Influences of Supply Chain Finance on the Mass Customization Program: Risk Attitudes and Cash Flow Shortage

Shu Guo
Management School, University of Liverpool, Liverpool, United Kingdom
Na Liu[1]
Business School, Beijing Institute of Fashion Technology, Beijing, China.

Abstract: In recent years, with the addresses on satisfying diversified customer needs in the target market, an increasing number of brands has launched mass customization (MC) programs as one of their core operations strategies. The flexibility of the production process and the personalization degree of the custom-made products (i.e., the MC products) have thus become as the key to success of the MC schemes. In the meantime, however, considering the high market uncertainty in consumer preferences and the challenges from the production process, there are plenty of risks in MC operations. In this paper, therefore, we develop a game theoretic model consisting of a MC brand and an upstream manufacturer, and aim to identify the influences of supply chain finance on the MC programs. The influences brought by the risk attitudes of both the MC brand and the manufacturer are analyzed. Besides, an extra interest rate for raising the working capital for production (e.g., from the bank) at the manufacturing level is also considered in this paper for addressing the cash flow shortage impacts. We find that when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high, the optimal product modularity level of the MC product is increasing with the MC brand's degree of risk averse. In addition, it can also be observed that when both the market demand's positive sensitivity to the modularity level of the MC product and the MC brand's opportunity cost rate for placing the advance order are sufficiently high, any increase in the risk averse degree of the MC brand or the manufacturer will lower the manufacturer's optimal wholesale price of the MC product as well as the MC brand's optimal rate of the advance order. Furthermore, the higher the interest that the manufacturer needs to pay (e.g., to the bank) for raising the working capital for the MC production process, the lower the optimal wholesale price of each finished MC product will be so as to help the manufacturer raise more money through the advance order from the MC brand. These findings complete the findings in extant literature and provide important managerial insights in managing MC operations.

Keywords: Supply Chain Finance, Mass Customization, Cash Flow Shortage, Risk Attitudes

[1] Corresponding author: sxyln@bift.edu.cn

1. Introduction

1.1. Background and Motivation

Spurred by the growth of Internet and related technologies, mass customization (MC) has been extensively deployed by many leading companies from various industries, which is a concept proposed quite a few years ago. In “Future Shock”, Toffler (1970) firstly proposed an innovative idea, which can meet the specified requirements of customers with the cost very close to the standardized production. After that, Davis (1989) named the concept of this mode as mass customization (MC) in “Future Perfect” and describes MC as ‘‘a world of paradox with very practical implications’’. It is deemed to be the creation of MC, and nowadays MC is widely known as a strategy based on the hybrid combination of both mass production (MP) and pure customization (PC). Some typical industry examples of MC are automotive (Audi, Chryslers and BMW), apparel (Brooks Brother, Benetton, Lands’ End, and Second Skin Swimwear), footwear (NikeiD, mi Adidas, Vans, and Custom Foot), luxury (Cartier, Louis Vuitton, Burberry), computer (HP and Dell), consumer goods (Proctor and Gamble), food (M&M’s), finance and insurance (MetaCapitalism) (Yeung et al. 2010; Liu et al. 2012; Liu et al. 2018).

In the MP process of MC, given the advantages of scale of economy (i.e., the large scale of the production volume), the cost is usually relatively low. In the PC process, however, due to the large variety of requirements on customization, the cost is always much higher than the MP process, which correspondingly leads to a high overall cost level of MC schemes (Mukhopadhyay and Setoputro 2005; Liu et al. 2012). Consequently, as we can observed from industry, an MC program requires huge amount of investments like the investments on various advanced technologies, such like computer aided design (CAD), computer aided manufacturing (CAM), big data, cloud computing, flexible manufacturing system (FMS), customization platform, as well as the other aspects like human resources. In practice, this requirement of huge amount of investments can be observed from the MC companies like Kutesmart, which is an MC fashion company in China (Liu et al. 2018) and have invested about 368 million RMB for the MC platform in 2018[2]. Therefore, it is obvious that adopting MC requires substantial financial investments (Sandrin et al. 2018), which will be used to purchase the advanced manufacturing systems, investing in new design technology such as virtual reality and multimedia technology, implementing integrated information systems, and so forth. In the meantime, although the latest IT developments sharply help increase the efficiency and performance of the MC programs like help improve the manufacturing systems for MC, a big and urgent barrier also occur, referring to both the requirements on the huge amount of financial resources (Sandrin et al. 2018). Consequently, some MC manufacturers with limited operations capital, especially small and medium-sized enterprises (SMEs) MC producers, may need to seek financial support from bank or other institutes to support their production activities for MC programs. The supply chain financing problem, therefore, have emerged in recent years among various literature and industries (Tang et al., 2017).

In the meantime, the high requirements on the huge amount of financial resources for MC schemes (e.g., the extra costs spent on the production and inventory management of components and the opportunity costs of advanced high capital investments in MC productions (Agrawal et al. 2001, Reichwald et al. 2003) also lead to high operations risks of involved supply chain members. Especially, for some SMEs, which may suffer from cash flow shortage (Chen and Zhang 2019), considerable risks can be induced in operations like the production process. For example, when an MC garment manufacturer received a millions-dollar order from the retailer, and the retailer paid a certain proportion of the deposit. Thus, the manufacturer must fulfill the order from the retailer according to the contract. However, the manufacturer did not have enough raw material (fabric) to produce this batch of garments. Due to the limited time constraint and lack of raw materials, the manufacturer has to purchase in the market immediately. As the huge investments have been devoted and it may seek help from the financial institutes. Thus, the MC manufacturer faced with higher costs including both

[2]http://www.jimo.gov.cn/n3201/n3234/n3241/180109185709082231.html [accessed in 28 December, 2018]

the procurement cost of raw materials and the interest paid to the financial institutes. Consequently, the uncertainties caused by the market demand and other sources, make the MC manufacturer faced with financial risk. Besides, as addressed by Piller et al. (2004) based on the MC cases of Adidas and Nike, a higher degree of product modularity level can always bring a higher level of the product costs of the MC schemes. All of these points shown above make the consideration of operations risks a more crucial issue to the MC schemes and deserve deep investigation, especially under the case with the participation of SMEs and the product modularity holds significance influences.

Motivated by the popularity of MC in practice and the importance of supply chain finance on MC operations, in this paper, we develop a game theoretic model consisting of a MC brand and an upstream manufacturer to identify the influences of supply chain finance on the MC programs. The influences brought by the risk attitudes of both the MC brand and the manufacturer are analyzed. Besides, an extra interest rate for raising the working capital for production (e.g., from the bank) at the manufacturing level is also considered. Notice that considering the manufacturer is the Stackelberg leader is this paper, for the discussions on the influences of capital constraints, we only explore the case on the manufacturer instead of the MC brand. This is because that the MC brand, as a Stackelberg follower only, has no dominant power in the cooperative relationship with the manufacturer. Accordingly, the influences brought by the manufacturer's capital constraints is much more important in this paper. To the best of our knowledge, this paper is the first analytical work to study the influences of supply chain finance on the mass customization program, with the focuses on both risk attitudes and cash flow shortage. To be specific, we aim to address the following three research questions:

(1) What are the optimal modularity level and optimal wholesale price of the MC product under the consideration of both the risk attitudes of supply chain members and cash flow shortage in the manufacturing level? How about the optimal rate of the advance order placed by the MC brand?

(2) What are the influences of the risk attitudes of supply chain members?

(3) What are the influences of cash flow shortage in the manufacturing level?

In this paper, we find that when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high, the optimal product modularity level of the MC product is increasing with the MC brand's degree of risk averse. In addition, it can also be observed that when both the market demand's positive sensitivity to the modularity level of the MC product and the MC brand's opportunity cost rate for placing the advance order is sufficiently high, any increase in the risk averse degree of the MC brand or the manufacturer will lower the manufacturer's optimal wholesale price of the MC product as well as the MC brand's optimal rate of the advance order. Furthermore, the higher the interest that the manufacturer needs to pay (e.g., to the bank) for raising the working capital, the lower the optimal wholesale price of each finished MC product will be so as to help the manufacturer raise more money from the advance order from the MC brand. All these findings highlight the significant influences of both the risk attitudes of supply chain members and cash flow shortage in the manufacturing level, which complete the findings in extant literature and provide important managerial insights in managing MC operations.

