturer i only offers the wholesale price w_i to the retailer in the contract, and the retailer will react by determining the optimal ordering quantity and placing the order, where $i\in\{O,L\}$. Under the MM contract, in addition to offering the wholesale price w_i, manufacturer $i\in\{O,L\}$ will also offer a unit markdown money s_i. This markdown money is used to sponsor the retailer for clearing any product leftover by the end of the selling season via markdown. Define:

$$s_i = \alpha_i w_i, i \in \{O, L\}, \tag{3.4}$$

where α_i represents the manufacturer i's "rate of partial refund" (with respect to the wholesale price) which is a kind of markdown sponsor under the MM contract.

In addition, we consider a carbon footprint taxation scheme in which the government imposes a carbon penalty cost c on product sourced from offshore manufacturer, and there is zero carbon penalty for sourcing from a local manufacturer. Since we only have two supply sources in which one from a local manufacturer and one from an offshore manufacturer, we only need to consider one single carbon penalty cost c. In this paper, we define *the proper carbon footprint tax* which can entice the fashion retailer to source from the local manufacturer to be the minimum value of c with which the fashion retailer's expected profit to source locally equals the expected profit to source from offshore manufacturer. In other words, under this *properly set* carbon footprint tax, the fashion retailer will be more environmentally friendly in terms of carbon footprint and will also receive the same amount of expected profit (compared to the conventional offshore sourcing) by employing the local manufacturer. This gives the proper (but not excessive) incentive for the fashion retailer to source from the local manufacturer and reduces the need of having excessive penalty on carbon footprint.

For a notational purpose, we denote the retailer's order quantity for the product supplied by manufacturer $i\in\{O, L\}$ with a supply chain contract $j\in$(WP,MM), and the corresponding profit function by $q_{R,i}^{(j)}$, and $\pi_{R,i}^{(j)}\left(q_{R,i}^{(j)}\right)$, respectively, where the subscript R represents "Retailer." Similarly, the supply chain's product quantity for the product supplied by manufacturer $i\in\{O, L\}$ and the corresponding profit are denoted by $q_{\mathrm{SC},i}$, and $\pi_{\mathrm{SC},i}$ $(q_{\mathrm{SC},i})$, respectively, where the subscript SC represents "Supply Chain."

4 The pure wholesale pricing contract scenario

We consider in this section the scenario where the manufacturer $i\in\{O,L\}$ only offers an WP contract to the fashion retailer. For the local sourcing case, we have the profit function derived as follows,

$$\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)=p\min\left(q_{R,L}^{\mathrm{WP}},D\right)-w_L q_{R,L}^{\mathrm{WP}}+v\max\left(q_{R,L}^{\mathrm{WP}}-D,0\right). \tag{4.1}$$

Since

$$\min(A,B)=A-\max(A-B,0), \tag{4.2}$$

we can rewrite (4.1) in two different forms below. (P.S.: We express the profit function in (4.3) to help with deriving the expected profit function, whereas the profit function in (4.4) relates to the further analysis in Section 6),

$$\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)=(p-w_L)q_{R,L}^{\mathrm{WP}}-(p-v)\max\left(q_{R,L}^{\mathrm{WP}}-D,0\right). \tag{4.3}$$

$$\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)=(p-v)\min\left(q_{R,L}^{\mathrm{WP}},D\right)-(w_L-v)q_{R,L}^{\mathrm{WP}}. \tag{4.4}$$

Define:

$$G(y)=\int_0^y F(x)dx. \tag{4.5}$$

$$\xi(y)=2y\int_0^y F(x)dx-2\int_0^y xF(x)dx-\left(\int_0^y F(x)dx\right)^2. \tag{4.6}$$

Taking expectation on (4.3), we have the expected profit,

$$E\left[\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)\right]=(p-w_L)q_{R,L}^{\mathrm{WP}}-(p-v)G\left(q_{R,L}^{\mathrm{WP}}\right). \tag{4.7}$$

Taking variance on (4.3), we have the variance of profit,

$$V\left[\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)\right]=(p-v)^2\xi\left(q_{R,L}^{\mathrm{WP}}\right). \tag{4.8}$$

It is a classic result that $E\left[\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)\right]$ is a concave function of $q_{R,L}^{\mathrm{WP}}$, and $V\left[\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)\right]$ is an increasing function of $q_{R,L}^{\mathrm{WP}}$. Thus, the optimal ordering quantity which maximizes $E\left[\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L}^{\mathrm{WP}}\right)\right]$, denoted by $q_{R,L*}^{\mathrm{WP}}$, can be found by solving the first order derivative. The result is shown as follows,

$$q_{R,L*}^{\mathrm{WP}}=F^{-1}[(p-w_L)/(p-v)]. \tag{4.9}$$

Similarly, for the offshore supply case, we have the profit, expected profit, and variance of profit functions derived as follows,

$$\pi_{R,O}^{\mathrm{WP}}\left(q_{R,O}^{\mathrm{WP}}\right)=(p-w_O-c)q_{R,O}^{\mathrm{WP}}-(p-v)\max\left(q_{R,O}^{\mathrm{WP}}-D,0\right). \tag{4.10}$$

$$\pi_{R,O}^{\mathrm{WP}}\left(q_{R,O}^{\mathrm{WP}}\right)=(p-v)\min\left(q_{R,O}^{\mathrm{WP}},D\right)-(w_O+c-v)q_{R,L}^{\mathrm{WP}}. \tag{4.11}$$

$$E\left[\pi_{R,O}^{\mathrm{WP}}\left(q_{R,O}^{\mathrm{WP}}\right)\right]=(p-w_O-c)q_{R,O}^{\mathrm{WP}}-(p-v)G\left(q_{R,O}^{\mathrm{WP}}\right). \tag{4.12}$$

$$V\left[\pi_{R,O}^{\mathrm{WP}}\left(q_{R,O}^{\mathrm{WP}}\right)\right]=(p-v)^2\xi\left(q_{R,O}^{\mathrm{WP}}\right). \tag{4.13}$$

Since $E\left[\pi_{R,O}^{\mathrm{WP}}\left(q_{R,O}^{\mathrm{WP}}\right)\right]$ is also concave, we have the optimal ordering quantity, denoted by $q_{R,O*}^{\mathrm{WP}}$, as follows,

$$q_{R,O*}^{\mathrm{WP}}=F^{-1}[(p-w_O-c)/(p-v)]. \tag{4.14}$$

With the above results, we have Proposition 4.1.

Proposition 4.1 (a) *When the carbon footprint tax is set as* $c\geq w_L-w_O$, *it is optimal for the fashion retailer to source locally.* (*b*) *The proper value of c which makes it optimal for the fashion retailer to source locally is* (*1*) *increasing in the manufacturer percentage profit margin, and* (*2*) *increasing in* Δm (i.e., *the difference of the product costs between the local and the offshore manufacturers*).

