Investigating the Feasibility of Supply Chain-Centric Business Models in 3D Chocolate Printing: A Simulation Study

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Abstract

3D chocolate printing provides the technology for manufacturing chocolates layer-by-layer, thus offering customers enhanced product value and personalized consumption experience. As business models in the chocolate industry are closely associated with the profitability of the supply chain constituents, it seems appropriate to investigate the financial viability of these supply-chain centric business models prior to their introduction in the real world. In this paper we present two business models pertaining to the supply chain for 3D printed chocolates; we evaluate the financial viability of these innovative models through the use of computer modeling and simulation. The study is based on the commercialization efforts of a UK based 3D chocolate printing technology provider (Choc Edge). The results of the study indicate that 1) the retailer dominant supply chain modelis a potentially disruptive business model innovations that are enabled by the 3D food printing technology, and as such, may pose a challenge to traditional high end chocolate products; 2) the manufacturer dominant model helps manufacturers gain more profits while retailer profits tend to be stagnant.

Keywords: 3D chocolate printing, case study, simulation, business model innovation, supply chain management

1. Introduction

Traditional chocolate manufacturers such as Dove, Cadbury, Hershey and Ferrero, capture the most market shares of the confectionary industry by offering standard chocolate bars and gift boxes. In order to deliver more customer value propositions, there are some small and medium sized chocolate manufacturers such as Chocolate Bouquets directly selling handmade chocolates via e-commerce platforms such as eBay or Amazon. Besides, some upscale chocolate manufacturers such as Teuscher (www.teuscher.com) provide highly customised chocolate products in terms of fruits, spices, nuts, confectionery and white/dark cocoa, which allows for more than 27 billion combinations (www.createmychocolate.com). Although the launch of customised chocolate products fulfill the increasing requirements for personalization, the mainstream chocolate consumers are faced with long order-to-delivery time and prices that are generally 2-3 times higher than traditional chocolate products. As the market requirement for customised chocolate keeps growing, satisfying customisation needs at relatively low costs is a challenge that is faced by many players in this industry. The application of 3D printing technology in the chocolate industry is an innovative approach towards mass customisation of chocolates.

The prototype 3D chocolate printing technology that was developed at the University of Exeter (BBC News, 2011; BBC News, 2012), represents a revolutionary product innovation and manufacturing approach which can engage consumers to create and produce chocolate gifts locally and share their digitized product design and innovation globally through online communities. Clearly this new technology represents great potential to reconstruct food innovation, production and supply chain in the future, in particular achieving a leagile and low carbon food value chain (Christopher, 2011). However, our search of literature in 3D food printing using bibliographic databases *ISI Web of Knowledge* and *Scopus* retrieved only 6 and 15 articles respectively (the keywords used were *3D food print*, additive manufacturing, rapid manufacturing, rapid prototyping, solid freeform fabrication, layer manufacturing;* search conducted on *articletitle, abstract and keywords*; final search was conducted in December, 2013). Of these, the relevant articles focused primarily on engineering and automation (e.g., Millen et al., 2012) and food science (Kim et al., 2012). There is presently little research carried out to date studying the impact of 3D food printing on the supply chain of innovative food products and their underlying business models; a possible reason for this is that 3D food printing is at its infancy and research in this topic should arguably be preceded by commercialization of this technology and the creation of associated supply chains, both of which are still developing. In the context of 3D chocolate printing, to the best of our knowledge there is only one technology provider attempting to commercialize operations in the UK: *Choc Edge*. The company was founded by a co-author of this paper and the University of Exeter for commercially exploiting 3D chocolate printing (https://chocedge.com/).