1.2. Contribution Statements and Organization

To the best of our knowledge, this paper is the first analytical work to study the influences of supply chain finance on the mass customization program, with the focuses on the influence of both risk attitudes and cash flow shortage. The significant influences of both the risk attitudes of supply chain members and cash flow shortage in the manufacturing level are revealed. Besides, the findings in this paper not only complete the findings in extant literature, but also provide important managerial insights in managing MC operations

The remainder of the paper are as follows: we conduct literature review in Section 2, which addresses the domains of MC operations, supply chain finance, cash flow shortage and risk attitude. Section 3 presents the model formulation, and related analyses are conducted in Section 4. Section 5 extends Section 4 to further investigate the influences of capital constraint. Finally, we conclude with the managerial insights and future research direction in Section 6.

2. Literature Review

This paper is related to the domains of MC operations, supply chain finance in MC, cash flow shortage and the risk attitudes of the supply chain members. In the following, we review the research domains respectively.

2.1 MC Operations

MC presents a paradox by combining customization and mass production, offering unique products in a mass-produced, low cost, high volume production environment (Duray, 2002). Modularity, related to the numbers and degree of modules that are combined to an MC product, is the essence of mass customization. Kumar (2004) defines the criteria to examine the degree of modularity level. The parts are standardized, and the final product is customized at the end of the chain (Davis, 1989), which means the modularity of the product is crucial in MC strategy. In this paper, we take modularity level as an important factor in MC supply chain. Other works study MC mode and structure include Pine et al. (1993), Duray et al. (2000), MacCarthy et al. (2003) and Fogliatto et al. (2012).

Recently, works related to MC have covered a large scale of research domain. Fisher et al. (1999) examine component sharing using automotive front brakes in the management of product variety. Dewan et al. (2003) examine the product customization and price competition on the Internet. Hopp and Xu (2005) explore the product line selection and pricing with modularity in design addresses the strategic impact of modular design on the optimal length and price of a differentiated product line. Hopp and Xu (2005) learn the product line selection and pricing with modularity in design. Chayet et al. (2011) study the product variety and capacity investments in congested production systems. Liu et al. (2012) study the optimal decisions under MC taking the risk into consideration. Choi et al. (2018) study the optimal pricing in mass customization supply chains with risk-averse agents and retail competition. A number of papers have explored MC product strategies (Pine 1993; Duray 2002), process technology (Hart 1995; Kotha 1996) and organizational factors (Hart 1995) can aid the implementation of MC. However, research on finance strategies for MC program is limited, and still presented scarce improvement in the past decade. As we observed, most of the research works explore the optimal decisions in the MC supply chain like price and modularity level, however, they do not consider the supply chain finance.

2.2 Supply Chain Finance in MC

Babich and Kouvelis (2018) conduct a compressive literature review on the interface of finance, operations, and risk management, and summarize that current research in this domain include supply chain finance (trade credit and buyer-intermediated finance and their effects on supply chain performance), agency problems (risk shifting and managerial short-termism and their influence on operational decisions), contracting between the firm and its investors and how it alters contracting with supply chain partners, and supply risk management with commodity price fluctuations. Supply chain finance (SCF) through online peer-to-peer (P2P) lending platforms has gained its popularity.

One challenge for SCF is to design financial metrics and transaction policies that can align operational decisions between the supply chain parties. For example, Shang et al. (2009) study the coordination schemes within supply chain finance and improve the performance of a supply chain by integrating material flows with financial flows. Osorio and Toro (2012) study an optimization problem on cash supply chain. Anderson and Lawrence (2014) examine the influence of online review scores on service firm financial performance. Tunay et al. (2017) analyze the role and efficiency of buyer intermediation in supplier financing. Ma et al. (2018) develop a closed-loop supply chain models with alliance recycling under the pay-as-you-throw and recycling fund system and examine the difference between the two financing systems.

Some scholars pay more attention to the trade credit influences on the supply chain. Yang and Birge (2017) discuss how trade credit enhance supply chain efficiency by allowing the retailer to partially share the demand risk with the supplier. Lee et al. (2017) explore the trade credit financing under competition and its impact on firm performance in supply chains. Cao and Yu (2018) investigate the interaction of financial decision and operational decision in an emission-dependent supply chain. The contract coordination in supply chain finance are also explored by numbers of researchers. Sieke et al. (2012) study the contract of flat penalty and unit penalty contracts for supply chain coordination. Kouvelis and Zhao (2017) study the impact of credit ratings on operational and financial decisions of a supply chain. Ta et al. (2018) examine the critical role of trustworthiness in the financial supply chain relationships in the event of a contract breach. Several works have learned supply chain finance considering the bankruptcy influences. Yang et al. (2015) examine the supply chain effects of bankruptcy. After that, Houston et al. (2016) explore how a firm's bankruptcy affects the bank financing costs of its key suppliers. Ning and Sobel (2017) study production and capacity management with internal financing by dynamic programming. Kouvelis et al. (2018) study the problem of hedging cash-flow risks in a supply chain. However, as we searched and reviewed from the literature, there is limited works which examine supply chain finance in MC. MC usually creates a challenge for companies who have to make additional investments to support customization (Wind and Rangaswamy, 2001) and this would lead to finance constraint and therefore, the financial problems in MC supply chain deserves more exploration.

2.3 Cash Flow Shortage

In the production, manufacturers and retailers often face the lack of cash flow, therefore, it attracts a few of the research interests from the scholars.

Kouvelis and Zhao (2015) propose a contract design and coordination of supply chain, where the members of the supply chain are capital constrained and in need of short-term financing for their operations. Results illustrate that it is important and necessary to coordinate initial cash positions and/or loan amounts among supply chain parties. Taleizadeh (2017) explore the lot-sizing model with advance payment pricing and disruption in supply under planned partial backordering. By studying a three-stage Stackelberg game between the supply chain members, Xiao and Zhang (2018) investigate the manufacturers optimal mix of financing strategy with preselling and propose a preselling-based incentive scheme which contains a pre-ordering contract and a bidirectional compensation contract so as to motivate the manufacturer to increase production quantity and coordinate the supply chain. Considering a well-capitalized manufacturer and a capital-constrained retailer that faces difficulties obtaining credit from the bank, Bi et al. (2018) focus on exploring the optimal solution of operational collaboration in the presence of manufacturer collateral, and find that when the bank credit with manufacturer collateral is considered as a mix of trade credit and bank credit, the retailer's financing equilibrium depending on the maximum wholesale price can be neither trade credit nor bank credit alone, but a combination of them.

The above works do not consider the uncertainties in the supply chain, whereas the following works take risk into consideration. Yan et al. (2014) formulate a bi-level Stackelberg game for the supply chain finance system, where the system contains a manufacturer, a retailer and a commercial bank where both the retailer and manufacturer are capital constrained under demand uncertainties and consider bankruptcy risks. Tang et al. (2017) study the sourcing from suppliers with financial constraints and performance risk through a game-theoretical model which captures the interactions among manufacturer, financially constrained supplier and a bank. Kouvelis et al. (2017) present a game-theoretic study of a bilateral monopoly supply chain with stochastic demand, stochastic input costs, production lead times, and working capital constraints, and derive necessary and sufficient conditions that the instruments of the general contract must satisfy for the contract to induce a coordinated outcome—both with and without working capital constraints. Gao et al. (2018) study a supply chain finance system with a manufacturer selling a product to a retailer that faces uncertain demand over a single period, where either the retailer or the manufacturer faces a capital constraint and must borrow capital through an online P2P lending platform. Results show that it is important for the retailer and the manufacturer to take the online P2P lending platform's financial decisions (such as the service rate) into account when making their operational decisions. Li et al. (2018) investigates a supply chain where the retailer is capital-constrained, and the supplier is risk-averse, under two financing strategies of partial credit guarantee and trade credit financing and find that there is a region where trade credit financing outperforms partial credit guarantee for both members. Different from the previous research work, we focus on the capital constraint of the manufacturer and also take the financial interest into consideration, for which these works do not account in.