From Proposition 4.1, we can see that the proper value of carbon emission tax which can entice the retailer to order from the local manufacturer is equal to the difference of the wholesale prices between the local and the offshore manufacturers. In addition, it possesses very nice structural property in which a higher percentage profit margin for the manufacturer will directly lead to a larger required carbon footprint tax. Since the manufacturers of more fashionable products and more specialized functional products usually charge a higher profit margin in the respective supply business, the analytical result of Proposition 4.1b(1) thus indicates that the required carbon footprint tax to entice local sourcing with these products will also be higher. Moreover, since the proper carbon footprint tax is increasing in the difference of the product costs between the local manufacturer and the offshore manufacturer and the product cost depends on the respective manufacturing cost, and the delivery cost (which further relates to the shipping distance), we have the following finding: If either the manufacturing cost or the delivery cost of the offshore manufacturer increases, the required carbon footprint tax which can entice the retailer to optimally source from the local manufacturer becomes smaller. In addition, employing the mean-variance approach of conducting risk analysis [16] in which variance of profit measures the level of risk associated with the decision, we have Proposition 4.2.

Proposition 4.2

$$V\left[\pi_{R,L}^{\mathrm{WP}}\left(q_{R,L*}^{\mathrm{WP}}\right)\right] = V\left[\pi_{R,O}^{\mathrm{WP}}\left(q_{R,O*}^{\mathrm{WP}}|c = w_L - w_O\right)\right].$$

Proposition 4.2 reflects the fact that when the carbon footprint tax is properly set according to Proposition 4.1, the level of risk associated with sourcing from the local manufacturer is the same as the one from the offshore manufacturer under the WP contract.

5 The markdown money contract scenario

In Section 4, we study the scenario when the manufacturers offer the WP contract to the fashion retailer. In this section, we examine the case when the manufacturers offer the MM contract. Notice that the MM contract is very different from the WP contract from the supply chain system perspective because the MM contract can successfully coordinate the supply chain by "aligning the incentive" so that the retailer will order a quantity (and the manufacturer will produce accordingly) which is equal to the optimal product quantity from the whole supply chain system's perspective.[2] However, notice that the WP contract can never coordinate the supply chain [13, 21].

Now, we consider the local sourcing case in the presence of the MM contract. We can derive the retailer's profit, expected profit, and variance of profit functions below,

$$\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right) = (p - w_L)q_{R,L}^{\mathrm{MM}} - (p - v - s_L)\max\left(q_{R,L}^{\mathrm{MM}} - D, 0\right). \tag{5.1}$$

$$\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right) = (p - v - s_L)\min\left(q_{R,L}^{\mathrm{MM}}, D\right) - (w_L - v)q_{R,L}^{\mathrm{MM}}. \tag{5.2}$$

$$E\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right)\right] = (p - w_L)q_{R,L}^{\mathrm{MM}} - (p - v - s_L)G\left(q_{R,L}^{\mathrm{MM}}\right). \tag{5.3}$$

$$V\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right)\right] = (p - v - s_L)^2\xi\left(q_{R,L}^{\mathrm{MM}}\right). \tag{5.4}$$

Similar to the WP contract case, it is easy to show that $E\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right)\right]$ is a concave function of $q_{R,L}^{\mathrm{MM}}$, and $V\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right)\right]$ is an increasing function of $q_{R,L}^{\mathrm{MM}}$. Thus, the optimal ordering quantity which maximizes $E\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L}^{\mathrm{MM}}\right)\right]$, denoted by $q_{R,L*}^{\mathrm{MM}}$, is given,

$$q_{R,L*}^{\mathrm{MM}} = F^{-1}[(p - w_L)/(p - v - s_L)]. \tag{5.5}$$

For the supply chain with local sourcing, we can derive the following supply chain's profit, expected profit, and variance of profit functions as follows,

$$\pi_{SC,L}^{\mathrm{MM}}\left(q_{SC,L}^{\mathrm{MM}}\right) = (p - m_L)q_{SC,L}^{\mathrm{MM}} - (p - v)\max\left(q_{SC,L}^{\mathrm{MM}} - D, 0\right). \tag{5.6}$$

$$E\left[\pi_{SC,L}^{\mathrm{MM}}\left(q_{SC,L}^{\mathrm{MM}}\right)\right] = (p - m_L)q_{SC,L}^{\mathrm{MM}} - (p - v)G\left(q_{SC,L}^{\mathrm{MM}}\right). \tag{5.7}$$

$$V\left[\pi_{SC,L}^{\mathrm{MM}}\left(q_{SC,L}^{\mathrm{MM}}\right)\right] = (p - v)^2\xi\left(q_{SC,L}^{\mathrm{MM}}\right). \tag{5.8}$$

It is obvious that $E\left[\pi_{SC,L}^{\mathrm{MM}}\left(q_{SC,L}^{\mathrm{MM}}\right)\right]$ is concave and the optimal product quantity which maximizes $E\left[\pi_{SC,L}^{\mathrm{MM}}\left(q_{SC,L}^{\mathrm{MM}}\right)\right]$, denoted by q_{SC,L^*}^{MM}, can be found as follows,

$$q_{SC,L^*}^{\mathrm{MM}} = F^{-1}[(p - m_L)/(p - v)]. \tag{5.9}$$

Similarly, for the offshore supply mode under the MM contract, we have the profit, expected profit, and variance of

---

[2] Because this quantity maximizes the respective whole supply chain system's expected profit.

profit functions for the retailer and the supply chain derived as follows,

$$\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O}^{\mathrm{MM}}\right) = (p - w_O - c)q_{R,O}^{\mathrm{MM}} - (p - v - s_O)\max\left(q_{R,O}^{\mathrm{MM}} - D, 0\right), \tag{5.10}$$

$$\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O}^{\mathrm{MM}}\right) = (p - v - s_O)\min\left(q_{R,O}^{\mathrm{MM}}, D\right) - (w_O + c - v)q_{R,O}^{\mathrm{MM}}, \tag{5.11}$$

$$E\left[\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O}^{\mathrm{MM}}\right)\right] = (p - w_O - c)q_{R,O}^{\mathrm{MM}} - (p - v - s_O)G\left(q_{R,O}^{\mathrm{MM}}\right), \tag{5.12}$$

$$V\left[\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O}^{\mathrm{MM}}\right)\right] = (p - v - s_O)^2\xi\left(q_{R,O}^{\mathrm{MM}}\right), \tag{5.13}$$

$$\pi_{SC,O}^{\mathrm{MM}}\left(q_{SC,O}^{\mathrm{MM}}\right) = (p - m_O - c)q_{SC,O}^{\mathrm{MM}} - (p - v)\max\left(q_{SC,O}^{\mathrm{MM}} - D, 0\right), \tag{5.14}$$

$$E\left[\pi_{SC,O}^{\mathrm{MM}}\left(q_{SC,O}^{\mathrm{MM}}\right)\right] = (p - m_O - c)q_{SC,O}^{\mathrm{MM}} - (p - v)G\left(q_{SC,O}^{\mathrm{MM}}\right), \tag{5.15}$$

$$V\left[\pi_{SC,O}^{\mathrm{MM}}\left(q_{SC,O}^{\mathrm{MM}}\right)\right] = (p - v)^2\xi\left(q_{SC,O}^{\mathrm{MM}}\right). \tag{5.16}$$