Robust business models are necessary for ensuring the economic sustainability of 3D chocolate printing. It should take into account the profitability aspects of the supply chain constituents, viz., the manufacturer and the retailer, and the utility derived by the end user (e.g., permitting both shape and mix customisation of chocolate products). Towards this, we present two business models that are being considered by Choc Edge – the *manufacturer-dominant model* and the *retailer-dominant model*. The question now arises as to how we assess the economic sustainability of business models based on supply chain configurations that do not yet exist? This brings us to the next part of the study which has applied *computer simulation* in the context of supply chains (supply chain simulation). A computer simulation is a quantitative technique that uses the power of computers to conduct experiments with models that represent either an existing or a proposed system of interest (Pidd, 2004). In this research we use simulation for modeling the supply chain constituents and their profitability functions with the aim of experimenting financial viability of the proposed manufacturer-dominant and the retailer-dominant model business models. Due to the nascent nature of the 3D food printing technology (Eisenhardt, 1989; Yin, 2003) a simulation case study is an effective experimentation-based approach to evaluate new business model innovations. Such an approach has been used previously in the context of ascertaining the financial viability of business models pertaining to telecommunication networks (Bohlin, 2007).

The contribution of the paper is twofold. First, it outlines two business models for 3D printing of chocolates and compares it to the traditional model for the production of standard chocolates. Second, the paper presents a simulation study to assess the financial viability of the two proposed business models. As discussed earlier in the paper, there is presently no literature on 3D food printing and its effects on existing food supply chains and business models; and thus the novelty of our contribution.

The remainder of the paper is structured as follows. Section two presents a literature review on business models in food supply chains. Section 3 then outlines our research methodology which uses computer modeling and simulation. Section 4 is on business models; it discusses them in relation to 3D printing-enabled customised chocolate production (the proposed manufacturer-dominant and retailer-dominant models) and standard chocolate production (*traditional model*). Section 5 presents the simulation logic and the equations that are implemented in the computer model. The simulation results are discussed in section 6. Section 7 presents a discussion on the entrepreneurial challenges faced by Choc Edge as it attempts to commercialize the technology and what adaptations to its business model and strategy might be necessary for it to be commercially successful. Section 8 is the concluding section of the paper.

2. Literature Review

Traditional chocolate making is a highly sophisticated process using specialized machinery. The production method may involve molding (e.g., pouring molding), enrobing and roll forming (Aasted, 1998; Beckett, 2009), among others. Furthermore, different moldings require different chocolate production machines and lines (Jeffery, Glynn and Khan, 1977). These traditional methods of chocolate production focus primarily on standard products and mass manufacturing (Akutagawa, 1983; Hunter, 1927) and capture the majority of the market share. However, they cannot match customer demands for customised chocolates (Beckett, 2009). Although traditional methods can manufacture such products, they are expensive and time consuming as they frequently necessitate the manufacture of customised molds (Aasted, 1998).

In this section we present a review of literature on business models in food supply chains (section 2.1). Robust business models are necessary for ensuring the economic sustainability of chocolate production, taking into account the profitability aspects of the supply chain constituents. In this paper this is referred to as supply chain-centric business model innovations and is further discussed in section 2.2.

2.1 A Review of Business Models for Food Supply Chains

Food Supply Chains (FSC) are an example of complex supply chains and consist of several inter-dependent steps, for example, farming, food processing, distribution, retailing and consumer handling (Vorst, 2000). In between these operations, storage, packaging and transport need special considerations due to food safety issues (Jennings, 2005). As a result of the long process flows and food storage, the logistics costs are high. With regard to FSC for chocolates, the chocolate production processes have strict requirements for temperature control, which pushes the cost even higher (Aasted, 1998). The main challenges of the traditional FSC are how to shorten the food process, reduce logistics and storage costs, and enhance the consumption value of products (Christopher, 2011). Nowadays, supply chain and logistics managers face another challenge and are required to re-evaluate their strategies and tactics to make the food supply chain more sustainable (Flint et al., 2008). The traditional FSC and production lines are more appropriate for mass manufacturing of standard products or for limited customisation products; customised products, on the other hand, require expert skills of hand-decoration which are often associated with high labor costs (Berkes et al., 1984).

