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Personality information sharing in supply chain systems for innovative products in the circular economy era

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ABSTRACT

This research explores the value of personality information sharing in a two-tier supply chain of innovative products that have a short life cycle and no pollution to the environment. We analyse the behaviour of supply chain participants with one-shot decision theory and present an analysis of wholesale pricing for these products. We introduce the retailer's personality information sharing into our models and show the importance of personality information sharing in the wholesale price contract of the supply chain system. Theoretical analysis gains managerial insights into the strategic selection of the manufacturer when facing retailers with different personalities.

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Personality information sharing; wholesale price contract; supply chain system; one-shot decision theory; innovative products

1. Introduction

As fundamental research in supply chain management, a single manufacturer selling one product to a single retailer who faces a newsvendor problem has been extensively researched (e.g. Lariviere and Porteus 2001; Qin et al. 2011). Due to its simplicity, the wholesale price contract is wildly used in practice and has been studied in various aspects (e.g. Guo, Cheng, and Liu 2020; Korpeoglu, Körpeoğlu, and Cho 2020). During the past 30 years, there has been pressure on business to pay more attention to the environmental consequences of the products and services. Supply chain management for green products is drawing increasing interest from managers and researchers (e.g. Kleindorfer, Singhal, and Van Wassenhove 2005; Vachon 2007; Guo, Cheng, and Liu 2020). On the other hand, in the increasingly fierce competitive environment, innovation has become a core competency of industrial organisations. For example, the newly released 13-inch MacBook Air with Retina display is the first Mac enclosure made with 100% recycled aluminium (Apple Inc 2018). Hence, the combination of product innovation and environmental protection has grown up to be a modern society and enterprise research topic (De Miguel and Pazó 2017).

In this research, we consider a two-tier supply chain with a single manufacturer and a single retailer for an innovative green product. The term 'green' refers to the product that has less impact on the environmental or is less detrimental to human health than traditional products. The innovative product is the one that has an intrinsic one-time feature, that is, its life cycle is usually shorter than the procurement lead-time so that there is only one opportunity for a manufacturer/retailer to produce/order it (Fisher 1997). Clearly, for such an innovative green product, determining its optimal production/order quantity for the manufacturer/retailer is typically a one-shot decision problem.

In the existing supply chain contract models (see the reviews by Cachon 2003; Qin et al. 2011), the manufacturer/retailer seeks an optimal contract/order to maximise the expected utility. In these models, choosing a contract/order is equivalent to choosing a lottery (or probability distribution) so that all possible demands have to be taken into account when evaluating a contract/order. However, only one quantity of market demand will occur owing to the short life cycle of the innovative product. Existing models did not characterise this one-time feature of innovative products. In the past few decades, the value of information sharing in the supply chain has attracted much attention from practitioners and researchers, such as demand information sharing (Lee, Padmanabhan, and Whang 1997a, 1997b; Lee, So, and Tang 2000; Zhou and Benton 2007; Rached, Bahroun, and Campagne 2016), inventory data sharing

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(Chen 1998; Cachon and Fisher 2000; Rached, Bahroun, and Campagne 2016), and inventory cost information sharing (Dada and Srikanth 1987; Wang and Wu 2000). However, plenty of work pointed out that different personal characteristics of decision-makers lead to different supply chain performances (Su 2008; Qin et al. 2011). Although researchers have noticed the importance of individual differences in supply chain models, until now, the information sharing of participants' personal characteristics are still on 'virgin territory'. Therefore, we propose two research questions: (1) How to characterise the one-time feature of innovative products; (2) What is the impact of personality information sharing in the supply chain systems.

Guo (2011) initially proposed the one-shot decision theory (OSDT) for dealing with one-shot decision problems. Several kinds of one-shot decision-making problems have been researched (see, e.g. Guo 2010a, 2010b; Guo, Yan, and Wang 2010; Guo and Li 2014; Wang and Guo 2017; Ma 2019; Zhu and Guo 2020). Recently, Guo (2019) proposed the focus theory of choice (FTC) that is a generalisation of OSDT. Guo and Ma (2014) investigated newsvendor models for innovative products with the one-shot decision theory, the personalities of the newsvendors are characterised by which demand (scenario) the newsvendor is focused on with considering the likelihood (probability) of its occurrence as well as the satisfaction (payoff) associated with it.

Based on the OSDT, we build the wholesale price contract model for the manufacturer and the retailer in the supply chain for innovative green products. Our research aims to show the value of the participant's personality information sharing in the supply chain contracting processes. We consider the one-time feature of innovative green products and the personality information sharing as follows. For each production/order quantity, the manufacturer/retailer chooses at least one market demand among all possible demands while considering the satisfaction level caused by the occurrence of the demand and the likelihood of the demand occurring. The selected demand is called the focus point of the production/order quantity. The optimal production/order quantity corresponds to the maximum satisfaction level of its focus points. Four types of focus points are constructed to characterise different personalities of different retailers. The proposed models are focus-based, which are fundamentally different from the existing lottery-based models. The manufacturer's choice on the types of focus points reflects his/her strategy selection.