It is easy to find that $E\left[\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O}^{\mathrm{MM}}\right)\right]$ and $E\left[\pi_{SC,O}^{\mathrm{MM}}\left(q_{SC,O}^{\mathrm{MM}}\right)\right]$ are concave functions and the optimal product quantities which respectively maximize them, denoted by $q_{R,O*}^{\mathrm{MM}}$ and $q_{\mathrm{SC,O}*}^{\mathrm{MM}}$, can be derived below,

$$q_{R,O*}^{\mathrm{MM}} = F^{-1}[(p - w_O - c)/(p - v - s_O)], \tag{5.17}$$

$$q_{SC,O*}^{\mathrm{MM}} = F^{-1}[(p - m_O - c)/(p - v)]. \tag{5.18}$$

With the above results, we define the following,

$$\alpha_{L*} = \frac{(p - v)\beta}{(p - m_L)(1 + \beta)}, \tag{5.19}$$

$$\alpha_{O*} = \frac{(p - v)\beta}{(p - m_O - c)(1 + \beta)}. \tag{5.20}$$

With (5.19) and (5.20), we further define the corresponding "rate of refund" under the MM contract as follows and then we have Proposition 5.1,

$$s_{L^*} = \alpha_{L^*}w_L,$$
$$s_{O^*} = \alpha_{O^*}w_O.$$

Proposition 5.1 *(a) For the local sourcing supply chain under the MM contract, the rate of partial refund α_L which can coordinate the supply chain by making $q_{R,L^*}^{\mathrm{MM}} = q_{SC,L^*}^{\mathrm{MM}}$ is equal to α_{L*}, and the partial refund S_L=S_{L*}. (b) For the offshore sourcing supply chain under the MM contract, the rate of partial refund α_O which can coordinate the supply chain by making $q_{R,O*}^{\mathrm{MM}} = q_{SC,O*}^{\mathrm{MM}}$ is equal to α_{O*}, and the partial refund S_O=S_{O*}.(c)α_{L*} and α_{O*} are increasing function of β.*

Proposition 5.1 indicates that the supply chain coordinating MM contract can be set easily when the cost-revenue parameters are available following (5.19) and (5.20). In particular, it is interesting to note from Proposition 5.1(c) that the "rates of partial refund" under the MM contract which can coordinate the respective supply chains (the local and the offshore cases) are increasing in the manufacturer's percentage profit margin. It thus implies that for the type of fashion products that has a higher percentage profit margin, the required rates of partial refund to coordinate the supply chains in both the local and the offshore manufacturing cases are also higher. Assuming that the supply chains are all internally coordinated with the "rates of partial refund" satisfying Proposition 5.1's conditions, we have some further findings summarized in Lemma 5.2.

Lemma 5.2 *Under the coordinating MM contracts respectively for the local and the offshore manufacturing supply chains, when the carbon footprint tax is set as c=m_L−m_O, we have: (1) $q_{\mathrm{SC,O}*}^{\mathrm{MM}} = q_{\mathrm{SC,L}*}^{\mathrm{MM}} = q_{R,O*}^{\mathrm{MM}} = q_{R,L*}^{\mathrm{MM}}$, (2) α_{L*}=α_{O*}, (3) $E\left[\pi_{\mathrm{SC,L}}^{\mathrm{MM}}\left(q_{\mathrm{SC,L}*}^{\mathrm{MM}}\right)\right] = E\left[\pi_{\mathrm{SC,O}}^{\mathrm{MM}}\left(q_{\mathrm{SC,O}*}^{\mathrm{MM}}\right)\right]$, and $V\left[\pi_{\mathrm{SC,L}}^{\mathrm{MM}}\left(q_{\mathrm{SC,L}*}^{\mathrm{MM}}\right)\right] = V\left[\pi_{\mathrm{SC,O}}^{\mathrm{MM}}\left(q_{\mathrm{SC,O}*}^{\mathrm{MM}}\right)\right]$, (4)$E\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L*}^{\mathrm{MM}}\right)\right] < E\left[\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O*}^{\mathrm{MM}}\right)\right]$, and (5) $V\left[\pi_{R,L}^{\mathrm{MM}}\left(q_{R,L*}^{\mathrm{MM}}\right)\right] < V\left[\pi_{R,O}^{\mathrm{MM}}\left(q_{R,O*}^{\mathrm{MM}}\right)\right]$.*

From Lemma 5.2, we can see that setting c=m_L−m_O can lead to various interesting results, such as the optimal retailer's ordering quantities under the local and the offshore souring modes are the same (and also equal the supply chain's optimal quantities), the rates of refund under the MM contract for coordinating the local and the offshore supply chains are the same, and the expected profits and the variances of profit of the respective supply chains are also the same. However, from the retailer's perspective, when $c = m_L - m_O$, the expected profit under the local sourcing mode is lower than the expected profit under the offshore sourcing model, which means that this carbon footprint tax of $c = m_L - m_O$ is insufficient to entice the retailer to adopt the local manufacturer as the supplier. As an important remark, notice that in this paper, we assume the retailer is risk neutral. However, when the retailer is risk averse, then having a carbon footprint tax of $c = m_L - m_O$ may lead to the retailer's adoption of the local sourcing model because from Lemma 5.2(v), the level of risk associated with the local sourcing mode is lower compared to the one associated with the offshore sourcing mode when $c = m_L - m_O$. Define:

$$\begin{aligned} c_*^{\mathrm{MM}} = \arg_c\{ & E[\pi_{R,L}^{\mathrm{MM}}(q_{R,L*}^{\mathrm{MM}} | \alpha_L = \alpha_{L^*})] \\ & - E[\pi_{R,O}^{\mathrm{MM}}(q_{R,O*}^{\mathrm{MM}} | \alpha_O = \alpha_{O^*})] = 0\}. \end{aligned} \tag{5.21}$$

Notice that (5.21) can be rewritten as (5.22) because when $\alpha_L = \alpha_{L*}$ and $\alpha_O = \alpha_{O*}$ hold, the respective supply chains are coordinated with $q_{R,O^*}^{\mathrm{MM}} = q_{\mathrm{SC,O^*}}^{\mathrm{MM}}$ and $q_{\mathrm{SC,L^*}}^{\mathrm{MM}} = q_{R,L^*}^{\mathrm{MM}}$.

$$\begin{aligned} c_*^{\mathrm{MM}} = \arg_c\{ & E[\pi_{R,L}^{\mathrm{MM}}(q_{\mathrm{SC,L^*}}^{\mathrm{MM}} | \alpha_L = \alpha_{L^*})] \\ & - E[\pi_{R,O}^{\mathrm{MM}}(q_{\mathrm{SC,O^*}}^{\mathrm{MM}} | \alpha_O = \alpha_{O^*})] = 0\}. \end{aligned} \tag{5.22}$$

With (5.21) and (5.22), we have Proposition 5.3.