Customisation involves seeing each customer as a potential market segment and designing and producing individualized products, and quickly delivering them to each customer (Fitzgerald, 1995). Boland (2008) illustrated that there are an increasing number of consumers who require personalized nutrition, and they are willing to pay a premium price to buy innovative food (Cohen et al., 2009; Hendry, 2010). Personalized nutrition becomes a mainstream in affluent societies (Boland, 2008), with a goal of healthy lifestyle (Boland, 2008; Martínez, 2008). At the same time, customers want to receive products and services with a certain degree of individualization (Gilmore and Pine, 1997; Franke et al., 2009).

As a result of manufacturers' decisions to configure their products to match every customer's individual preferences, the relationship between manufacturers and customers has been enhanced (Wong and Eyers, 2011; Simonson, 2005). However, the manufacturer's total cost (e.g., production and logistics) would increase linearly with the number of products available to the market (Banerjee and Golhar, 2013). Furthermore, in the midst of fierce competition and diversified product offerings in the market, manufacturers find it difficult to simply expand product ranges, and they do not have enough flexibility to respond to this rapid change in customer demands (Wang, 2011), such as in regards to product designs, colour, sizes and packaging (Childerhouse et al., 2002; Wang, 2011). Therefore, it has become a common trend to continuously improving the level of customisation in the FSC for producing standard products in the market (Lyons et al., 2013).

Discussing the impact of the customisation on the FSC, Wang (2011) proposes a dynamic model, which states that product customisation level would be affected by product costs and potential profit margin, inventory cost of semi-finished products, shortage costs and inventory costs. Echoing Wang (2011), Wong and Eyers (2011) concentrated on several key factors such as the inventory level, number of product variety, price, and delivery lead-time, which may inhibit or promote the use of a higher level of customisation. In addition, producing customised products may create solutions for postponement in FSC. For instance, customised production will not start until manufacturers receive a clear order from customer preference (Periard et al., 2007), thus, the issue of delaying or postponing production of a product can be solved (Banerjee and Golhar, 2013; Getschmann, 2013).

Arguably, the FSC factors which inhibit the large scale adoption of personalized food products will also apply to the supply chains for customised chocolates. However, it's possible that impact on the latter may be diminished considering that an innovative food processing technology (like 3D chocolate printing) may simplify logistics and thereby reduce inventory cost; further, the promise of co-creation of value together with customers (through design of customised chocolates) has provide a unique Customer Value Proposition and thereby the potential to enhance the company's competitive advantage (Vorst, 2010). This presents an opportunity for new supply chain-centric business models in 3D chocolate printing.

2.2 A Critique of Business Model Innovations for 3D Chocolate Printing

In business, innovation is divided into two broad categories: (1) continuous or dynamic evolutionary innovation, which brings about incremental advances in technology or processes; and (2) disruptive innovations, which is the emergent or step-function innovation (Yu and Hang, 2010). Disruptive innovation is the introduction of new technology, products or services, as well as the efforts to promote, reform and obtain superiority in the competition and mainly includes business-model innovation and technology innovation (Markides, 2006). Such innovations are an effective way to develop and expand new markets (Govindarajan and Kopalle, 2006; Schmidt and Druehl, 2008) and they may also have a profound influence on the existing market (Schmidt and Druehl, 2008).

It is arguable that 3D chocolate printing is a disruptive innovation enabled not only by the 3D print technology *but also* by the changes in the underlying supply chain configurations that are necessitated through its use. However, it is important to also consider the level of maturity of this innovation in the food industry. An immature disruptive innovation cannot substitute the traditional business (Yu and Hang, 2010). 3D chocolate printing technology requires high quality of raw materials since the chocolate viscosity affects the quality of the end product; such conditions increase the operational problems (Finkel, 1987; Lipton, 2010).Accordingly, although 3D chocolate printing technology has enormous potentials to change food innovation, it is not a disruptive innovation just yet as it currently is a new and immature technology for manufacturing. The focus of this paper is not on technology but on supply chain-centric business model innovations that complement the use of this technology.