2.4 Risk Attitudes

With the inherent risks in a firm's portfolios of customers and suppliers, the risk will extend beyond financial and operational performance, including credit risks. The increasing call for MC in many industries has made today's global supply chains very complex, requiring a multitude of parallel information and physical flows to be controlled to ensure high customer service levels (Giannakis and Louis, 2011). This increased complexity raises the level of uncertainty and risks that companies are faced with (Manuj and Mentzer, 2008). Focused on analytical models, Chiu and Choi (2016) review selected papers related to supply chain risk analysis.

To deal with the problems in supply chain management, a few works take the risk attitude into consideration. Baker and Fox (2003) study the capital investment problem with risk consideration. Birnbaum and Bahra (2007) examine gain-loss separability and coalescing in risky decision making. Wu et al. (2013) study the risk-averse newsvendor problem with random capacity. He et al. (2017) explore the capacity investment in supply chain with risk averse supplier under risk diversification contract. Jindal (2014) explores the risk preferences and demand drivers of extended warranties. Other related works considering risk include risk mitigation (Van Mieghem, 2007), supply chain performance (Chen and Yano, 2010), risk attitude (Bisiere et al., 2014), residual value extended warranties (Gallego et al., 2014), inventory management (Chen et al., 2007), B2B contract (Ning et al., 2018). Choi et al. (2018) study the optimal pricing in mass customization supply chains with risk-averse agents and retail competition. The above research works study the supply chain problem with risk consideration but do not study the supply chain finance.

Recently, risk is studied with supply chain finance in lots of research works. For example, Babich et al. (2007) study the effects of disruption risk in a supply chain where one retailer deals with competing risky suppliers who may default during their production lead times. Yan et al. (2014) consider a supply chain finance system with a bank, where both the retailer and manufacturer are capital constrained under demand uncertainties and consider bankruptcy risks. Assumed that both the bank and the manufacturer are risk- averse, Yan et al. (2017) explore the effects of the risk preferences and decision preferences on supply chain finance equilibriums. Li and Zhan. (2018) examine the effect of product market threats on firms' stock crash risk and find that firms facing more threats are more prone to stock crashes. Serrano et al. (2018) explore the variability of payments to suppliers and its impact on how risk is generated and propagates upstream. Lin et al. (2018) investigate the optimal mode to coordinate the supply chain in confirming warehouse financing develop models when demand is uncertain. However, most of the research works do not study finance under MC supply chain, and financial interest is not accounted in the model. In this paper, we will study these factors.

3. Model Formulation

In this paper, we consider a game theoretic model which consists of a risk averse MC brand and a risk averse manufacturer. The MC brand buys finished MC products from the upstream manufacturer, and then sells the MC products to consumers in the market, and the MC brand has one single opportunity to order the MC product from the upstream manufacturer to satisfy future uncertain demand. Both of the manufacturer and the MC brand make optimal decisions to maximize their respective expected profit (Choi, 2013; Hopp et al. 2005; Liu et al. 2012), and the cost and revenue parameters of the upstream manufacturer and the MC brand are elaborated as follows.

First of all, for cost and revenue parameters of the upstream manufacturer, the per-unit production cost of the standard (i.e., basic) products is c_s, and the additional per-unit production cost for the MC products is c_c. The manufacturer also has an extra modularity dependent cost $C(m) = \frac{1}{2}hm^2$, where h is the sensitivity of the manufacturer's unit modularity cost with respect to the modularity level of the MC product (Choi et al., 2013). Besides, due to the long lead time in production, the manufacturer suffers from cash flow shortage and has to deal with two parts of supply cost. It includes both the procurement cost of raw materials from the supply market and the interest paid (e.g., to the bank) to raise the working capital for producing MC products for the MC brand. The unit material procurement purchasing cost is c_p, and the interest rate is τ_M; that is, if the manufacturer borrows money from the bank, the unit total procurement cost is $(1+\tau_M)c_p$. Notice that a similar cost structure for the cash flow shortage case can also found in other literature like Xiao and Zhang (2018). As a result, the unit overall production cost C of the manufacturer for each MC product is $C = c_s + c_c + (1+\tau_M)c_p$. In the meantime, anticipating the interest cost of the working capital, we assume the transaction between the manufacturer and the MC brand is based on a preselling contract offered by the manufacturer, through which the manufacturer collects a certain amount of cash before production. The preselling contract thus helps the manufacturer reduce the potential overall interest cost for capital raising. Under the preselling contract, in order to motivate the MC brand to place such advance orders, the manufacturer also offers a discounted unit wholesale price of each finished MC product ηw for each advance order, where $\eta \in (0,1)$ is the discount rate determined by the manufacturer and is given in the preselling contract. As a remark, this paper only explores the case when the manufacturer suffers from cash flow shortage, since the major focus of this paper is to investigate the interactions between the upstream manufacturer and the MC brand when the manufacturer has the chance to solve his cash flow shortage problem by stimulating the advance order from the MC brand. Under case when the MC brand has the cash flow shortage problem, however, the MC brand can never solve his cash flow shortage problem by acquiring cash from the manufacturer.

Secondly, for cost and revenue parameters of the MC brands, the product modularity level of the MC product, i.e., the number of options available for customization, is m. the retail price of the MC product is p, and the consumer returns are allowed for the MC products with full refund. Each returned MC product has a salvage value of $V(m) = s - vm,\ v > 0.$ s is the unit primary salvage value of each consumer return. v is the negative sensitivity of the salvage value of consumer returns with respect to the modularity level of the MC product, which provided by the MC brand. Notice that based on the observation of industrial practices, we assume that a higher modularity level can lead to a lower salvage value of consumer returns in this paper. Because according to Gu et al. (2002), the components of a finished MC product usually can be classified into three main categories, i.e., the standardized one, the similar one, as well as the special one. Among these three categories, those standardized components can always be directly re-used for the next designing or manufacturing process cycle. While differently, if for those special ones, they should be further designed before any reuse, which reflects the highest degree of difficulties of reuse. As a result, this is a reasonable and meaningful assumption in this paper. Besides, given the opportunity to purchase at a lower unit wholesale price under the preselling contract offered by the manufacturer, the MC brand may split his ordering quantity into two batches: the advance and regular orders. The advance order accounts for ξ $(0 < \xi < 1)$, and the regular order is $(1-\xi)$. These two batches occur before and after the manufacturer's production activities, respectively. For the advance order, we assume the MC brand will pay the manufacturer immediately whenever she places orders. At the same time, however, the MC brand has a rate of opportunity cost θ_B for each dollar paid to the manufacturer in advance, considering holding the cash can also bring benefits (e.g., the MC brand can deposit to a bank and generate additional revenue). As a remark, to ensure a profitable business for both supply chain members, the cost and revenue parameters described above are assumed to satisfy $p > C = c_s + c_c + (1+\tau_M)c_p$, $\eta(1+\theta_B) < 1$,[3] $\theta_B \le \tau_M$. Furthermore, for the risk attitudes of the supply chain

[3] This is to ensure that the MC brand will accept the preselling contract offered by the manufacturer, and make both the advance and regular orders.

members, in this paper, k_B represents the MC brand's degree of risk averse and k_M represents the manufacturer's degree of risk averse. Correspondingly, $\frac{k_B}{k_M}$ shows the ratio difference between the risk attitudes of the MC brand and the manufacturer.