Proposition 5.3 *Under the MM contract*: (*a*) c_*^{MM} *exists within the range of* $(0, p - w_O)$. (*b*) *When the carbon footprint tax is properly set as* $c = c_*^{\mathrm{MM}}$, *it is optimal for the fashion retailer to source locally.*

Similar to the case with the WP contract, Proposition 5.3 shows that it is always possible to provide a carbon footprint tax which can entice the retailer to employ the local manufacturer as the sourcing mode under the MM contract (in terms of having a larger expected profit). In addition, since the local sourcing supply chain is already internally coordinated (and hence optimal) under the MM contract with $\alpha_L = \alpha_{L*}$, the setting of the carbon footprint tax equals c_*^{MM} will not affect the supply chain system's optimal efficiency.

6 Extended models and further analysis

In the above analysis, we assume that market demand for the fashion product is exogenously given and is independent of the supply mode (and hence it is independent of whether the fashion retailer is more environmentally friendly or not). In this section, we consider the situation under which if the retailer sources locally (and indicates this act as an environmental move to its customers in the consumer market), its demand under the local supply mode (D_L) will be stochastically higher than the corresponding demand under the offshore supply mode (D_O), i.e.,

$$D_L \underset{\text{Stochastic}}{\geq} D_O. \tag{6.1}$$

Notice that this can also reflect the consumer preference in favoring products produced in more environmental-conscious and developed countries/markets than the developing countries/markets from both the sustainability and quality perspectives. Under this setting, at any given retail ordered quantity q, the expected sales amount under the local supply mode ($\mathrm{SALE}_L(q) = \min(q, D_L)$) will be higher than the expected sales amount under the offshore supply model ($\mathrm{SALE}_O(q) = \min(q, D_O)$). That is,

$$\mathrm{SALE}_L(q) \underset{\text{Stochastic}}{\geq} \mathrm{SALE}_O(q) \cdot \tag{6.2}$$

With the above details, we have Proposition 6.1.

Proposition 6.1 *If* $D_L \underset{\text{Stochastic}}{\geq} D_O$ (*which implies* $\mathrm{SALE}_L(q) \underset{\text{Stochastic}}{\geq} \mathrm{SALE}_O(q)$): (*a*) *Under the WP contract*: *When the carbon footprint tax is set as* $c = w_L - w_O$, *we have* $\pi_{R,L}^{\mathrm{WP}}(q) \underset{\text{Stochastic}}{\geq} \pi_{R,O}^{\mathrm{WP}}(q)$. (b) *Under the coordinating MM contracts respectively for the local and the offshore manufacturing supply chains, setting* $c = w_L - w_O$ *does NOT suffice to imply* $\pi_{R,L}^{\mathrm{MM}}(q | \alpha_L = \alpha_{L^*}) \underset{\text{Stochastic}}{\geq} \pi_{R,O}^{\mathrm{MM}}(q | \alpha_O = \alpha_{O^*})$.

Proposition 6.1 indicates various important findings when the demand and the sales amount under the local sourcing mode are stochastically larger than the respective ones under the offshore sourcing model. To be specific, Proposition 6.1(a) reveals that when the carbon footprint tax c is set to be $w_L - w_O$, the retailer's profit under the local sourcing mode will stochastically dominate the retailer's profit under the offshore sourcing mode in the WP contract case. This finding is very meaningful as it shows that not only the expected profit but also the "profit" is actually better under the local sourcing mode when carbon footprint tax=w_L-w_O. It thus further shows the significance of offering this carbon footprint tax to attract the retailer to adopt the local sourcing mode. However, for the case with the MM contract, the situation is more complex, and a simple setting of the same carbon footprint tax=w_L-w_O will not lead to a stochastically dominating result as in the WP contract case.

In order to derive more analytical insights, we consider the case when D_L and D_O are normally distributed with the following details,

$$D_L \sim \text{Normal}\left(\mu_{\text{L}}, \sigma^2\right), \tag{6.3}$$

$$D_O \sim \text{Normal}\left(\mu_{\text{O}}, \sigma^2\right), \tag{6.4}$$

where μ_i is the mean of demand for the retailer which gets the product from manufacturer $i \in \{O,L\}$, and $\mu_L > \mu_O$.

With the specific demand models as given in (6.3) and (6.4), we can derive the optimal order quantities for the case when the product comes from manufacturer $i \in \{O,L\}$ under both contract settings as follows (the subscript "Normal" indicates the case when the demand distributions are normal),

$$q^{\text{WP}}_{R,L,\text{Normal}*} = \mu_L + \sigma \Phi^{-1}[(p-w_L)/(p-v)], \tag{6.5}$$

$$q^{\text{WP}}_{R,O,\text{Normal}^*} = \mu_O + \sigma \Phi^{-1}[(p-w_O-c)/(p-v)], \tag{6.6}$$

$$q^{\text{MM}}_{R,L,\text{Normal}*} = \mu_L + \sigma \Phi^{-1}[(p-w_L)/(p-v-s_L)], \tag{6.7}$$

$$q^{\text{MM}}_{R,O,\text{Normal}*} = \mu_O + \sigma \Phi^{-1}[(p-w_O-c)/(p-v-s_O)], \tag{6.8}$$

where $\phi(\cdot)$is the density function of the standard normal distribution function,

$\Phi^{-1}(\,)$ is the inverse function of the standard normal cumulative distribution function.

By incorporating the demand normal distributions of (6.3) and (6.4) into the retailer's expected profits in (4.7), (4.12), (5.3), and (5.12), we have the retailer's expected profit functions given by $E\left[\pi^{\text{WP}}_{R,L,\text{Normal}}\left(q^{\text{WP}}_{R,L,\text{Normal}}\right)\right]$, $E\left[\pi^{\text{WP}}_{R,O,\text{Normal}}\left(q^{\text{WP}}_{R,O,\text{Normal}}\right)\right]$, $E\left[\pi^{\text{MM}}_{R,L,\text{Normal}}\left(q^{\text{MM}}_{R,L,\text{Normal}}\right)\right]$, and $E\left[\pi^{\text{MM}}_{R,O,\text{Normal}}\left(q^{\text{MM}}_{R,O,\text{Normal}}\right)\right]$, respectively. By putting (6.5), (6.6), (6.7) and (6.8) into these retailer's expected profit functions with the normally distributed demands, we can derive the retailer's optimal expected profits under the WP and the MM contracts with each source of supply as follows,

$$\begin{aligned} &E\left[\pi^{\text{WP}}_{R,L,\text{Normal}}\left(q^{\text{WP}}_{R,L,\text{Normal}^*}\right)\right] \\ &\quad = (p-w_L)\mu_L - \sigma(p-v)\phi\left[\Phi^{-1}\left(\frac{p-w_L}{p-v}\right)\right], \end{aligned} \tag{6.9}$$

$$\begin{aligned} &E\left[\pi^{\text{WP}}_{R,O,\text{Normal}}\left(q^{\text{WP}}_{R,O,\text{Normal}^*}\right)\right] \\ &\quad = (p-w_O-c)\mu_L - \sigma(p-v)\phi\left[\Phi^{-1}\left(\frac{p-w_O-c}{p-v}\right)\right], \end{aligned} \tag{6.10}$$

$$\begin{aligned} &E\left[\pi^{\text{MM}}_{R,L,\text{Normal}}\left(q^{\text{MM}}_{R,L,\text{Normal}^*}\right)\right] \\ &\quad = (p-w_L)\mu_L \\ &\qquad - \sigma(p-v-s_{L^*})\phi\left[\Phi^{-1}\left(\frac{p-w_L}{p-v-s_{L^*}}\right)\right], \end{aligned} \tag{6.11}$$

$$\begin{aligned} &E\left[\pi^{\text{MM}}_{R,O,\text{Normal}}\left(q^{\text{MM}}_{R,O,\text{Normal}^*}\right)\right] \\ &\quad = (p-w_O-c)\mu_L \\ &\qquad - \sigma(p-v-s_{O^*})\phi\left[\Phi^{-1}\left(\frac{p-w_O-c}{p-v-s_{O^*}}\right)\right]. \end{aligned} \tag{6.12}$$