3. Computer Modelling and Simulation

Computer simulation enables us to experiment with a computer model and to know more about the system under scrutiny and to evaluate various strategies for its operation (Shannon 1998). Computer simulations are generally used because they are cheaper than building (and discarding) real systems; they assist in the identification of problems in the underlying system and allow testing of different scenarios in an attempt to resolve them; allow faster than real-time experimentation; provide a means to depict the behavior of systems under development; facilitate the replication of experiments, among others (Brooks et al., 2001; Pidd, 2004). All the aforementioned advantages of computer simulation apply to our study.

Supply Chains, from their very nature, are complex as they entail all the processes from procurement and manufacturing to sales and support (Stevens, 1989). Moreover, modern supply chain management approachesfavour a global, holistic view in which the individual echelons share information and trust each other, rather than simply trying to optimize their own local processes independently of its neighbors (Chapman and Corso, 2005). This is also true of the supply chains for chocolates. Most of these multi-echelon and complex supply chains can benefit from Operational Research (OR) techniques. One such OR technique is simulation; application of this technique to supply chain management is called supply chain simulation (SCS). SCS helps organizations determine the strategies that have the potential to provide the most flexible and profitable operating environment (Huang et al., 2003). SCS differs from the conventional types of simulations (e.g., traditional manufacturing simulation) because it spans far beyond the confines of a single entity and its goal is to improve the financial position of an entire enterprise or a group of trading partners (Bagchi et al., 1998). This particular goal makes the application of this OR technique relevant to our study.

Our computer simulation models three supply chain-centric business models (see section

4). The first model is the traditional model for the production of standard chocolate products that presently exists in the chocolate industry. The remaining two models are the proposed models and are based on, (a) the researchers' observation of business development of *Choc Edge*, and (b) extensive consultations and semi-structured interviews with food/chocolate production experts including plant managers, R&D managers, marketing managers and supply chain managers of large multinational food corporations based in the UK and China. The objective of carrying out the interviews in both UK and China is that it is realized that the latter, being an emerging economy and increasingly the financial powerhouse of the world, tends to accept new technologies faster than the developed economies. These interviews were also crucial in providing input data for the models (e.g., inventory levels maintained by the manufacturer, product cost and retailer selling price). The computer models were implemented using the commercially available *ExtendSim* (ExtendSim.com) software (Krahl, 2009).

4. Business Models

In this section, we first present a supply chain model for the traditional chocolate production (section 4.1), then move on to proposing two business models based on the 3D chocolate printing technology: *manufacturing dominant model* and *retailer dominant model* (sections 4.2 and 4.3 respectively). The former represents a business model wherein a chocolate manufacturer adopts this technology, with production taking place at the manufacturers' plants and the manufacturers then choosing to sell the products through retailers and through e-commerce platforms. The latter scenario is that of a retailer adopting this technology with the final production (3D printing) taking place at the retailers' stores with the retailers then selling the products through its stores and its online platform. The novelty of the supply-centric business model innovation is described in section 4.4.

4.1 Traditional Chocolate Production Business Model (model 1)

The supply chain strategy for traditional chocolate production is make-to-stock. The supply chain comprises of the suppliers of raw material, the manufacturer, a network of retailers and the end consumers. Figure 1 shows the materials flow from right (raw materials provider) to the left (end consumers) and are depicted through arrows. The flow of information is from the left to the right and is illustrated by dotted arrows. This flow can be specific to the customer (demand flow), the retailer (order flow for finished goods)or to the manufacturer (order flow for raw materials). The manufacturer's process is further divided into the inventory for raw material, the production process and the inventory for the finished product. Similar to the material and information flow above, there are upstream and downstream flows between these sub-processes and they are depicted by dotted blue arrows. The figure also includes icons for representing inventory and the upstream transportation. Finally, the readers should take note of three variables (*D*, *P* and *W*) included in the figure; these refer to the variables that will be subsequently used in the simulation. *D* is the consumer demand for the standard chocolate products; *P* is the price for the traditional chocolates and *W* is the wholesale price.