For the market demand of the MC product, notice that this paper is based on a make-to-order (MTO) system, which is affected by the level of product modularity of the product m. That is, the market demand of MC product follows: $D = \alpha + \delta m + \overline{\varepsilon_D}$, $\delta > 0$. α is the primary market scale of the MC product. δ is the positive sensitivity of the market demand with respect to the modularity level of the MC product provided by the MC brand. $\overline{\varepsilon_D}$ is a random variable of the market demand. Its probability density function and cumulative distribution function are $f(x)$ and $F(x)$ respectively. Similar modeling approaches have also been used in a number of other papers (Mukhopadhyay and Setoputro, 2005; Liu et al., 2012). Besides, as the supply chain system in this paper is a MTO, we consider the case that the market demand could be totally fulfilled, i.e., $q = D$. (Xiao and Jin, 2011). As for the return quantity function, similar to Choi et al. (2013), Mukhopadhyay and Setoputro (2005), and Li et al. (2013), it follows: $R = \phi + \overline{\varepsilon_R}$. ϕ is the constant return quantity of the MC product, which can be observed from the historical data. $\overline{\varepsilon_R}$ is the random noise of the return quantity. In the meantime, since in real world practice the most common return policy adopted by the MC brands is full refund policy, we explore the case of full refund in this paper. Notice that the consumer return policy here refers to the product return from consumers who are unhappy with the purchase with any reason (probably within some reasonable time, such as 30 days in Nike), it is not induced by the manufacturing mistakes, defects, or other product quality related problems. Besides, following Liu (2012), the return quantity R is modelled as independent of the demand function D in this paper.

Additionally, we also have several other assumptions as follows.

1. The relationship between the rate of MC brand's opportunity cost rate θ_B for paying the manufacturer in advance and the manufacturer's interest rate τ_M to raise the working capital for production follows $\theta_B \leq \tau_M$. It is reasonable since in an arbitrage-free market, the investment return is usually lower than the capital acquisition cost.
2. The market has full information, i.e., all the parameters in each model are common knowledge to both two participants (Gao et al., 2018).
3. Inventory cost, shortage cost, and the time value of money are zero (Lin et al., 2018).

The notations used in this chapter are listed in Table 1 for readers' reference.

Table 1. Notations.

p	The retail price of the MC product
m	The level of product modularity of the MC product
c_s	The downstream manufacturer's per-unit production cost of the standard (i.e., basic) products
c_c	The additional per-unit production cost for the MC products
c_p	The unit material procurement purchasing cost for the manufacturer
h	The sensitivity of the manufacturer's unit modularity cost with respect to the modularity level of the MC product
τ_M	The interest paid (e.g., to the bank) to raise the working capital for producing MC products for the MC brand
w	The original unit wholesale price of each finished MC product
η	The discount rate determined by the manufacturer for each advance order
ξ	The rate of the advance order placed by the MC brand
θ_B	The MC brand's opportunity cost rate for each dollar paid to the manufacturer in advance
α	The primary market scale of the MC product

Otherwise, when $\eta(1 + \theta_B) \geq 1$, there is no wholesale price advantage of the advance order. As a result, the MC brand will make no advance order, which is not the focus of this paper.

δ	The positive sensitivity of the market demand with respect to the modularity level of the MC product provided by the MC brand
$\overline{\varepsilon_D}$	The random variable in the market demand
ϕ	The constant return quantity of the MC product.
$\overline{\varepsilon_R}$	The random noise in the return quantity
V	The salvage value of each returned MC product
s	The unit primary salvage value of each consumer return.
v	The negative sensitivity of the salvage value of consumer returns with respect to the modularity level by the MC brand.
k_B	The degree of risk averse for the MC brand
k_M	The degree of risk averse for the manufacturer

The sequence of events is shown as follows and the manufacturer is the Stackelberg leader in this paper:
(1) The manufacturer determines the unit wholesale w for each regular order, and offers the preselling contract (w, η) to the MC brand. (Notice that in this paper, the discount rate η for each advance order is exogenously given in the preselling contract).
(2) After accepting the preselling contract, the MC brand, which is the Stackelberg follower, decides the level of product modularity of the product m and the percentage of the advance order ξ; and in the meantime, pays to the manufacturer for the advance order.
(3) The manufacturer obtains additional cash (if necessary) from a bank with interests, and starts his total production activities.
(4) The manufacturer ships the finished MC products to the MC brand. MC brand pays to the manufacturer for the regular order.
(5) The market demand D is realized. Consumers who are not satisfied with the products will return the product back to the MC brand.
(6) At the end of the selling season, the MC brand salvages all consumer returned items.

Objective function:

1) The MC brand:

The profit function of the MC brand is expressed as follows:

$$\pi_B = p(\alpha + \delta m + \overline{\varepsilon_D}) - p(\phi + \overline{\varepsilon_R}) + (s - vm)(\phi + \overline{\varepsilon_R}) - \eta w\xi(\alpha + \delta m + \overline{\varepsilon_D}) - \eta w\xi(\alpha + \delta m + \overline{\varepsilon_D})\theta_B - w(1-\xi)(\alpha + \delta m + \overline{\varepsilon_D}) \quad .$$

(1)

As can be seen from (1), both $\overline{\varepsilon_D}$ (i.e., the random variable of the market demand) and $\overline{\varepsilon_R}$ (i.e., the random noise of the return quantity of the MC product) can lead to the uncertainty in the profit function of the MC brand. Besides, notice that as we have mentioned earlier that by following the extant literature like Liu (2012), the return quantity and the demand function are modeled as independent in this paper. Therefore, there is no correlation between the two random noises of $\overline{\varepsilon_D}$ and $\overline{\varepsilon_R}$. This is a reasonable setting since in most cases, the consumer returns are the result of quality problems, which is not the major focus of this paper. Therefore, by setting the independence between the return quantity and the demand function, we can isolate the influences of the product quality issue and focus on supply chain finance management in MC operations.

Accordingly, we have the expected profit and the variance of profit the MC brand as follows:

$$E[\pi_B] = [p - \eta w\xi(1+\theta_B) - w(1-\xi)](\alpha + \delta m) + (s - vm - p)\phi;$$

$$V[\pi_B] = [p - \eta w\xi(1+\theta_B) - w(1-\xi)]^2\sigma_D^2 + [p - (s - vm)]^2\sigma_R^2.$$

To determine the MC brand's optimal decisions on the modularity level of the MC product and the percentage of the advance order respect to different degree of risk aversion of the upstream manufacturer and himself, we follow the mean-variance (MV) models in Choi and Chow (2008) and Liu et al. (2012) to define the following MV utility function for the of the MC brand:

$U[\pi_B] = E[\pi_B] - k_B V[\pi_B] = \{[p - \eta w\xi(1+\theta_B) - w(1-\xi)](\alpha + \delta m) + (s - vm - p)\phi\} - k_B\{[p - \eta w\xi(1+\theta_B) - w(1-\xi)]^2\sigma_D^2 + [p - (s - vm)]^2\sigma_R^2\}$.
(2)

2) The downstream manufacturer:
Similarly, we can know that the profit function of the downstream manufacturer is:
$\pi_M = \eta w\xi(\alpha + \delta m + \overline{\varepsilon_D}) + w(1-\xi)(\alpha + \delta m + \overline{\varepsilon_D}) - [c_s + c_c + (1+\tau_M)c_p](\alpha + \delta m + \overline{\varepsilon_D}) - \frac{1}{2}hm^2$. (3)

Different from the case of the MC brand, as is shown in (3), the uncertainty in the profit function of the upstream manufacturer comes only from $\overline{\varepsilon_D}$ (i.e., the random variable of the market demand) since the MC brand is the only one responsible for handling the consumer returned items.

The expected profit and the variance of profit of the manufacturer therefore are:
$E[\pi_M] = \{[\eta w\xi + w(1-\xi)] - [c_s + c_c + (1+\tau_M)c_p]\}(\alpha + \delta m) - \frac{1}{2}hm^2$;
$V[\pi_M] = \{[\eta w\xi + w(1-\xi)] - [c_s + c_c + (1+\tau_M)c_p]\}^2\sigma_D^2$.