Define:

$$\begin{aligned} H^{\text{WP}}(c) = {} & E\left[\pi^{\text{WP}}_{R,L,\text{Normal}}\left(q^{\text{WP}}_{R,L,\text{Normal}^*}\right)\right] \\ & - E\left[\pi^{\text{WP}}_{R,O,\text{Normal}}\left(q^{\text{WP}}_{R,O,\text{Normal}^*}\right)\right], \end{aligned} \tag{6.13}$$

$$\begin{aligned} H^{\text{MM}}(c) = {} & E\left[\pi^{\text{MM}}_{R,L,\text{Normal}}\left(q^{\text{MM}}_{R,L,\text{Normal}^*}\right)\right] \\ & - E\left[\pi^{\text{MM}}_{R,O,\text{Normal}}\left(q^{\text{MM}}_{R,O,\text{Normal}^*}\right)\right], \end{aligned} \tag{6.14}$$

$$c^{\text{WP}}_{\text{Normal}^*} = \underset{c}{\arg}\left\{H^{\text{WP}}(c) = 0\right\}, \tag{6.15}$$

$$c^{\text{MM}}_{\text{Normal}^*} = \underset{c}{\arg}\left\{H^{\text{MM}}(c) = 0\right\}. \tag{6.16}$$

With the above details, we have Proposition 6.2.

Proposition 6.2 *When demand distributions under the local sourcing mode and the offshore sourcing mode follow the normal distributions as shown in* (6.3) *and* (6.4): (*a*) *Under the WP contract*: *By setting the carbon footprint tax as* $c = c^{WP}_{\mathrm{Normal}*}$, *the retailer will be enticed to order from the local manufacturer. Moreover,* $c^{WP}_{\mathrm{Normal}*}$ *exists within the range of* $(0, w_L - w_O)$. (*b*) *Under the coordinating MM contracts respectively for the local and the offshore manufacturing supply chains*, *By setting the carbon footprint tax as* $c = c^{WP}_{\mathrm{Normal}*}$, *the retailer will be enticed to order from the local manufacturer.*

Proposition 6.2 shows that for the normally distributed demand cases: There always exists a "proper" carbon footprint taxation scheme to entice the retailer to source from the local manufacturer under each contract case. In addition, Proposition 6.2(a) reveals that under the WP contract, the required carbon footprint tax (under the case when $D_L \underset{\text{Stochastic}}{\geq} D_O$) is actually lower than the one required under the case when $D_L \underset{\text{Stochastic}}{=} D_O$ (cf: Proposition 4.1).

7 Research implications, insights, and conclusion

Motivated by the importance of green supply chain management in the fashion industry and the popularity of carbon footprint tax, this paper analytically explores the use of carbon footprint tax on fashion supply chain systems to entice the use of local supply. By making reference to the observed industrial norm and practice in the fashion industry, formal supply chain optimization models are constructed. The impacts brought by carbon footprint taxation scheme on the fashion supply chains and their supply chain agents, under the pure wholesale pricing (WP) contract and the markdown money (MM) contract scenarios, are examined. We conclude this paper by discussing some important analytical findings and insights derived from the analysis.

1. Under the WP contract case: A properly set carbon footprint tax, which relies on the product's manufacturing and shipping costs, and manufacturer's profit margin, can successfully entice the retailer to source locally. The setting is simple and effective. As the manufacturers of more fashionable products and more specialized functional products usually charge a higher profit margin in the respective supply business, the analytical result (cf: Proposition 4.1b(1)) thus reveals that the required carbon footprint tax to entice local sourcing with these special products will also be higher. Moreover, since the proper carbon footprint tax is increasing in the difference of the product costs, if the manufacturing cost or the delivery cost of the offshore manufacturer decreases, the proper value of the carbon footprint tax which can entice the retailer to optimally source from the local manufacturer will become smaller.
2. Under the MM contract case where the MM contract is set in a way that the supply chain is coordinated: (1) If the carbon footprint tax is equal to the positive difference between the product costs from the local and offshore sourcing, then the optimal MM rates and the optimal supply chain product quantities from the local and offshore sourcing modes are the same. (2) A carefully set carbon footprint tax can always be found which can successfully entice the retailer to source locally.
3. The carbon footprint taxation scheme affects the coordination mechanism of the fashion supply chain with the offshore manufacturer as the "rate of partial refund" under the coordinating MM contract relies on the carbon footprint tax. Thus, the carbon footprint tax will affect not only the retailer's optimal decision and profit but also the whole supply chain's profit. Fortunately, when the supply chains are internally coordinated by the MM contract, it is always possible to find a proper carbon footprint tax which can attract the retailer to take the local manufacturer as the sourcing mode, and the supply chain remains coordinated.
4. By considering the scenario when the demand and the sales amount under the local sourcing mode are stochastically larger than the respective ones under the offshore sourcing mode, we find that by setting the carbon footprint tax equal to the positive difference between the product costs from the local and offshore sourcing, the resulting retailer's profit under the local sourcing mode will be stochastically larger than the retailer's profit under the offshore sourcing mode in the WP contract case. This finding is very important because it shows that not only the expected profit but also the (random) "profit" is actually always better under the local sourcing mode when the carbon footprint tax is set as the positive difference between the product costs from the local and offshore sourcing under the WP contract. It thus further shows the significance of offering this carbon footprint tax to entice the retailer to adopt the local sourcing mode. However, for the case with the MM contract, the situation is more complex and a simple setting of the same carbon footprint tax (i.e., equal to the positive difference between the product

costs from the local and offshore sourcing) will not lead to a stochastically dominating result. It thus calls for more careful planning, and *further research is needed* to explore the robust way of setting the carbon footprint tax which can attract the retailers who are adopting different kinds of supply chain contracts to choose the more sustainable local manufacturers as their preferred suppliers.

Acknowledgments The author sincerely thanks the guest editor Professor Kannan Govindan and the anonymous reviewers for their kind comments. This research is partially supported by The Hong Kong Polytechnic University under the research grant with an account number of G-YJ23.