--Insert Figure 1 about here--

4.2 Manufacturer-dominant Business Model for 3D Chocolate Production (model 2)

The production of customised chocolates will necessitate changes to be made to the traditional supply chain and its underlying business model and should take into account the revised role of the supply chain constituents in fulfilling customer demand. The manufacturer-dominant model is the first supply-centric business model innovation presented in the paper. Here the manufacture is not only responsible for the make-to-stock (as in the traditional model) but also for the customised production of chocolates. The conventional *retailer-manufacturer channel* for make-to-stock is complemented by processes pertaining to the production of customised chocolates, wherein, (a) customers order personalized chocolates through the retailers, (b) the orders are communicated to the manufacturer, (c) the chocolates manufactured using semi-finished products inventory and 3D chocolate printing machines, (d) the manufacturer transports the customised chocolates back to the retailer, and (e) the customer collects the customized chocolates from the retailers (Figure 2). The proposed supply-chain structure also includes the*customer-manufacturer channel* which facilitates communication between the customer and the manufacturer with the objective of fulfilling customer demand. The dual channel may be realized through the development of an online e-commerce portal by the manufacturer, wherein (a) the portal enables customers to put forward their customisations through the internet, (b) the manufacturer then produces personalized chocolates using 3D printing technology and semi-finished chocolate inventory, and (c) the manufacture delivers the chocolates directly to the customers. In the customer-manufacturer channel the role of the retailer is made redundant. Figure 2 shows the customer demand for finished products (i.e., standard chocolates) (D_f),the demand for customized chocolates that are ordered and delivered through the retailer channel(D_c) and those ordered online and transported directly from the manufacturer (D_c'); the corresponding prices are P_f, P_c and P_c' respectively. Finally the variables W_f and W_c refer to the price the retailer has to pay to the manufacturer for the standard and customized chocolates.

--Insert Figure 2 about here--

4.3 Retailer-dominant Business Model for 3D Chocolate Production (model 3)

In retailer-dominant supply chain the customized product is created using the 3D chocolate printer by the retailer. The customer can either place an online order for such chocolates through the retailer website or can come into a store to place an order; in case of the latter it may be possible to manufacture the personalized chocolate in the presence of the customer (an aesthetic appeal!) or it can be shipped to the customer, as is the case with online orders. The chocolate is manufactured using semi-finished products which have to be ordered from the manufacturer. Thus, there exist two inventories in the case of retailer-dominant supply chains - the inventory for standard chocolates and the inventory for semi-finished goods (Figure 3). Compared to the manufacturer-dominant business model wherein the manufacturer has processes pertaining to customised chocolate production, in model 3 this is incorporated with retailers’ processes. However, the manufacturer will continue to produce and maintain an additional inventory for semi-finished products to fulfill the retailers' demand for the raw materials for customised chocolate production. The variables shown in Figure 3 are similar to those in Figure 2 since in both scenarios customer demand exists for standard chocolates (D_f), customised chocolates ordered and delivered through the retailer channel(D_c) and customised chocolates ordered online (D_c'); however, unlike the previous scenario wherein the manufacturer fulfilled the order, in retailer-dominant model the customer receives the chocolate from the retailer. The price for $D_{f,}$ D_c and D_c' are P_f, P_c and P_c' respectively. Similarly, the variables W_f and W_c refer to the price the retailer has to pay to the manufacturer for standard and semi-finished chocolates.

For both models 2 and 3 there is no inventory subsequent to the process for manufacturingcustomised chocolates (shown in grey) since this is a make-to-order strategy. Finally, for all the three models presented, there exists an inventory for standard chocolates at both manufacturer and retailers since it is make-to-order.