As a result, to determine the upstream manufacturer's optimal decisions on the wholesale price of the MC product respect to different degree of risk aversion of the MC brand and herself, we have the utility function of the upstream manufacturer as:
$U[\pi_M] = E[\pi_M] - k_M V[\pi_M] = \{[\eta w\xi + w(1-\xi)] - [c_s + c_c + (1+\tau_M)c_p]\}(\alpha + \delta m) - \frac{1}{2}hm^2 - k_M\{[\eta w\xi + w(1-\xi)] - [c_s + c_c + (1+\tau_M)c_p]\}^2\sigma_D^2$.

4. Analysis

In the following, we aim to solve the optimal solutions of the supply chain members (i.e., research question (1)) and explore the influences of two important supply chain finance factors on the MC program: 1) the risk attitudes of the supply chain members, and 2) cash flow shortage (i.e., research question (2) and (3), respectively).

For research question (1), we proceed backwards to derive the equilibrium results of the MC game, and the decision variables for each supply chain member are listed in Table 2. Accordingly, we have Proposition 1.

Table 2. Decision variables.

Supply chain members	MC brand	The manufacturer
Decision variable	$m, \ \xi$	w

Proposition 1. *When* $\delta < 2k_B v\sigma_D\sigma_R$ *,the optimal solutions of the MC brand are* $m^* = \frac{\delta\alpha - 2k_B\sigma_D^2 v\phi - 4k_B^2\sigma_D^2\sigma_R^2(p-s)v}{A}$*, and* $\xi^* = \frac{-2k_B\sigma_R^2 B(k_B+k_M) + \delta v\phi(k_B+k_M) + Ak_M(p-C)}{2k_B\sigma_R^2 BD - \delta v\phi D + Ak_M(1-\eta)(p-C) + Ak_M\eta\theta_B C}$*, respectively; the optimal solution of the upstream manufacturer is* $w^* = \frac{2k_B\sigma_R^2 BD - \delta v\phi D + Ak_M(1-\eta)(p-C) + Ak_M\eta\theta_B C}{A\eta\theta_B k_M}$.

Proposition 1 shows the equilibrium results of the MC game in a supply chain consisting of one risk averse manufacturer, which suffers from cash flow shortage, and one risk averse MC brand. As a remark, $\delta < 2k_B v\sigma_D\sigma_R$ is a reasonable condition in real world practices since the positive sensitivity of the market demand with respect to the modularity level of the MC product provided by the MC brand cannot be infinite. Based on Proposition 1, it can be observed that the optimal solutions have close relationships with both the supply chain members' risk averse degrees and the cash flow shortage costs of the upstream manufacturer.

In the following, we therefore proceed to explore research question (2) and (3), i.e., the influences of the risk attitudes of the supply chain members and cash flow shortage in the manufacturing level on the equilibrium results, respectively. The detailed sensitivity analyses are shown in Table 3.

Table 3. Sensitivity analyses on the equilibrium results

<table>
<tr><th>Equilibrium results</th><th>m^*</th><th>w^*</th><th colspan="2">ξ^*</th></tr>
<tr><td rowspan="2">$k_B \uparrow$</td><td rowspan="2">$\uparrow$ if $\delta > \frac{v\alpha}{p-s}$</td><td rowspan="2">$\downarrow$ if $\delta > \frac{v\alpha}{p-s}$</td><td>if $\delta > \frac{v\alpha}{p-s}$</td><td>$\downarrow$ if $\frac{1}{\theta_B} < \frac{\eta(\delta v\phi F - 2\sigma_R^2 BG)}{-2(1-\eta)B\delta^2\sigma_R^2(p-C)k_B}$</td></tr>
<tr><td>if $\delta < \frac{v\alpha}{p-s}$</td><td>$\downarrow$ if $\frac{1}{\theta_B} > \frac{\eta(\delta v\phi F - 2\sigma_R^2 BG)}{-2(1-\eta)B\delta^2\sigma_R^2(p-C)k_B}$</td></tr>
<tr><td>$k_M \uparrow$</td><td>$-$</td><td>$\downarrow$ if $\delta > \frac{v\alpha}{p-s}$</td><td colspan="2">$\downarrow$ if $\delta > \frac{v\alpha}{p-s}$</td></tr>
<tr><td>$\tau_M \uparrow$</td><td>$-$</td><td>$\downarrow$</td><td colspan="2">$\downarrow$ if $\delta > \frac{v\alpha}{p-s}$</td></tr>
<tr><td>$\theta_B \uparrow$</td><td>$-$</td><td>$\downarrow$ if $\delta > \frac{v\alpha}{p-s}$</td><td colspan="2">$\downarrow$ if $\delta > \frac{v\alpha}{p-s}$ and $\frac{k_B}{k_M} < \frac{AC}{\delta v\phi - 2k_B\sigma_R^2 B}$</td></tr>
<tr><td>$\eta \uparrow$</td><td>$-$</td><td>$\uparrow$ if $\delta > \frac{v\alpha}{p-s}$</td><td colspan="2">$\uparrow$ if $\delta > \frac{v\alpha}{p-s}$ and $\frac{k_B}{k_M} > \frac{A[(p-C)-\theta_B C]}{(1+\theta_B)(2k_B\sigma_R^2 B - \delta v\phi)} - \frac{1}{(1+\theta_B)}$</td></tr>
</table>

Lemma 1. *For the optimal product modularity level* m^**: i) When the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high (i.e.,* $\delta > \frac{v\alpha}{p-s}$*): if the MC brand's degree of risk averse* k_B *increases, the optimal product modularity level* m^* *increases; ii) The optimal product modularity level* m^* *is independent of the manufacturer's degree of risk averse* k_M*, the interest paid by the manufacturer (e.g., to the bank) for raising the working capital* τ_M*, the MC brand's opportunity cost rate for the advance order* θ_B*, and the discount rate provided by the manufacturer for the advance order* η*.*

Lemma 1 reveals the crucial influences of the MC brand's degree of risk averse on the optimal product modularity level of the MC product.

As can be seen from Lemma 1, when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high, the optimal product modularity level of the MC product is increasing with the MC brand's degree of risk averse. In the meantime, the opportunity cost rate of the MC brand and the manufacturer's capital situation will never influence the optimal decisions of the MC brand concerning the product modularity of the MC product. This is a reasonable result since the core idea of MC is to turn the heterogeneous needs of target customers into an opportunity to create value, which means the customers' heterogeneous needs always play a dominant role in the MC brand's decision-making process, especially when the MC brand is risk averse. Differently, the manufacturer's capital situation plays a more important role in influencing the wholesale pricing related decision of the MC product, which will correspondingly impact the ordering quantity of the MC product, rather than the product modularity.

Managerial insights: Understanding the different preferences and traits of the target consumers is of great importance for the MC game, especially when the MC brand is risk averse. The success of MC schemes thus requires a suitable modular approach. In particular, this finding can be of great significance to new MC schemes like Sonic Blocks, which is a recent MC scheme launched by Sonic. The MC system for Sonic Blocks is completely modular. It allows the consumers to choose between different woofers, tweeters, to upgrade the individual speakers, and even to add some additional components.[4] In the meantime, however, since it is a newly launched MC scheme and is also the world's 1st MC scheme in the domain of modular wireless speaker, little history data or referential cases are available for operations management of this MC scheme. Consequently, the operations risks of this new MC scheme can be very high. As a result, if Sonic wants to lower the operations risks of this new MC scheme, close attention should be paid to the positive sensitivity of the market demand with respect to the modularity level of the MC product when making a decision about the product modularity level. For instance, if the market demand's positive sensitivity with respect to the modularity level of Sonic Blocks is high, while Sonic wants to avoid as much operations risks of

[4] Interested readers can refer to https://www.cnet.com/news/sonic-blocks-crazy-wireless-speaker-lets-you-customize-everything/ for more details. (Retrieved in December, 2018)

this new MC scheme as possible, then a high product modularity level of Sonic Block can be a good choice. Similarly, it can also be the case for other innovative and new MC schemes with high operations risks.