We build the wholesale price contract model with the OSDT, which fits the one-time feature of the decision related to innovative green products. In the proposed models, the manufacturer produces a kind of innovative green product and sells it to the retailer. Due to the characteristics of innovative products, there is no chance for the manufacturer to perform reproduction. With conjecturing the retailer's order quantity, the manufacturer charges a wholesale price of the product. After observing the wholesale price, the retailer who is facing uncertain demand needs to decide his/her order quantity. It is a typical Stackelberg game in the supply chain where the manufacturer acts as a leader and the retailer acts as a follower. The proposed model is different from Guo and Ma (2014)'s model in which there is only one decision maker-the retailer.

The remainder of this paper is organised as follows. In Section 2, we construct the models of personality information sharing of the supply chain in the structure of the Stackelberg game. In Section 3, we obtain the analysis results. Some summary of concluding remarks is given in Section 4.

2. Personality information sharing in the wholesale price contract of the supply chain system

2.1. OSDT-based newsvendor models for innovative green products

For the retailer, the wholesale price $w > 0$ is provided by the manufacturer. The retailer orders $q > 0$ units before the selling season. When the demand x is observed, the retailer sells units (limited by the supply q and the demand x) at the exogenous retail price r with $r \geq w$. If there is a shortage, the unit opportunity cost is $s_u > 0$.

The unsold products can be recycled directly from the retailer to the manufacturer at a price r_0, the unit value of them for the manufacturer is s_0 ($r_0 < s_0 < w$). The recycle rate of the unsold product is assumed to be a constant $\delta_0 \in [0, 1]$. $\delta_0 = 1$ means that unsold products are all recycled by the manufacturer. The sold products are recycled from the costumers to the manufacturer at a price r_1, the unit value of these products for the manufacturer is s_1 ($r_1 < s_1 < s_0$). We assume the recycle rate of the sold product is $\delta_1 \in [0, 1]$. The system is shown as Figure 1.

The demand of the innovative green product is assumed to be a random variable X with the probability density function $f(\cdot)$ and cumulative distribution function $H(\cdot)$. Denote the set of demand as $D \subseteq \mathbb{R}_+$. Since the set of uncertain demand is D, a reasonable order quantity should also lie in this region. For an observed value (a realisation) x of the random variable X, the retailer's profit function can be given as

$$v(x, q) := \begin{cases} rx + r_0\delta_0(q - x) - wq, & \text{if } x < q, \\ (r - w)q - s_u(x - q), & \text{if } x \geq q. \end{cases} \quad (1)$$

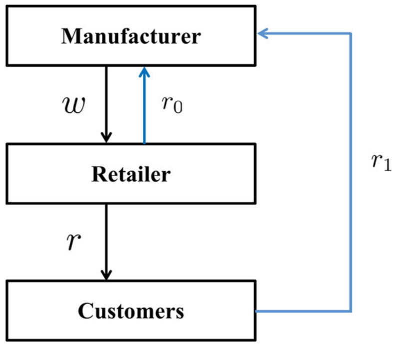

Figure 1. Recycle system of innovative green products.

Definition 2.1: Let V denote the range of the function (1) over the Cartesian product $D \times D$. The satisfaction function is the following strictly increasing function:

$$u : V \to [0, 1].$$

The satisfaction function is used to represent the relative position of the payoff. Because (1) is a function of x and q, we write the satisfaction function of the retailer as $u(x, q)$. For any $x \in D$ and $q \in D$, $u(x, q)$ is called the satisfaction level of q for x.

Definition 2.2: Given the probability density function $f : D \to \mathbb{R}_+$, a function $\pi : D \to [0, 1]$ is called the relative likelihood function if it satisfies that $\pi(x_1) > \pi(x_2) \Longleftrightarrow f(x_1) > f(x_2)$ for all $x_1, x_2 \in D$ and $\max_{x \in D} \pi(x) = 1$.