--Insert Figure 3 about here--

4.4 Contribution to Supply Chain-Centric Business Model Innovation

Why do we consider the manufacturer dominant model a supply-chain centric business model innovation? There are numerous examples of business models that circumvent the retailer, for example, those based on home shopping catalogue, e-commerce and e-business. Business models based on the internet have particularly been disruptive; such models have frequently allowed limited customisation of the manufactured good (e.g., Apple which allows personalization of a gadget through laser engravings) or non-trivial customisation (e.g., make-to-order strategy of DELL computers allows customers to choose CPU, memory, Operating System, and a host of other configurations) - these are examples of Business to Consumer (B2C) business models. Business models offering no customisations may include Customer to Customer (C2C) interactions realized through e-Bay and Amazon. Shifting our focus from internet-based business models to traditional and hybrid models, the strategy of augmenting the conventional *brick and mortar* stores with online channels (*bricks and clicks*) have proved to be an effective strategy among high-street retailers in the UK and elsewhere. For example, John Lewis chain of departmental stores in the UK reported a rise of 23% in their brick and click operations as against 1.2% for store operations for the 2013 Christmas sales (BBC, 2014). Again the question arises as to why we consider retailer dominant supply-centric business model as a novel innovation?

Complementing the traditional make-to-stock *retailer-manufacturer* channel (model 2) and *retailer-customer* channel (model 3) with make-to-order products and further extending it to the *customer-manufacturer* channel (model 2) is in itself not a novel business model innovation in terms of e-Commerce since Internet is now widely recognized as a disruptive technology. And indeed, with the ubiquity of the Internet, we take this as granted; our argument for the novelty of our business model innovation lies in the 3D printing technology. In other words, our business model for customisation of chocolates could not be realized without the invention of 3D chocolate printing technology; the use of the online e-commerce portal would only assist in the efficient communication of designs (shape customisation) and product mix to the manufacturer. The opposite of this is not true, i.e., having an online portal for shape and mix-based customisation but not the 3D printing machine would fail to realize the two supply-chain centric business model innovations that have been proposed in the paper for personalisation of chocolates. The value of the 3D printing technology is that it enables the adopter of the technology to co-create value with consumers in terms shape design and enhances consumer experience of being involved in the design process of final chocolate products.

5. Choc Edge Simulation Study

The Choc Edge engineered 3D chocolate printing machines will enable manufacturers (as in business model 2) and retailer (as in business model 3) to produce chocolates based on customer preferences; this is especially true for the manufacture of chocolates with shape-customisation. In 3D chocolate printing, production does not commence until an order is received with clear customer preference information; thus the business model associated with traditional chocolate production (business model 1) is not viable for the production of shape customised chocolates. However, for the purposes of comparison, we have implemented computer models for all the three business models outlined in the previous section. These are discussed next.

5.1 Simulation Logic

For each of the three supply chain-centric business models, the objective of the simulation is to find the lowest total cost of the supply chain. The models can realize the maximum profit of supply chain through the optimization of inventory. The simulation models are developed using *ExtendSim*. Figure 4 presents a screenshot of retailer-dominant business model. The simulation logic pertaining to the retailer-dominant business model is shown as a flowchart in Figure 5. For the other two models, the simulation logic will be described in the body of the text. The retailer-dominant business model is chosen for the flowchart as it is relatively more complicated than the remaining two.

--Insert Figure 4 about here—

--Insert Figure 5 about here--

The simulation logic for the retailer-dominant business model is as follows (refer to Figure 5).

(1) Initialization of model parameters.

(2) Start simulation, set 120 days as the model end time and set the number of replications to100. Thus, for each run the model executes for simulated time equivalent to 120 days; this is then replicated 100 times, each time with a different random number stream which samples from the identified distributions (see below). The inventory results are calculated based on the average of the 100 replications.