Lemma 2. *For the optimal wholesale price of each finished MC product* w^**, when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high (i.e.,* $\delta > \frac{v\alpha}{p-s}$*):i) If the MC brand's degree of risk averse* k_B *increases, the optimal wholesale price of each finished MC product* w^* *decreases; ii) If the manufacturer's degree of risk averse* k_M *increases, the optimal wholesale price of each finished MC product* w^* *decreases.*

Lemma 2 indicates how the risk attitudes of the MC brand and the manufacturer impacts the manufacturer's decision on the optimal wholesale price of each finished MC product when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high.

As is shown in Lemma 2, any increase in either the MC brand's degree of risk averse or the manufacturer's degree of risk averse will lower the manufacturer's optimal wholesale price of the MC product. First of all, from the perspective of the MC brand, the ordering cost of the MC product is a kind of operations risks and a lower ordering cost is definitely helpful in reducing the overall operations risks of the MC scheme. As a consequence, the advance order offer given by the upstream manufacturer will be much more attractive to the MC brand only when the wholesale price of the MC product is lower, which means a lower opportunity cost for the MC brand. Similarly, a low wholesale price of the finished MC product is also helpful for alleviating the financial burden of the capital constrained manufacturer since it can help induce a larger advance order from the MC brand and collect more capital before the start of the production activities.

Lemma 3. *For the optimal wholesale price of each finished MC product* w^**, when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high (i.e.,* $\delta > \frac{v\alpha}{p-s}$*): i) Any increase in the interest paid by the manufacturer (e.g., to the bank) for raising the working capital* τ_M*, or in the MC brand's opportunity cost rate for the advance order* θ_B*, can lead to the decrease in the optimal wholesale price of each finished MC product* w^**; ii) The increases in the discount rate provided by the manufacturer for the advance order* η *can lead to the increase in the optimal wholesale price of each finished MC product* w^**.*

Lemma 3 illustrates under the condition of a high positive sensitivity of the market demand with respect to the modularity level of the MC product, how the interest paid by the manufacturer (e.g., to the bank) for raising the working capital, the MC brand's opportunity cost rate for the advance order, and the discount rate provided by the manufacturer for the advance order influence the decision making process of the manufacturer on the optimal wholesale price of each finished MC product.

It can be seen that among these three factors, the increase in the interest paid by the manufacturer (e.g., to the bank) for raising the working capital will contribute to a lower wholesale price of the MC product. Because under the capital constraints, the larger number of the advance order that the manufacturer can get from the MC brand, the less loan that the manufacturer needs to raise from, for instance, the bank. Therefore, the higher the interest that the manufacturer needs to pay (e.g., to the bank) for raising the working capital, the lower the optimal wholesale price of each finished MC product will be so as to help the manufacturer raise more money from the advance order placed by the MC brand before the production activities. Meanwhile, when the MC brand's opportunity cost rate for the advance order increases, in order to reduce the overall opportunity cost of the MC brand for paying for the advance order and persuade the MC brand to place a larger number of the advance order, the manufacturer will also lower the wholesale price of the MC product.

As for the influences of the discount rate provided by the manufacturer for the advance order, it is interesting to notice that although it helps stimulate the advance order from the MC brand, it also lowers the profit of the manufacturer for each MC product ordered through the advance order. Consequently, the manufacturer has to raise the wholesale price of each finished MC product when a higher discount rate is provided for the advance order, which is for ensuring a profitable practice.

Managerial insights: Lemma 2 and Lemma 3 above reveals an important managerial guideline for the capital constrained manufacturer when cooperates with a risk averse MC brand. The capital constrained manufacturer will have the motivation to stimulate a larger number of the advance order from the MC brand by offering the wholesale price discount when there is some increase in the manufacturer's degree of risk averse, the interest paid by the manufacturer (e.g., to the bank) for raising the working capital, or the MC brand's opportunity cost rate for the advance order. The manufacturer therefore, should effectively control and lower the overall production costs of the MC products, e.g., by reducing the production cost of the standard ones, which is effective in ensuring a profitable business as well as reducing the operations risks for the manufacturer when lowering the wholesale price of the MC product. Under such consideration, low capital-intensive MC process steps like model sharing are suggested. In real world practices, considering the case of MC schemes in car makers, for instance, it is common to share identical components among various modern car models, which are usually mass produced first before the final customization step. This helps spread over the overall production cost of the manufacturer while in the meantime maintains the manufacturer's capability to handle a wide variety of different MC products (i.e., a high modularity of the MC product). Typical examples of such business practices are Toyota, Peugeot, and Citroën. Specifically, it is well known that Toyota Aygo, Peugeot 107, and the Citroën C1 are all based on the same basic car model, which are later processed with only minor cosmetic modifications before sold to the consumers.[5] By adopting this kind of model sharing strategy therefore, the manufacturer can not only reduce the number of working capital that needs to be raised (e.g., from the bank) before the production activities, but also simultaneously decrease the relevant capital risks induced by offering the wholesale price discount.

Lemma 4. *For the optimal rate of the advance order placed by the MC brand* ξ^**, when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high (i.e.,* $\delta > \frac{v\alpha}{p-s}$*): i) If the MC brand's degree of risk averse* k_B *increases, the optimal rate of the advance order* ξ^* *decreases if and only if the MC brand's opportunity cost rate for the advance order is sufficiently large (i.e.,* $\frac{1}{\theta_B} < \frac{\eta(\delta v\phi F-2\sigma_R^2 BG)}{-2(1-\eta)B\delta^2\sigma_R^2(p-C)k_B}$*); ii) If the manufacturer's degree of risk averse* k_M *increases, the optimal rate of the advance order decreases.*

Lemma 4 shows impacts brought by the risk averse degree of the MC brand and the manufacturer on the optimal rate of the advance order placed by the MC brand.

It can be found that a higher opportunity cost rate for placing the advance order will induce the MC brand to reduce his rate of the advance order when his risk averse degree increases, even if the market demand's positive sensitivity to the modularity level of the MC product is sufficiently high. It is because when the MC brand holds a higher risk averse level, a higher opportunity cost rate for placing the advance order, which means more operations risks, will be avoided by the MC brand. In the meantime, it is interesting to notice that when the manufacturer's degree of risk averse is high, the optimal rate of the advance order will also be low. This is because as is indicated in Lemma 2 ii), when the risk averse degree of the manufacturer is high, the manufacturer will charge a low wholesale price. This, however, will reduce the motivation of the MC brand to place an advance order (since the full rate of the ordering cost is already low) when making the tradeoff between the benefits from the advance order and the corresponding opportunity costs.

Lemma 5. *For the optimal rate of the advance order placed by the MC brand* ξ^**, when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high (i.e.,* $\delta > \frac{v\alpha}{p-s}$*): i) If the interest paid by the manufacturer (e.g., to the bank) for raising the working capital* τ_M *increases, the optimal rate of the advance order* ξ^* *decreases; ii) If the MC brand's opportunity cost rate for the advance order* θ_B *increases, the optimal rate of the advance order* ξ^* *decreases if and only if the ratio difference of*

[5] https://www.allaboutlean.com/mass-customization/. (Retrieved in December, 2018).

between the risk attitudes of the MC brand and the manufacturer is sufficiently small (i.e., $\frac{k_B}{k_M} < \frac{AC}{\delta v\phi - 2k_B\sigma_R^2 B}$*);*

iii) If the discount rate provided by the manufacturer for the advance order η *increases, the optimal rate of the advance order* ξ^* *increases if and only if the ratio difference of between the risk attitudes of the MC brand and the manufacturer is sufficiently large (i.e.,*$\frac{k_B}{k_M} > \frac{A[(p-C)-\theta_B C]}{(1+\theta_B)(2k_B\sigma_R^2 B-\delta v\phi)} - \frac{1}{(1+\theta_B)}$*).*

Lemma 5 demonstrate when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high, how the optimal rate of the advance order placed by the MC brand is affected by the interest paid by the manufacturer (e.g., to the bank) for raising the working capital, the MC brand's opportunity cost rate for the advance order, as well as the discount rate provided by the manufacturer for the advance order.