The relative likelihood function is used to represent the relative position of the probability of x. For any $x \in D$, $\pi(x)$ is called the relative likelihood degree of x. Clearly, the smaller the probability the smaller the relative likelihood degree. By normalising the original probability density function, we can give a simple relative likelihood function as follows:

$$\pi(x) := \frac{f(x) - \min_{y \in D} f(y)}{\max_{y \in D} f(y) - \min_{y \in D} f(y)}. \tag{2}$$

Since we consider the innovative green product with a short life cycle (the life cycle is generally shorter than the procurement lead-time), there is only one chance for the retailer to determine the order quantity and only one demand will appear. It is reasonable for the retailer to contemplate which demand ought to be taken into account before making the order decision. Considering the relative likelihood degree and the satisfaction level, we take into account four types of demands (scenarios) for each order quantity, that is the demands with a higher satisfaction and a higher likelihood (Type A), a lower satisfaction and a higher likelihood (Type B), a higher satisfaction and a lower likelihood (Type C), a lower satisfaction and a lower likelihood (Type D). It is intuitively acceptable that active, passive, daring and apprehensive retailers are inclined to take into account Type A, Type B, Type C and Type D demands, respectively. Therefore, Type A, Type B, Type C and Type D demands are called as active, passive, daring and apprehensive focus points, respectively (shown in Table 1).

Table 1. Four types of focus points.

Focus point	Likelihood	Satisfaction
Active	Higher	Higher
Passive	Higher	Lower
Daring	Lower	Higher
Apprehensive	Lower	Lower

Definition 2.3 (Guo and Ma 2014): Given a vector $[z_1, z_2, \ldots, z_n]$, $\min[z_1, z_2, \ldots, z_n]$ and $\max[z_1, z_2, \ldots, z_n]$ are defined as follows:

$$\begin{aligned} &\min[z_1, z_2, \ldots, z_n] \\ &\quad := [\wedge_{i=1,\ldots,n} z_i, \wedge_{i=1,\ldots,n} z_i, \ldots, \wedge_{i=1,\ldots,n} z_i], \end{aligned} \tag{3}$$

$$\begin{aligned} &\max[z_1, z_2, \ldots, z_n] \\ &\quad := [\vee_{i=1,\ldots,n} z_i, \vee_{i=1,\ldots,n} z_i, \ldots, \vee_{i=1,\ldots,n} z_i]. \end{aligned} \tag{4}$$

(3) and (4) represent the lower and upper bounds of $[z_1, z_2, \ldots, z_n]$, respectively. For example, the relative likelihood degree and the satisfaction level of a state x are 0.3 and 0.8, respectively, which is represented as the vector $[0.3, 0.8]$. We have $\min[0.3, 0.8] = [0.3, 0.3]$ represents that x has at least 0.3 relative likelihood degree and 0.3 satisfaction level and $\max[0.3, 0.8] = [0.8, 0.8]$ represents that x has at most 0.8 relative likelihood degree and 0.8 satisfaction level.

Next, we introduce how to obtain four types of focus points (Guo and Ma 2014).

Active focus point: The active focus point of the order quantity q is

$$x_1(q) \in \arg\max_{x \in D} \min[\pi(x), u(x, q)]. \tag{5}$$

Passive focus point: The passive focus point of the order quantity q is

$$x_2(q) \in \arg\max_{x \in D} \min[\pi(x), 1 - u(x, q)]. \tag{6}$$

Apprehensive focus point: The apprehensive focus point of the order quantity q is

$$x_3(q) \in \arg\min_{x \in D} \max[\pi(x), u(x, q)]. \tag{7}$$

Daring focus point: The daring focus point of the order quantity q is

$$x_4(q) \in \arg\min_{x \in D} \max[\pi(x), 1 - u(x, q)]. \tag{8}$$

Comment 1. (5), (6), (7) and (8) are presenting the demands that have the higher relative likelihood degree and the higher satisfaction level, the higher relative likelihood degree and the lower satisfaction level, the lower relative likelihood degree and the lower satisfaction level, the lower relative likelihood degree and the higher satisfaction level, respectively. From (5), we know that no other $[\pi(x), u(x,q)]$ both satisfies $\pi(x) > \pi(x_1(q))$ and $u(x,q) > u(x_1(q),q)$, similar results can be obtained for (6) to (8). It means that $x_1(q)$, $x_2(q)$, $x_3(q)$ and $x_4(q)$ are Pareto optimal solutions of the above four bi-objective optimisation problems, respectively. In other words, for any q no demand can cause a higher satisfaction with a higher relative likelihood than its active focus point $x_1(q)$; no demand can provide an even lower satisfaction with an even higher relative likelihood than its passive focus point $x_2(q)$; no demand can lead to an even lower satisfaction with an even lower relative likelihood than its apprehensive focus point $x_3(q)$; no demand can generate an even higher satisfaction with an even lower relative likelihood degree than its daring focus point $x_4(q)$. For one order quantity, more than one demand might exist as a particular type of focus point, therefore we denote the sets of four types of focus points of an alternative q as $X_1(q)$, $X_2(q)$, $X_3(q)$ and $X_4(q)$, respectively.