Appendix: All proofs

Proof of proposition 4.1

1. From (4.7), (4.9), (4.12), and (4.14), we have:

$$q^{\mathrm{WP}}_{R,O*} = F^{-1}[(p - w_O - c)/(p - v)],$$
$$q^{\mathrm{WP}}_{R,L*} = F^{-1}[(p - w_L)/(p - v)],$$
$$E\left[\pi^{\mathrm{WP}}_{R,O}\left(q^{\mathrm{WP}}_{R,O}\right)\right] = (p - w_O - c)q^{\mathrm{WP}}_{R,O} - (p - v)G\left(q^{\mathrm{WP}}_{R,O}\right),$$
$$E\left[\pi^{\mathrm{WP}}_{R,L}\left(q^{\mathrm{WP}}_{R,L}\right)\right] = (p - w_L)q^{\mathrm{WP}}_{R,L} - (p - v)G\left(q^{\mathrm{WP}}_{R,L}\right)\cdot$$

It is obvious that when $c = w_L - w_O$, we have $q^{\mathrm{WP}}_{R,O*}(c = w_L - w_O) = q^{\mathrm{WP}}_{R,L*}$ and $E\left[\pi^{\mathrm{WP}}_{R,O}\left(q^{\mathrm{WP}}_{R,O}(c = w_L - w_O)\right)\right] = E\left[\pi^{\mathrm{WP}}_{R,L}\left(q^{\mathrm{WP}}_{R,L}\right)\right]$. Thus, by definition of the "proper" value of c, the proposition is shown.

2. The proper value of $c = w_L - w_O$. Since from (3.3), we have $w_L = (1+\beta)m_L$ and $w_O = (1+\beta)m_O$, we can thus rewrite the proper value of c in the following, $c = (1+\beta)(m_L - m_O) = (1+\beta)(m)$, and the results of parts (1) and (2) follow. (Q.E.D.)

Proof of proposition 4.2

From (4.8) and (4.13), we have $V\left[\pi^{\mathrm{WP}}_{R,L}\left(q^{\mathrm{WP}}_{R,L}\right)\right] = (p - v)^2\xi\left(q^{\mathrm{WP}}_{R,L}\right)$, and $V\left[\pi^{\mathrm{WP}}_{R,O}\left(q^{\mathrm{WP}}_{R,O}\right)\right] = (p - v)^2\xi\left(q^{\mathrm{WP}}_{R,O}\right)$. Since $q^{\mathrm{WP}}_{R,O*}(c = w_L - w_O) = q^{\mathrm{WP}}_{R,L*}$, directly putting these values into the variance of profit functions yields,

$$V\left[\pi^{\mathrm{WP}}_{R,L}\left(q^{\mathrm{WP}}_{R,L*}\right)\right] = V\left[\pi^{\mathrm{WP}}_{R,O}\left(q^{\mathrm{WP}}_{R,O*}(c = w_L - w_O)\right)\right].$$

(Q.E.D.)

Proof of proposition 5.1

1. From (5.5), (5.9), (5.17), and (5.18), we have:

$$q^{\mathrm{MM}}_{R,L*} = F^{-1}[(p - w_L)/(p - v - s_L)],$$
$$q^{\mathrm{MM}}_{\mathrm{SC,L}*} = F^{-1}[(p - m_L)/(p - v)],$$
$$q^{\mathrm{MM}}_{R,O*} = F^{-1}[(p - w_O - c)/(p - v - s_O)],$$
$$q^{\mathrm{MM}}_{\mathrm{SC,O}*} = F^{-1}[(p - m_O - c)/(p - v)].$$

To make $q^{\mathrm{MM}}_{R,L*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*}$, we need to set a value of S_L (which means the partial refund and hence the markdown sponsor under the MM contract) to attract the retailer to order at the supply chain's optimal quantity with the local sourcing mode. Thus,

$$q^{\mathrm{MM}}_{R,L*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*}$$
$$\Leftrightarrow F^{-1}[(p - w_L)/(p - v - s_L)] = F^{-1}[(p - m_L)/(p - v)] \tag{A5.1a}$$

By putting $w_L = (1+\beta)m_L$ into (A5.1a) and rearranging terms, we have,

$$q^{\mathrm{MM}}_{R,L*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*} \Leftrightarrow s_{L*}$$
$$= \frac{1}{p - m_L}(p - v)\beta m_L \cdot \tag{A5.1b}$$

Since by definition,

$$s_{L*} = \alpha_{L*}w_L = \alpha_{L*}(1+\beta)m_L, \tag{A5.1c}$$

solving (A5.1b) and (A5.1c) yields the coordinating "rate of partial refund,"

$$\alpha_{L*} = \frac{(p - v)\beta}{(p - m_L)(1+\beta)}\cdot$$

2. Similarly, to make $q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{\mathrm{SC,O}*}$, with a given carbon footprint tax c, we need to set an appropriate value of S_O as follows,

$$q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{\mathrm{SC,O}*}$$

$$\Leftrightarrow F^{-1}[(p - w_O - c)/(p - v - s_O)]$$
$$= F^{-1}[(p - m_O - c)/(p - v)] \tag{A5.1}$$

$$\Leftrightarrow s_{O*} = \frac{1}{p - m_O - c}(p - v)\beta m_O$$

$$\Leftrightarrow \alpha_{O*} = \frac{(p - v)\beta}{(p - m_O - c)(1+\beta)}\cdot$$

3. Since $\alpha_{L*} = \frac{(p-v)\beta}{(p-m_L)(1+\beta)}$ and $\alpha_{O*} = \frac{(p-v)\beta}{(p-m_O-c)(1+\beta)}$, by checking the first order derivatives, we find that

$$\partial\alpha_{L*}/\partial\beta = \frac{(p-v)}{(p-m_L)(1+\beta)^2} > 0, \text{ and}$$

$$\partial\alpha_{O*}/\partial\beta = \frac{(p-v)}{(p-m_O-c)(1+\beta)^2} > 0\cdot$$

Thus, $\alpha_{\mathrm{L}*}$ and $\alpha_{\mathrm{O}*}$ are increasing functions of β. (Q.E.D.)

Proof of Lemma 5.2

1. From (5.5), (5.9), (5.17), and (5.18), we have the closed form expressions of $q^{\mathrm{MM}}_{\mathrm{SC,O}*}, q^{\mathrm{MM}}_{\mathrm{SC,L}*}, q^{\mathrm{MM}}_{R,O*}$, and $\mathrm{q}^{\mathrm{MM}}_{\mathrm{R,L}*}$ as shown below.

$$q^{\mathrm{MM}}_{R,O*} = F^{-1}[(p-w_O-c)/(p-v-s_O)],$$
$$q^{\mathrm{MM}}_{\mathrm{SC,O}*} = F^{-1}[(p-m_O-c)/(p-v)],$$
$$q^{\mathrm{MM}}_{\mathrm{SC,L}*} = F^{-1}[(p-m_L)/(p-v)],$$
$$q^{\mathrm{MM}}_{R,L*} = F^{-1}[(p-w_L)/(p-v-s_L)]\cdot$$

Under the coordinating MM contract, we automatically have (by definition) $q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{\mathrm{SC,O}*}, q^{\mathrm{MM}}_{R,L*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*}$. When $c{=}m_L{-}m_O$, it is obvious to see that $q^{\mathrm{MM}}_{\mathrm{SC,O}*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*} = q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{R,L*}$

2. Since $\alpha_{L*} = \frac{(p-v)\beta}{(p-m_L)(1+\beta)}$ and $\alpha_{O*} = \frac{(p-v)\beta}{(p-m_O-c)(1+\beta)}$, putting $c{=}m_L{-}m_O$ into their analytical expressions directly yields: $\alpha_{L*}{=}\alpha_{O*}$ when $c{=}m_L{-}m_O$.