(3) The demand for chocolate (D_f , D_c& Dc') is calculated based on the Poisson Distribution.

(4) θ is the ratio of customised demand against standard products demand ($\theta = \frac{Dc+Dc'}{D_f}$).

In the beginning of simulation, we assume this to be$< 20\%$.

The reader should take note that θ is an important variable in our simulation and the results of the simulation are presented with reference to data points specific to the varying mix of standard and customised chocolate as represented by the θ value (see section 6).

(5)The retailer holds the inventory of semi-finished products (used by the 3D chocolate printing machine to produce customised chocolates) and standard products, and places orders based on *(s, S)* strategy, wherein *'s'* stands for safety stock/reorder point and *'S'* is the maximum inventory. The *(s, S)* strategy dictates that the system regularly check for the inventory level; if the inventory is less than *'s'* then an order is placed to replenish semi-finished products to the maximum inventory of *'S'*, otherwise no order is placed. The manufacturer holds the stock of semi-finished products and standard products. The manufacturer produces chocolates based on *(s, Q)* strategy, wherein *'s'* stands for safety stock/reorder point and the production lot size is denoted by *'Q'*. According to the *(s, Q)* strategy the system regularly checks the inventory level; if inventory is less than the reorder point *'s'*, then the manufacturer will start the production process with the lot size being equal to *'Q'*, else, the production process is not started.

(6) The retailer will satisfy the end user demand for standard products if the existing stock can meet the demand; otherwise, the system will show out of stock information.

(7) After receiving the orders for customised products, the retailer will satisfy the end user demand by using semi-finished products from its inventory to produce and deliver the finished products.

(8) The manufacturer will supply the finished standard products and/or semi-finished products to the retailer based on the orders placed. If the stock cannot meet the demand from the retailer, the manufacturer will start the production process for the manufacture of more standard and/or semi-finished products.

The simulation logic of the manufacturer-dominant business model (model 2) is similar to model 3, with the differences being for model 2, (a) the retailer holds only standard products stock, while the manufacturer holds both the stock of semi-finished products and standard products, (b) the customized products can be supplied from either the retailer or the manufacturer, here the demand information obtained from the consumers will be transferred from the retailer to the manufacturers who will produce end products. Finally, with regard to the simulation logic of model 1, there is only the inventory of standard products.

5.2 The impacts of customised products on chocolate market demands

Shape-customised chocolates, as a substitute of traditionally manufactured chocolates which we term in this paper as standard chocolate products, would affect the market demand of standard chocolates. For the benefits of simulation we make the following two assumptions:

- Total chocolate market value is invariable.
- The market demand for customised products is influenced by the degree of customisation, the price of customised products and the price of standard products.

Consumer utility is a central concept of consumer demand theory derived from economics theory and depicts the ability of a good to satisfy needs or wants of a consumer (Marshall, 1920). In our research, consumer utility (u) depends on the degree of customisation and also the price (p). Prices remaining constant, a higher degree of customisation will lead to an increase in utility for the customer. Similarly, when the degree of customisation is unchanged, an increase is price will lead to less consumer utility and vice versa. Thus, the function of consumer surplus is:

$$\varphi u - p$$

Market demand will exist if consumer surplus is greater than 0 ($\varphi u - p > 0$).As a result, $\varphi > \frac{p}{u}$ is the type of consumer who requires customised products, and the quantity of these consumers should be $D = \int_{\varphi}^{1} f(\varphi)\, d_{\varphi}$. It is expected that the utility derived by customers for customised products will be greater than that of standard products (since customers are involved in the process of co-creation), which means $u_c > u_f$.