In the newsvendor problem, the retailer regards the focus point as his/her most appropriate demand and chooses one order quantity which can bring about the best consequence (highest satisfaction level) once the focus point comes true. The optimal order quantities for active, passive, apprehensive and daring retailers are as follows:

$$q_1 \in \arg\max_{q \in D} \max_{x_1(q) \in X_1(q)} u\big(x_1(q), q\big), \tag{9}$$

$$q_2 \in \arg\max_{q \in D} \min_{x_2(q) \in X_2(q)} u\big(x_2(q), q\big), \tag{10}$$

$$q_3 \in \arg\max_{q \in D} \min_{x_3(q) \in X_3(q)} u\big(x_3(q), q\big), \tag{11}$$

$$q_4 \in \arg\max_{q \in D} \max_{x_4(q) \in X_4(q)} u\big(x_4(q), q\big). \tag{12}$$

q_1, q_2, q_3 and q_4 are called optimal active, passive, apprehensive and daring order quantities, respectively. It should be noted that the optimal orders are obtained only based on the satisfaction levels of the focus points. In conclusion, the retailer's order quantity decision is assumed to follow one of the behaviour styles described above.

2.2. Stackelberg games in the supply chain of innovative green products

In this section, two types of supply chains are examined: make-to-order and make-to-stock. (1) In the make-to-order supply chain, the manufacturer performs production after the retailer's ordering decision. In this case, there is no demand uncertainty for the manufacturer. (2) In the make-to-stock supply chain, the manufacturer executes production before the retailer's ordering decision. In this case, if the manufacturer's production quantity is more than the retailer's order, the unsold products will be recycled; otherwise, he/she will suffer an opportunity cost.

2.2.1. Make-to-order supply chain

We introduce the models of Stackelberg game in the make-to-order supply chain. A manufacturer produces a kind of innovative green product and sells it to a retailer. The manufacturer's production cost is assumed to be c_p, where $w > c_p > s_0$. The manufacturer acts as a Stackelberg leader, offering the wholesale price w. The retailer's behaviour (order quantity) follows one of the behaviour styles described in Section 2.1. With conjecturing the retailer's order quantity q, the manufacturer charges an optimal wholesale price by maximising his/her profit (net value). After observing w, the retailer, who is the Stackelberg follower, places an optimal order quantity, which maximises his/her own satisfaction level.

For the wholesale price contract w, the retailer's optimal response $q_1(w)$, $q_2(w)$, $q_3(w)$ or $q_4(w)$ is obtained by (9), (10), (11) or (12). Thus, the profit function of the manufacturer who is facing active, passive, apprehensive or daring retailer is

$$F\big(w, q_i(w)\big) = (w - c_p)q_i(w) + v_r \delta q_i(w), \quad i = 1, 2, 3 \text{ or } 4. \tag{13}$$

δ is the total recycle rate for the MTO supply chain, which is usually estimated by the historical data of similar products. The total recycled quantity contains two parts: the one of unsold products and the one of sold products. v_r is the unit profit that the manufacturer earns from the recycling (assume the manufacturer earns the same unit profit from the two types of recycling, that is, $s_0 - r_0 = s_1 - r_1 = v_r$).

The manufacturer's optimal wholesale prices when he/she is facing different retailers are as follows:

$$w_i^* \in \arg\max_{w} F\big(w, q_i(w)\big), \quad i = 1, 2, 3 \text{ or } 4. \tag{14}$$

w_1^*, w_2^*, w_3^* and w_4^* are the optimal wholesale prices of the manufacturer when he/she is facing active, passive, apprehensive and daring retailers, respectively.

The profit function of the whole supply chain when the manufacturer is facing active, passive, apprehensive or daring retailer is as follows:

$$\Omega_i^* = \begin{cases} \left(r - c_p + v_r\delta\right) q_i\left(w_i^*\right) \\ \quad -c_p\Big(q_i\left(w_i^*\right) - x_i\big(q_i(w_i^*)\big)\Big), \\ \qquad\qquad \text{if } q_i\left(w_i^*\right) \geq x_i\big(q_i(w_i^*)\big), \\ \left(r - c_p + v_r\delta\right) q_i\left(w_i^*\right) \\ \quad -s_u\Big(x_i\big(q_i(w_i^*)\big) - q_i\left(w_i^*\right)\Big), \\ \qquad\qquad \text{if } q_i\left(w_i^*\right) < x_i\big(q_i(w_i^*)\big), \end{cases} \tag{15}$$

where $i = 1, 2, 3$ or 4. Ω_1^*, Ω_2^*, Ω_3^* and Ω_4^* are called the optimal active, passive, apprehensive and daring profits, respectively.

2.2.2. Make-to-stock supply chain

Due to the short life cycles of such products, there is no chance for the manufacturer to perform reproduction. With conjecturing the retailer's order quantity, the manufacturer charges a wholesale price of the product. After observing the wholesale price, the retailer who is facing uncertain demand needs to decide his/her order quantity. Facing the retailers with different personalities, the manufacturer selects a strategy and its corresponding optimal wholesale price contract to coordinate the supply chain (production quantity equals to order quantity).