First of all, it is interesting to notice that any increase in the interest paid by the manufacturer (e.g., to the bank) for raising the working capital of the MC production activities will induce the decrease in the optimal rate of the advance order. It is similar to the results in Lemma 4 ii). In particular, when the loan interest faced by the manufacturer is high, the manufacturer has sufficient incentive to lower the wholesale price, which instead, will reduce the motivation of the MC brand to place an advance order since the full rate of the ordering cost is already low. Based on the same logic, in Lemma 5 ii), when the MC brand's opportunity cost are high, the optimal rate of the advance order for the MC brand is relatively low when the risk averse degree of the MC brand is sufficiently small compared to the risk averse degree of the manufacturer (i.e., $\frac{k_B}{k_M}$ is sufficiently small). Because under this case, although the MC brand will order less advance order considering the high opportunity cost of the advance order, he can still enjoy a low ordering cost given the low full rate wholesale price provided by the manufacturer (as discussed in Lemma 2 ii) and Lemma 3 i) before). Furthermore, Lemma 5 iii) reveals that any increase in the discount rate provided by the manufacturer for the advance order can effectively increase the optimal rate of the advance order placed by the MC brand if the risk averse of the MC brand is large enough (when compared with the risk averse degree of the manufacturer). This means that the manufacturer can stimulate a larger number of advance order from the MC brand by enhancing the discount rate of the advance order if the MC brand holds a relatively high risk averse degree.

Managerial insights: Findings in Lemma 4 and Lemma 5 provide a crucial managerial guideline for the advance order activities of MC schemes. In particular, MC as a strategy aiming at providing customization services to individual customers at a mass production price, a low retail price of MC products is of great importance to ensure the success of MC brands, especially for the MC brands which offers general MC products instead of luxury ones (e.g., the apparel companies of Levi Strauss and NIKEiD). While in practices, considering the consumers' high positive sensitivity to the modularity level of the MC product, the MC brand may have to choose a high product modularity level, which can induce a high level of operations costs of the MC scheme. Under such consideration, accepting the preselling contract can be an efficient way for the MC brands to lower the retail price of MC products. The results shown in Lemma 4 and Lemma 5 then can be a good reference for the MC brands when deciding the optimal rate of the advance order. For instance, a high rate of the advance order may not be a good choice when the MC brand's degree of risk averse is high, or when there is a high opportunity cost rate for the advance order for the MC brand.

5. Extensions: The influences of capital constraint

In previous discussions, we assume that the manufacturer is with capital constraints, and analyze the influences of risk attitudes of the supply chain members as well as the cash flow shortage on the optimal solutions of the MC brand and the manufacturer (i.e., both research question (2) and (3)). In the following, we continue to address research question (3) and further discuss the case when the upstream manufacturer always has sufficient working capital for the production activities of the MC scheme. That is, no interest has to be paid by the manufacturer (e.g., to the bank) for raising capital, i.e., $\tau_M = 0$. Consequently, we have the new unit overall production cost C^1 of the manufacturer for each MC product as $C^1 = c_s + c_c + c_p$. By following the same logic as Section 4, we then have Proposition 2.

Proposition 2. *When $\delta < 2k_B v\sigma_D\sigma_R$, the optimal solutions of the MC brand under the case of a capital sufficient manufacturer are* $m^{1*} = \frac{\delta\alpha - 2k_B\sigma_D^2 v\phi - 4k_B^2\sigma_D^2\sigma_R^2(p-s)v}{A}$, *and* $\xi^{1*} = \frac{-2k_B\sigma_R^2 B(k_B+k_M)+\delta v\phi(k_B+k_M)+Ak_M(p-C^1)}{2k_B\sigma_R^2 BD-\delta v\phi D+Ak_M(1-\eta)(p-C^1)+Ak_M\eta\theta_B C^1}$, *respectively; the optimal solution of the upstream manufacturer is* $w^{1*} = \frac{2k_B\sigma_R^2 BD-\delta v\phi D+Ak_M(1-\eta)(p-C^1)+Ak_M\eta\theta_B C^1}{A\eta\theta_B k_M}$.

Proposition 2 shows the equilibrium results of the MC game under the consideration of a capital sufficient manufacturer. Comparing with the equilibrium results under the case of a capital constrained manufacturer before, we have Proposition 3.

Proposition 3. *The capital constraint can lead to different influences on optimal solutions of the MC brand and the upstream manufacturer: 1) For the optimal modularity level of the MC product: $m^{1*} = m^*$; 2) For the optimal wholesale price of each finished MC product $w^{1*} > w^*$; 3) For the optimal rate of the advance order $\xi^{1*} > \xi^*$.*

Proposition 3 shows several important managerial insights for managing a MC supply chain with a capital constrained manufacturer. As can be observed from Proposition 3, the optimal product modularity level of the MC product is exactly the same regardless of whether the manufacturer suffers from capital constraints or not. This result is consistent with the findings in Lemm1 in Section 4, and proves the robustness of Lemma 1. At the same time, both the optimal wholesale price provided by the manufacturer and the optimal rate of the advance order placed by the MC brand are larger in the case when the manufacturer has sufficient working capital since the manufacturer's motivation to stimulate a larger number of the advance order is much lower in the case with sufficient capital. Therefore, it is distinct that the capital constraint of the upstream manufacturer can lead to dominant effects on the decision-making process of both the MC brand and the manufacturer concerning the wholesale price of the finished MC product and the rate of the advance order.

Managerial insights: From the perspective of the upstream manufacturer, capital tied up with the MC schemes is associated with the inventory costs of the standard products, the material purchasing cost for production, the production costs, the labor costs, as well as the associated loss of interest on that capital. All these costs occur before the start of the selling season. Sufficient capital access facilitates therefore are of great significance to the upstream manufacturer to ensure his ability of meeting the needs of an investment program for MC product productions, which ensures a higher control power of the manufacturer when offering the wholesale contract to the MC brand. Otherwise, when the manufacturer has capital constraints, he has to lower the wholesale price of the finished MC product so as to have some advance order from the MC brand. This however, can considerably reduce the manufacturer's control power on the determination of the wholesale price.

6. Conclusion

6.1. Concluding Remarks and Managerial Implications

In this paper, we develop a game theoretic model consisting of a risk averse MC brand and a risk averse upstream manufacturer and address the influences of supply chain finance on the MC programs. The influences brought by the risk attitudes of both the MC brand and the manufacturer are systematically analyzed in this paper. Besides, an extra interest rate for raising the working capital for production (e.g., from the bank) at the manufacturing level is also considered. To be specific, we have following findings.

For the influences of the risk attitudes of supply chain members: We find that when the positive sensitivity of the market demand with respect to the modularity level of the MC product is sufficiently high, the optimal product modularity level of the MC product is increasing with the MC brand's degree of risk averse. Besides, when both the market demand's positive sensitivity to the modularity level of the MC product and the MC brand's opportunity cost rate for placing the advance order is sufficiently high, any increase in the risk averse degree of the MC brand or the manufacturer will lower the manufacturer's optimal wholesale price of the MC product as well as the MC brand's optimal rate of the advance order. Managerial implication: Considering the various risks in MC operations, the success of MC schemes therefore requires a suitable modular approach. It is especially important for some new or innovative MC schemes like Sonic Blocks, which is with little history or referential data for MC operations management but has relatively high operations risks. For instance, if the market demand's positive sensitivity with respect to the modularity level of Sonic Blocks is high, while Sonic wants to avoid as much operations risks of this new MC scheme as possible, then a high product modularity level of Sonic Block can be a good choice.