3. Similarly, from (5.12), and (5.15) [for expected profits] and from (5.13), and (5.16) [for variance of profits], we have,

$$E\left[\pi^{\mathrm{MM}}_{\mathrm{SC,L}}\left(q^{\mathrm{MM}}_{\mathrm{SC,L}}\right)\right] = (p-m_L)q^{\mathrm{MM}}_{\mathrm{SC,L}} - (p-v)G\left(q^{\mathrm{MM}}_{\mathrm{SC,L}}\right),$$
$$E\left[\pi^{\mathrm{MM}}_{\mathrm{SC,O}}\left(q^{\mathrm{MM}}_{\mathrm{SC,O}}\right)\right] = (p-m_O-c)q^{\mathrm{MM}}_{\mathrm{SC,O}} - (p-v)G\left(q^{\mathrm{MM}}_{\mathrm{SC,O}}\right),$$
$$V\left[\pi^{\mathrm{MM}}_{\mathrm{SC,L}}\left(q^{\mathrm{MM}}_{\mathrm{SC,L}}\right)\right] = (p-v)^2\xi\left(q^{\mathrm{MM}}_{\mathrm{SC,L}}\right),$$
$$V\left[\pi^{\mathrm{MM}}_{\mathrm{SC,O}}\left(q^{\mathrm{MM}}_{\mathrm{SC,O}}\right)\right] = (p-v)^2\xi\left(q^{\mathrm{MM}}_{\mathrm{SC,O}}\right).$$

By having $c{=}m_L{-}m_O$, since $q^{\mathrm{MM}}_{\mathrm{SC,O}*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*} = q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{R,L*}$ and $\alpha_{L*}{=}\alpha_{O*}$ hold (see the results of parts (1) and (2)), we have,

$$E\left[\pi^{\mathrm{MM}}_{\mathrm{SC,L}}\left(q^{\mathrm{MM}}_{\mathrm{SC,L}*}\right)\right] = E\left[\pi^{\mathrm{MM}}_{\mathrm{SC,O}}\left(q^{\mathrm{MM}}_{\mathrm{SC,O}*}\right)\right], \text{ and}$$
$$V\left[\pi^{\mathrm{MM}}_{\mathrm{SC,L}}\left(q^{\mathrm{MM}}_{\mathrm{SC,L}*}\right)\right] = V\left[\pi^{\mathrm{MM}}_{\mathrm{SC,O}}\left(q^{\mathrm{MM}}_{\mathrm{SC,O}*}\right)\right].$$

4. From (5.3), (5.7), we have the following.

$$E\left[\pi^{\mathrm{MM}}_{R,L}\left(q^{\mathrm{MM}}_{R,L}\right)\right] = (p-w_L)q^{\mathrm{MM}}_{R,L} - (p-v-s_L)G\left(q^{\mathrm{MM}}_{R,L}\right),$$
$$E\left[\pi^{\mathrm{MM}}_{R,O}\left(q^{\mathrm{MM}}_{R,O}\right)\right] = (p-w_O-c)q^{\mathrm{MM}}_{R,O} - (p-v-s_O)G\left(q^{\mathrm{MM}}_{R,O}\right).$$

Directly putting $c{=}m_L{-}m_O$, $q^{\mathrm{MM}}_{\mathrm{SC,O}*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*} = q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{R,L*} = q*$ and $\alpha_{L*}{=}\alpha_{O*}$ into them and noting that "$-q* + G(q*)F(q*) < -q* + q*F(q*) < 0$" yields $E\left[\pi^{\mathrm{MM}}_{R,L}\left(q^{\mathrm{MM}}_{R,L^*}\right)\right] < E\left[\pi^{\mathrm{MM}}_{R,O}\left(q^{\mathrm{MM}}_{R,O^*}\right)\right]$.

5. From (5.4), and (5.8), we have the following,

$$V\left[\pi^{\mathrm{MM}}_{R,L}\left(q^{\mathrm{MM}}_{R,L}\right)\right] = (p-v-s_L)^2\xi\left(q^{\mathrm{WP}}_{R,L}\right),$$
$$V\left[\pi^{\mathrm{MM}}_{R,O}(q^{\mathrm{MM}}_{R,O})\right] = (p-v-s_O)^2\xi\left(q^{\mathrm{MM}}_{R,O}\right).$$

Directly putting $c{=}m_L{-}m_O$, $q^{\mathrm{MM}}_{\mathrm{SC,O}*} = q^{\mathrm{MM}}_{\mathrm{SC,L}*} = q^{\mathrm{MM}}_{R,O*} = q^{\mathrm{MM}}_{R,L*}$, and $\alpha_{L*}{=}\alpha_{O*}$ into them yields

$$V\left[\pi^{\mathrm{MM}}_{R,L}\left(q^{\mathrm{MM}}_{R,L*}\right)\right] < V\left[\pi^{\mathrm{MM}}_{R,O}\left(q^{\mathrm{MM}}_{R,O*}\right)\right].$$

(Q.E.D.)

Proof of Proposition 5.3

1. From (5.22), we have,

$$c^{\mathrm{MM}}_* = \arg_c\{E[\pi^{\mathrm{MM}}_{R,L}(q^{\mathrm{MM}}_{\mathrm{SC,L}*}|\alpha_L = \alpha_{L*})]$$
$$- E[\pi^{\mathrm{MM}}_{R,O}(q^{\mathrm{MM}}_{\mathrm{SC,O}*}|\alpha_O = \alpha_{O*})] = 0\}.$$

Define: $J^{\mathrm{MM}}(c) = E\left[\pi^{\mathrm{MM}}_{R,L}\left(q^{\mathrm{MM}}_{\mathrm{SC,L}*}|\alpha_L = \alpha_{L*}\right)\right] - E\left[\pi^{\mathrm{MM}}_{R,O}\left(q^{\mathrm{MM}}_{\mathrm{SC,O}*}|\alpha_O = \alpha_{O*}\right)\right]$.

Notice that $\lim_{c\to 0} J^{\mathrm{MM}}(c) < 0$, $\lim_{c\to p-w_O} J^{\mathrm{MM}}(c) > 0$, and $J^{\mathrm{MM}}(c)$ is a continuous function. Thus, c^{MM}_* must exist.