In this make-to-stock supply chain, the manufacturer needs to predict the retailer's behaviour and decides a production quantity in advance. The profit function of the whole supply chain becomes

$$G(x,p) = \begin{cases} rx + s_0(p - x) + v_r\delta_1 x - c_p p, & \text{if } x < p, \\ (r - c_p)p + v_r\delta_1 p - s_u^M(x - p), & \text{if } x \geq p, \end{cases} \tag{16}$$

where x is the market demand, p is the production quantity, s_0 is the unit salvage price, s_u^M is the unit opportunity cost, $c_p \in (s_0, w)$ is the production cost, δ_1 is the recycle rate of sold products and v_r is the unit profit that the manufacturer earns from the recycling. The satisfaction function of the integrated manufacturer is written as $u_G(x,p)$.

Similar as Section 2.1, there are active, passive, apprehensive and daring focus points leading to active, passive, apprehensive and daring production quantities, i.e. p_1, p_2, p_3 and p_4, which represent active, passive, apprehensive and daring strategies, respectively.

3. Analysis results

In order to perform the analysis conveniently, we assume the following demand probability distribution. The information of the demand probability distribution is regarded as the shared knowledge between the manufacturer and the retailer. From now on, the analysis in this paper is following Assumption 3.1.

Assumption 3.1: The probability density function $f(x)$ is continuous and strictly quasi-concave on the interval $D = [d_l, d_u]$, the mode is $d_c \in (d_l, d_u)$ and $f(d_l) = f(d_u)$.

Clearly, $f(x)$ is strictly increasing in $[d_l, d_c]$ and strictly decreasing in $[d_c, d_u]$. Note that we generalise our assumption as far as possible, several of common demand distributions, including triangular distribution, truncated (logarithmic) normal distribution and truncated gamma distribution, are all satisfied Assumption 3.1.

3.1. Analysis results of the newsvendor model

Proposition 3.1 (Guo and Ma 2014): *With the increasing of the wholesale price w, the optimal active order quantity is decreasing, the optimal apprehensive and daring order quantities are keeping the same.*

Comment 2 (Comparison with the lottery-based newsvendor models). In the lottery-based newsvendor models, for the risk neutral retailer, the optimal order quantity q^* is determined by the following equation:

$$H(q^*) = \frac{r - w + s_u}{r - r_0\delta_0 + s_u}. \tag{17}$$

The risk averse and risk seeking newsvendor models have the same monotonicity with the risk neutral newsvendor model.

The relationship between the wholesale price and the optimal passive order quantity is depending on the setting of parameters. Table 2 gives the sensitivity analysis for newsvendors with different behaviour styles (Guo and Ma 2014).

3.2. Analysis results of the make-to-order (MTO) supply chain

By Definition 2.1, we set the satisfaction function of the retailer as

$$u(w,x,q) = \frac{v(x,q) - v_l(w)}{v_u(w) - v_l(w)}. \tag{18}$$

$v_u(w)$ and $v_l(w)$ are the retailer's highest and lowest profit, respectively, which are obtained as follows:

$$v_u(w) = (r - w)d_u. \tag{19}$$

$$v_l(w) = d_l r + (d_u - d_l)\, s_0 - d_u w, \ \left(\text{supposing } w \geq s_0 + s_u\right). \tag{20}$$

Table 2. Sensitivity analysis for different newsvendors.

Parameters	Lottery-based Newsvendor	OSDT-based Newsvendor (active)	OSDT-based Newsvendor (passive)	OSDT-based Newsvendor (apprehensive)	OSDT-based Newsvendor (daring)
r	Increasing	Increasing	$+/-$	Decreasing	No effect
w	Decreasing	Decreasing	$+/-$	No effect	No effect
r_0	Increasing	No effect	$+/-$	Increasing	No effect
s_u	Increasing	No effect	Increasing	Increasing	No effect

In the following, we analyse the MTO supply chain with the retailer's personality information sharing.

Proposition 3.2: *Suppose that the relative likelihood function π is continuously differentiable on (d_c, d_u). When the manufacturer faces an active retailer, the manufacturer's profit function $F(w, q_1(w)) = wq_1(w)$ is strictly concave about the wholesale price w.*

From Proposition 3.2, we know that facing an active retailer, there exists a unique wholesale price w^* that maximises the manufacturer's profit. When the manufacturer faces a passive retailer, we have Proposition 3 as follows.