For the influences of cash flow shortage in the manufacturing level: We find that the higher the interest that the manufacturer needs to pay (e.g., to the bank) for raising the working capital, the lower the optimal wholesale price of each finished MC product will be so as to help the manufacturer raise more money from the advance order from the MC brand. Managerial implication: Sufficient capital access facilitates therefore are of great significance to the manufacturers which offer MC production services to the MC brands so to ensure the ability of meeting the needs of an investment program for MC product productions and also a higher control power of the wholesale price when offering contracts to the MC brand. Besides, low capital-intensive MC process steps like model sharing are also suggested. For instance, the manufacturer can share identical components among various MC products like the modern car MC models, which helps spread over the overall production cost of the manufacturer while in the meantime maintains the manufacturer's capability to handle a wide variety of different MC products (i.e., a high modularity of the MC product).

All these findings highlight the significant influences of both the risk attitudes of supply chain members and cash flow shortage in the manufacturing level. Besides, the findings above also provide important guidelines for managing a MC supply chain in which the customization process is under the responsibility of the MC brand. For instance, the MC brand should also carefully design the modular approach in its daily operations, given that the modular approach is of great help for dealing with the uncertainties and risks induced by the ever-changing market demand and consumer preferences. Besides, different from the case of the manufacturer, the capital constraint of which is usually related to the long lead time in the production processes, the capital constraint in the MC brand level can be a result of the MC brand itself. That is, the MC brand can be small or medium firms, which have a higher chance to suffer from cash flow shortage (Chen and Zhang 2019). This can consequently limit the flexibility in the product modularity level design, especially in the case when the MC brand is risk averse. However, with the help of some special schemes, for example model sharing, the MC brand can still have the chance to offer a high product modularity level to the target market even with limited product family of the basic products. As a result, this paper completes the findings in extant literature and provide important managerial insights in managing MC operations.

6.2. Future Directions

In this paper, motived by the real cases in MC application, we develop a game theoretic model consisting of a MC brand and an upstream manufacturer, and examine the influences of supply chain finance on the MC programs.

For future research, it can be interesting to explore the influences brought by the strategic behavior of target consumers on a MC supply chain with cash flow shortage and demand-dependent consumer returns. Different utility functions of the consumers can be utilized and compared. Besides, meaningful insights can also be inspired by examining how credit financing (Lee et al. 2017) competition affect the MC supply chain, currently in this paper, we focus on the supply cost and interest paid caused by flow shortage, while in future credit financing competition could be more common in practice. It will be also promising to explore the contract design and coordination of MC supply chain (Shen and Li 2015; Sarkar et al. 2019), it is important and necessary to coordinate initial cash positions and/or loan amounts among supply chain parties. Last but not least, other issues such as the cases with multiple suppliers (Sun et al. 2015), the effects of disruption risk (Wang and Sun 2019), and the variability of payments to suppliers and its impact (Serrano et al. 2018) can be explored more in the future.

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Appendix A: All proofs

Proof of Proposition 1. For $U[\pi_B]$ to be strictly concave in m and ξ, The Hessian determinant:
$$|H_{U[\pi_B]}| = \begin{vmatrix} \frac{d^2U[\pi_B]}{dm^2} & \frac{d^2U[\pi_B]}{dmd\xi} \\ \frac{d^2U[\pi_B]}{d\xi dm} & \frac{d^2U[\pi_B]}{d\xi^2} \end{vmatrix} = \begin{vmatrix} -2k_B v^2\sigma_R^2 & -\delta[\eta w(1+\theta_B)-w] \\ -\delta[\eta w(1+\theta_B)-w] & -2k_B[\eta w(1+\theta_B)-w]^2\sigma_D^2 \end{vmatrix}$$ should be negative definite. The minors satisfy: $D_1 = -2k_B v^2\sigma_R^2 < 0$, $D_2 = (4k_B^2 v^2\sigma_D^2\sigma_R^2 - \delta^2)[\eta w(1+\theta_B)-w]^2 > 0$ if and only if $4k_B^2 v^2\sigma_D^2\sigma_R^2 - \delta^2 > 0$. Hence the first order conditions are sufficient for the MC brand's decision variables' global optimality when $\delta < 2k_B v\sigma_D\sigma_R$.

Then by solving $\frac{dU[\pi_B]}{dm} = 0$ and $\frac{dU[\pi_B]}{dm} = 0$ together, we can find the optimal solutions of the MC brand are:

$$m^* = \frac{\delta\alpha - 2k_B\sigma_D^2 v\phi - 4k_B^2\sigma_D^2\sigma_R^2(p-s)v}{4k_B^2 v^2\sigma_D^2\sigma_R^2 - \delta^2}, \tag{A1}$$

$$\xi^*|w = \frac{(4k_B^2 v^2\sigma_D^2\sigma_R^2 - \delta^2)(p-w) + \delta v\phi + 2k_B v\delta(p-s)\sigma_R^2 - 2k_B v^2\alpha\sigma_R^2}{(4k_B^2 v^2\sigma_D^2\sigma_R^2 - \delta^2)[\eta(1+\theta_B)-1]w}. \tag{A2}$$

Replace (A1) and (A2) into $U[\pi_M]$, we have the optimal solution of the upstream manufacturer as:

$$w^* = \frac{\alpha\cdot 2k_B\sigma_R^2 v^2 D - \delta v\phi D - (p-s)\cdot 2k_B\sigma_R^2\delta v D - Ak_M(\eta-1)(p-C) + Ak_M\eta\theta_B C}{A\eta\theta_B k_M}. \tag{A3}$$

Solving (A1), (A2) and (A3) together, we have:

$$m^* = \frac{\delta\alpha - 2k_B\sigma_D^2 v\phi - 4k_B^2\sigma_D^2\sigma_R^2(p-s)v}{A}, \tag{A4}$$

$$\xi^* = \frac{-2k_B\sigma_R^2 B(k_B+k_M) + \delta v\phi(k_B+k_M) + Ak_M(p-C)}{2k_B\sigma_R^2 BD - \delta v\phi D + Ak_M(1-\eta)(p-C) + Ak_M\eta\theta_B C}. \tag{A5}$$

$$w^* = \frac{2k_B\sigma_R^2 BD - \delta v\phi D + Ak_M(1-\eta)(p-C) + Ak_M\eta\theta_B C}{A\eta\theta_B k_M}. \tag{A6}$$

Proof of Lemma 1. It can be proved by taking the first-order derivative of m^* in (A4) with respect to k_B, k_M, τ_M, θ_B and η.

Proof of Lemma 2. It can be proved by taking the first-order derivative of w^* in (A6) with respect to k_B, and k_M.

Proof of Lemma 3. It can be proved by taking the first-order derivative of w^* in (A6) with respect to τ_M, θ_B and η.

Proof of Lemma 4. It can be proved by taking the first-order derivative of ξ^* in (A5) with respect to k_B, and k_M.

Proof of Lemma 5. It can be proved by taking the first-order derivative of ξ^* in (A5) with respect to τ_M, θ_B and η.

Proof of Proposition 2. It can be proved by following the same logic as Proposition 1.

Proof of Proposition 3. It can be proved by comparing the equilibrium results listed in Proposition 1 and Proposition 2.

Appendix B: Supplementary Tables

Table B1. All abbreviations.

$A = 4k_B^2 v^2 \sigma_D^2 \sigma_R^2 - \delta^2$	$B = \alpha v^2 - (p - s) \cdot \delta v$
$D = k_B(\eta - 1 + \eta\theta_B) + k_M(\eta - 1)$	$E = 4k_B^2 v^2 \sigma_D^2 \sigma_R^2 + \delta^2$
$F = Ep + 4B\sigma_D^2 k_B - \delta v\phi + 8Ck_B k_M v^2 \sigma_D^2 \sigma_R^2$	$G = \delta^2(3p - C)k_B + CEk_M + 2B\sigma_R^2 k_B^2$