2. Be definition, when $c{=}c^{\mathrm{MM}}_*$, we have the following,

$$E\left[\pi^{\mathrm{MM}}_{R,L}\left(q^{\mathrm{MM}}_{\mathrm{SC,L}*}|\alpha_L = \alpha_{L*}\right)\right]$$
$$= E\left[\pi^{\mathrm{MM}}_{R,O}\left(q^{\mathrm{MM}}_{\mathrm{SC,O}*}|\alpha_O = \alpha_{O*}\right)\right],$$

which means $c{=}\,c^{\mathrm{MM}}_*$ is the minimum value of the carbon footprint tax which can entice the retailer to source locally. (Q.E.D.).

Proof of Proposition 6.1

1. Directly from (4.4) and (4.11), we have the following profit functions under the WP contract,

$$\pi^{\mathrm{WP}}_{R,L}(q) = (p-v)\mathrm{SALE}_L(q) - (w_L - v)q,$$
$$\pi^{\mathrm{WP}}_{R,O}(q) = (p-v)\mathrm{SALE}_O(q) - (w_O + c - v)q.$$

When $\mathrm{SALE}_L(q) \underset{\text{Stochastic}}{\geq} \mathrm{SALE}_O(q)$ holds: If $c{=}w_L{-}w_O$, we have, $\pi^{\mathrm{WP}}_{R,L}(q) \underset{\text{Stochastic}}{\geq} \pi^{\mathrm{WP}}_{R,O}(q)$

2. Similarly, from (5.2) and (5.11), we have the profit functions expressed in terms of $\mathrm{SALE}_L(q)$ and $\mathrm{SALE}_O(q)$ under the MM contract. Now, under the coordinating MM contracts respectively for the local and the offshore manufacturing supply chains, by direct substitution and comparison, it is easy to note that setting $c{=}w_L{-}w_O$ does NOT suffice to imply $\pi_{R,L}^{\mathrm{MM}}(q|\alpha_L=\alpha_{L*}) \underset{\text{Stochastic}}{\geq} \pi_{R,O}^{\mathrm{MM}}(q|\alpha_O=\alpha_{O*})$. (Q.E.D.).

Proof of Proposition 6.2

Similar to the Proof of Proposition 5.3 and by definition of the proper value of c. (Q.E.D.)

References

1. Caniato F, Caridi M, Crippa L, Moretto A (2012) Environmental sustainability in fashion supply chains: an exploratory case based research. Int J Prod Econ 135:659–670
2. Ho HPY, Choi TM (2012) A five-R analysis for sustainable fashion supply chain management in Hong Kong: a case analysis. J Fash Mark Manag 16:161–175
3. Choi TM (2013) Local sourcing and fashion quick response system: the impacts of carbon footprint tax. Transportation Research–Part E. doi:10.1016/j.tre.2013.03.006
4. de Brito MP, Carbone V, Blanquart CM (2008) Towards a sustainable fashion retail supply chain in Europe: organisation and performance. Int J Prod Econ 114:534–553
5. Elmaghraby W, Gulcu A, Keskinocak P (2008) Designing optimal preannounced markdowns in the presence of rational customers with multiunit demands. Manuf Serv Oper Manag 10:126–148
6. Gemechu ED, Butnar I, Llop M, Castells F (2012) Environmental tax on products and services based on their carbon footprint: a case study of the pulp and paper sector. Energ Pol 50: 336–344
7. Hossein M, Zarandi F, Sisakht AH, DavariInt S (2012) Design of a closed-loop supply chain (CLSC) model using an interactive fuzzy goal programming. Int J Adv Manuf Technol 56:809–821
8. Hua G, Cheng TCE, Wang S (2011) Managing carbon footprints in inventory management. Int J Prod Econ 132:178–185
9. Larsen HN, Solli C, Pettersena J (2012) Supply chain management how can we reduce our energy/climate footprint? Energ Procedia 20:354–363
10. Lee KH (2011) Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry. J Clean Prod 19:1216–1223
11. Lo CKY, Yeung ACL, Cheng TCE (2012) The impact of environmental management systems on financial performance in fashion and textiles industries. Int J Prod Econ 135:561–567
12. Nagurney A, Yu M (2012) Sustainable fashion supply chain management under oligopolistic competition and brand differentiation. Int J Prod Econ 135:532–540
13. Pasternack BA (1985) Optimal pricing and returns policies for perishable commodities. Mark Sci 4:166–176
14. Perry P (2012) Exploring the influence of national cultural context on CSR implementation. J Fash Mark Manag 16:141–160
15. Aichele R, Felbermayr G (2012) Kyoto and the carbon footprint of nations. J Environ Econ Manag 63:336–354
16. Shen B, Choi TM, Wang Y, Lo CKY (2013) The coordination of fashion supply chains with a risk averse supplier under the markdown money policy. IEEE Transactions on Systems, Man, and Cybernetics– Systems 43:266–276
17. Song J, Leng M (2012) Analysis of the single-period problem under carbon emission policies. In: Choi TM (ed) Handbook of newsvendor problems: models, extensions and applications. Springer, New York, pp. 297–314
18. Sundarakani B, de Souza R, Goh M, Wagner SM, Manikandan S (2010) Modeling carbon footprints across the supply chain. Int J Prod Econ 128:43–50
19. Whang SJ (2009) Markdown competition. In: N Aggrawal and SA Smith (eds) Retail supply chain management. Springer, Boston, pp. 1–15
20. Bhattacharya R, Bandyopadhyay S (2011) A review of the causes of bullwhip effect in a supply chain. Int J Adv Manuf Technol 54:1245–1261
21. Cachon GP (2001) Supply chain coordination with contracts. Working paper, University of Pennsylvania
22. Chiu CH, Choi TM, Tang CS (2011) Price, rebate, and returns supply contracts for coordinating supply chains with price dependent demand. Prod Oper Manag 20:81–91
23. Yin R, Aviv Y, Pazgal A, Tang CS (2009) Optimal markdown pricing: implications of inventory display formats in the presence of strategic customers. Manag Sci 55:1391–1408
24. Marks and Spencer's Plan A Report: URL: http://plana.marksandspencer.com/media/pdf/how_we-do_business_report_2011.pdf. Accessed 4 Mar 2013.
25. Kenny T, Gray NF (2009) Comparative performance of six carbon footprint models for use in Ireland. Environ Impact Assess Rev 29:1–6
26. Choi TM (2013) Game theoretic analysis of a multi-period fashion supply chain with a risk averse retailer. International Journal of Inventory Research (in press)
27. Weber CL, Matthews HS (2008) Quantifying the global and distributional aspects of American household carbon footprint. Ecol Econ 66:379–391
28. Bocken NMP, Allwood JM (2012) Strategies to reduce the carbon footprint of consumer goods by influencing stakeholders. J Clean Prod 35:118–129
29. Fan J, Guo X, Marinova D, Wu Y, Zhao D (2012) Embedded carbon footprint of Chinese urban households: structure and changes. J Clean Prod 33:50–59
30. Rizet C, Browne M, Cornelis E, Leonardi J (2012) Assessing carbon footprint and energy efficiency in competing supply chains: review—case studies and benchmarking. Transp Res Part D: Transp Environ 17:293–300