Proposition 3.3: *Suppose that the relative likelihood function π is symmetric about the line $x = d_c$ and continuously differentiable on both (d_l, d_c) and (d_c, d_u). When the manufacturer faces a passive retailer, the manufacturer's profit function $F(w, q_2(w)) = wq_2(w)$ is strictly concave about the wholesale price w.*

Proposition 3.4: *When the manufacturer is facing an apprehensive or a daring retailer, he/she always sets the wholesale price equal to the retail price and obtains the whole profit in the supply chain.*

From Proposition 3.4, we see that the MTO supply chain is coordinated by the personality information sharing when the manufacturer is facing apprehensive or daring retailers. From Propositions 3.2, 3.3 and 3.4, we find that there are optimal wholesale prices for the manufacturer facing different types of retailers, which lead to different imaged profits of the supply chain. We would like to check the relationships of the imaged profits in the following proposition.

Proposition 3.5: *Suppose that the relative likelihood function π is symmetric about the line $x = d_c$. The imaged profits of the supply chain when the manufacturer is facing different types of retailers have the following relationship:*

$$\Omega_3^* < \Omega_2^* < \Omega_1^* < \Omega_4^*. \tag{21}$$

3.3. Analysis results of the make-to-stock (MTS) supply chain

In the MTS supply chain system, the manufacturer performs the production before any orders are made by the retailer, therefore it is not trivial for the supply chain to be coordinated, e.g. the production quantity equals to the order quantity. However, if the personality information of the retailer is a common knowledge, the manufacturer may predict the behaviour of the retailer and the channel coordination could happen in some cases.

Proposition 3.6: *If $\pi(\cdot)$ and $u_G(\cdot, p)$ are continuously differentiable on (d_c, d_u), there is a unique $w \in (c_p, r)$ satisfying $q_1(w) = p_2$.*

Proposition 3.6 indicates that when the manufacturer faces an active retailer, the passive manufacturer can coordinate the supply chain. When the manufacturer faces a passive retailer, we have Proposition 3.7 as follows.

Proposition 3.7: *When the manufacturer is facing a passive retailer, no strategy can surely coordinate the supply chain.*

From Proposition 3.1, the wholesale price has no effect on apprehensive and daring order quantities, we obtain the following Proposition 3.8.

Proposition 3.8: *When the manufacturer is facing apprehensive/daring retailers, the apprehensive/daring strategy can coordinate the supply chain.*

From Propositions 3.6, 3.7 and 3.8, we see that with the personality of the retailer as a common knowledge, there is a certain strategy to coordinate the supply chain if the manufacturer is facing active, apprehensive or daring retailers.

Comment 3. Generally speaking, the wholesale price contract is not considered to be a coordinating contract (as discussed by Cachon 2003). This problem is also called double marginalisation (Spengler 1950). However, with the personality information sharing, the problem can be solved in the supply chain systems with active, apprehensive and daring retailers (as shown in Propositions 3.6, 3.7 and 3.8). In other words, with the personality information sharing, the wholesale price contract in some situations could coordinate the supply chain. These results provide a novel angle of view to study the wholesale-price contract.

3.4. The comparison between MTO and MTS supply chain systems

We perform the comparison of MTO and MTS supply chain systems under two conditions: with personality information sharing and without personality information sharing. First, let us see the result when the personality information of the retailer is common knowledge in the supply chain system.

Proposition 3.9: *With personality information sharing, MTO and MTS supply chain systems perform the same functions.*

Proposition 3.9 tells that with the information sharing of the retailer's personality, we can have the same profit and production quantity in MTO and MTS supply chain systems. Next, let us see the result when the personality information of the retailer is not a common knowledge in the supply chain system.

Proposition 3.10: *Without the personality information sharing, the MTO supply chain system performs better than the MTS supply chain system.*

Proposition 3.10 tells that without the information sharing of the retailer's personality, the MTO supply chain earns more profit than the MTS supply chain and there is a mismatch between the production quantity and order quantity in the MTS supply chain system.

4. Conclusions

In this research, the wholesale price contract in a two-tier supply chain of the recyclable innovative product with the short life cycle is investigated. We analyse the behaviours of supply chain participants and the personalities information sharing based on the one-shot decision theory. Stackelberg equilibrium is proposed to analyse the optimal wholesale price of the manufacturer and the optimal order quantity of the retailer both in make-to-order (MTO) and make-to-stock (MTS) supply chains. Different types of retailers, called active, passive, apprehensive and daring retailers, lead to different Stackelberg equilibrium. The analysis results show the importance of personality information sharing in the wholesale price contract.

There are several contributions that distinguish this research from the previous work. First, the personality information sharing is for the first time studied in the supply chain system. Second, the Stackelberg game analysis is first conducted with one-shot decision theory for the supply chain contracting problem. The models describe the differences of the supply chain participants' personalities. Third, managerial insights into the values of the personality information sharing in the supply chain performance and behaviours of the manufacturer and the retailer are also obtained. Specifically, in the MTO supply chain, when the manufacturer faces an active or a passive retailer, there is a wholesale price contract to optimise the manufacturer's profit; when the manufacturer faces an apprehensive or a daring retailer, the manufacturer's optimal wholesale price equals to the retail price and the whole profit in the supply chain goes to the manufacturer. Also, the total imaged profit of the supply chain is decreasing for the manufacturer from facing the daring retailer to the active retailer, the passive retailer and the apprehensive retailer.

We show that in the MTS supply chain with the retailer's personality as a common knowledge, when the manufacturer faces an active retailer, the passive manufacturer can coordinate the supply chain; when the manufacturer is facing a passive retailer, no type of manufacturer can surely coordinate the supply chain; when the manufacturer faces apprehensive/daring retailers, the apprehensive/daring manufacturer can coordinate the supply chain. MTO and MTS supply chain systems are also compared. We found that the MTO and MTS supply chain systems perform the same functions with personality information sharing. On the other hand, the MTO supply chain system performs better than the MTS supply chain system without the personality information sharing. Therefore, we suggest the application of personality information sharing in the MTS supply chain system, especially when the manufacturer is facing the active, apprehensive or daring retailer.

This work can be extended along with several directions. First, the supply chain system is constructed with the wholesale price contract, an extension of this work can be devoted to other forms of contracts. Second, we assume there is only one innovative product in the supply chain, a natural extension of this research is to study alternative products and their effects to the supply chain performance. Third, this research focuses on the two-tier supply chain with one manufacturer and one retailer, a more complicated supply chain including more participants deserves further investigation.

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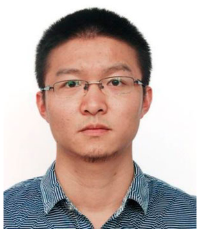

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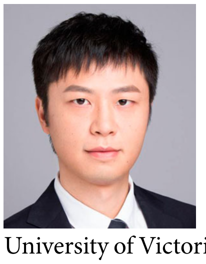

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Appendix

Proof of Proposition 3.1: The details of the proof can be found in Guo and Ma (2014). ■

Proof of Proposition 3.2: According to Lemma 15 as shown in Guo and Ma (2014), the optimal order quantity for active retailer q_1 is singleton and it is the solution of following equation:

$$u(w,q,q)-\pi(q)=0,\quad q\in(d_c,d_u). \tag{A1}$$

The optimal active focus point, i.e. $x_1(q_1)$, is equal to q_1.

Since $q\in(d_c,d_u)$, with considering (1), (2) and Definition 2.1, we have

$$\pi'(q)<0, \tag{A2}$$

$$\frac{\partial u(w,q,q)}{\partial q}=\frac{r-w}{(d_u-d_l)\,(r-r_0\delta_0)}>0, \tag{A3}$$

$$\frac{\partial u(w,q,q)}{\partial w}=\frac{d_u-q}{(d_u-d_l)\,(r-r_0\delta_0)}>0, \tag{A4}$$

$$\frac{\partial^2 u(w,q,q)}{\partial w^2}=0, \tag{A5}$$

$$\frac{\partial^2 u(w,x,x)}{\partial x\partial w}=\frac{-1}{(d_u-d_l)\,(r-r_0\delta_0)}<0. \tag{A6}$$

Using the implicit function theorem to (A1), we have

$$\frac{\partial u(w,q,q)}{\partial w}+\left(\frac{\partial u(w,q,q)}{\partial q}-\pi'(q)\right)q_1'(w)=0, \tag{A7}$$

which leads to

$$q_1''(w)=\frac{\frac{\partial^2 u(w,q,q)}{\partial w^2}\left(\frac{\partial u(w,q,q)}{\partial q}-\pi'(x)\right)-\frac{\partial u(w,q,q)}{\partial w}\frac{\partial^2 u(w,q,q)}{\partial q\partial w}}{\left(\frac{\partial u(w,q,q)}{\partial q}-\pi'(q)\right)^2}. \tag{A8}$$

From (15), we have

$$F''\big(w,q_1(w)\big)=2q_1'(w)+(w-c_p)q_1''(w). \tag{A9}$$

From (A2) to (A9), we obtain $F''(w,q_1(w))<0$. ■

Proof of Proposition 3.3: According to Lemma 16 shown in Guo and Ma (2014), the optimal order quantity for passive retailer q_2 is singleton and it is the solution of following equation:

$$u\big(w,d_{pl}(q),q\big)-u\big(w,d_{pu}(q),q\big)=0, \tag{A10}$$

where $d_{pl}(q)$ and $d_{pu}(q)$ are the solutions of $u(w,x,q)=1-\pi(x)$ within $[d_l,\min(q,d_c)]$ and $[\max(q,d_c),d_u]$, respectively. The optimal passive focus point, i.e. $x_2(q_2)$ is $d_{pl}(q_2)$ or $d_{pu}(q_2)$.

Using the implicit function theorem to (A10), we have

$$\frac{\partial\pi\left(d_{pl}(w,q)\right)-\partial\pi\left(d_{pu}(w,q)\right)}{\partial w}+\frac{\partial\pi\left(d_{pl}(w,q)\right)-\partial\pi\left(d_{pu}(w,q)\right)}{\partial q}q_2'(w)=0, \tag{A11}$$

which leads to

$$q_2''(w)=-\frac{\frac{\partial\pi\left(d_{pl}(w,q)\right)-\partial\pi\left(d_{pu}(w,q)\right)}{\partial w}\,\frac{\partial^2\pi\left(d_{pu}(w,q)\right)-\partial^2\pi\left(d_{pl}(w,q)\right)}{\partial q\partial w}}{\left(\frac{\partial\pi\left(d_{pu}(w,q)\right)-\partial\pi\left(d_{pl}(w,q)\right)}{\partial q}\right)^2}. \tag{A12}$$

With considering (1), (2) and Definition 2.1, we have $q_2'(w)<0$ and $q_2''(w)<0$, which lead to

$$F''\big(w,q_2(w)\big)=2q_2'(w)+(w-c_p)q_2''(w)<0. \tag{A13}$$

This completes the proof. ■

Proof of Proposition 3.4: According to Lemma 17 shown in Guo and Ma (2014), the optimal order quantity for apprehensive retailer $q_3=((r-r_0\delta_0)d_l+s_ud_u)/(r-r_0\delta_0+s_u)$, which is not related with the wholesale price w. Recalling the profit functions of the manufacturer (13), we know that the optimal wholesale price for the manufacturer is the retail price r, that is also the upper bound of the wholesale price. Similar result can be obtained for the daring retailer. ■

Proof of Proposition 3.5: According to Lemma 19 shown in Guo and Ma (2014), the optimal order quantities for four types of retailers have the following relationships:

$$q_3<q_2<q_1<q_4. \tag{A14}$$

Recalling the profit functions of the whole supply chain (15), we know the imaged profits of the supply chains $\Omega_3^*<\Omega_2^*<\Omega_1^*<\Omega_4^*$. ■

Proof of Proposition 3.6: Using the implicit function theorem, we know that $q_1(w)$ is a continuously differentiable function of w, and $q_1'(w) < 0$. With considering Lemma 19 in Guo and Ma (2014), we know that there is a unique $w \in (c_p, r)$ which satisfies $q_1(w) = p_2$. ■

Proof of Proposition 3.7: From Table 2, we can see that with the changing of the wholesale price, the changes of the passive order quantity are depending on the setting of parameters. Therefore, there is no unique wholesale price w to make the production quantity equal to the order quantity. That is, when the manufacturer is facing the passive retailer, no strategy can surely coordinate the supply chain. ■

Proof of Proposition 3.8: According to Lemmas 17 and 18 shown in Guo and Ma (2014), the optimal order quantity for apprehensive retailer $q_3 = ((r - r_0\delta_0)d_l + s_u d_u)/(r - r_0\delta_0 + s_u)$ and the optimal order quantity for the daring retailer $q_4 = d_u$. Therefore, the wholesale price has no effect on apprehensive and daring order quantities. Similar results can be obtained for the apprehensive and daring production quantities. That is, when the manufacturer is facing the apprehensive/daring retailer, the apprehensive/daring strategy can coordinate the supply chain. ■

Proof of Proposition 3.9: Suppose the manufacturer is facing an active retailer, first let us consider the MTO supply chain system. From (A1), the active retailer's order quantity $q_1(w^*)$ satisfies

$$u\big(w^*, q_1(w^*), q_1(w^*)\big) - \pi\big(q_1(w^*)\big) = 0,\ q_1(w^*) \in (d_c, d_u). \tag{A15}$$

Meanwhile, in the MTS supply chain system, knowing the retailer's type of personality is active, the manufacturer's production quantity $p_1(w_p^*)$ also satisfies Equation (A15), therefore, we have $w^* = w_p^*$ and $q_1(w^*) = p_1(w_p^*)$. In other words, the MTO and MTS supply chain systems perform the same. Similar results can be obtained for other types of retailers. ■

Proof of Proposition 3.10: Suppose the manufacturer is facing an active retailer, first let us consider the MTO supply chain system. Similar as the proof in Proposition 3.9, the active retailer's order quantity $q_1(w^*)$ still satisfies Equation (A15). Meanwhile, in the MTS supply chain system, without the information of the retailer's type of personality, the manufacturer images the retailer is risk-neutral and perform the production in advance and the production quantity p^* satisfies Equation (17). Immediately, we know $q_1(w^*) = p^*$ and $\Omega_1^* > G_1^*$. ■