Thus, the prerequisite of purchasing customised products is:

$$\varphi u_f - p_f > 0 \text{ and } \varphi u_c - p_c > \varphi u_f - p_f$$

Solving the aforementioned equation we get:

$$\varphi > \frac{p_f}{u_f} \text{ or } \varphi > \frac{p_c - p_f}{u_c - u_f}$$

Thus, only when $\frac{p_f}{u_f} < \frac{p_c - p_f}{u_c - u_f} < 1$, would consumers who belong to the type φ ∈ $[\frac{p_f}{u_f}, \frac{p_c - p_f}{u_c - u_f}]$ purchase standard products and those of the type φ ∈ $[\frac{p_c - p_f}{u_c - u_f}, 1]$ purchase customised products (Figure 6). At this time, the demand quantity of standard products is:

$$D_f = \int_{\frac{p_f}{u_f}}^{\frac{p_c - p_f}{u_c - u_f}} f(\varphi)\, d_\varphi \quad (1)$$

The demand of customised products is:

$$D_c = \int_{\frac{p_c - p_f}{u_c - u_f}}^{1} f(\varphi)\, d_\varphi \quad (2)$$

Price (p_c and p_f) was determined based on the actual data from a food processing company; utility (u_c and u_f) was also determined based on this data and the condition ($\frac{p_f}{u_f} < \frac{p_c - p_f}{u_c - u_f} < 1$). Based on customers' preference over channels (i.e., online or store), it can be decided whether customized products are provided through online or retail stores.

--Insert Figure 6 about here--

5.3 Parameter Definitions

In this section we present the modeling parameters which have been used in the subsequent equations to calculate inventory and the profitability functions pertaining to the supply-chain centric business models.

T is operating cycle of simulation;

k is the order times contained in a simulation cycle;

n is the produce times contained in a simulation cycle;

$I(t)$ is the inventory in theory;

$I_k(t)$ is the real inventory when produce an new order;

Q is the product quantity;

D_f is the consumer demand for standard products per day;

D_c is the consumer demand for customised products from retailer per day;

D_c' is the consumer demand for customised products online per day;

P_f is the price of traditional chocolate;

P_c is the price of customised chocolate from retailer;

P_c' is the price of customised chocolate from manufacturer online;

W_f is the wholesale price of traditional chocolate;

W_c is the wholesale price of customised chocolate;

C is cost;

C_h is inventory holding cost;

C_s is the shortage cost which exists when customer demand cannot be met;

C_o is the cost of placing new order each time;

C_p is the setup cost each time;

C_u is the material cost of every product;

The aforementioned parameters are distinguished by their superscript and subscript values. Superscript ^{1} denotes the traditional supply chain model (model 1) catering only to standard chocolate products. Superscripts ^{2} and ^{3} represent the manufacturer-dominant (model 2) and the retailer-dominant business models respectively, both of which cater to standard and customised chocolate products. Next, superscripts ^{m} and ^{r} represent parameters pertaining to the manufacturer and the retailer respectively and are related to all three models.

For all the three models which will be discussed in the following sections, customer arrival follows Poisson distribution while the demand of each consumer is independent and follows discrete distribution. The lead-time of ordering and production are random within the defined range. Input parameters for simulation are presented in Table 1.

--Insert Table 1 about here--

5.4 Business Model 1: Traditional Chocolate Supply Chain

Retailer's profit(RP) is the retailer's income minus order cost of finished product, inventory holding cost and shortage cost.

$$RP^1 = \frac{(P_f - W_f)D_f - C_{fh}^r - C_{fs}^r - C_{fo}^r}{T} \quad (3)$$

Manufacture's profit(MP) is the manufacture's wholesale income minus raw material cost of finished products, produce cost and inventory holding cost.

$$MP^1 = \frac{\sum_1^k (W_f - C_{fu}^m) Q_f^m - C_{fp}^m - C_{fh}^m - C_{fs}^m}{T} \quad (4)$$

5.5 Business Model 2: Manufacturer-dominant double-channel supply chain

Printing of customised chocolates by the manufacturer decreases the inventory cost of the retailer. This is brought about by the fact that the demand for chocolates will now comprise of the demand for standard chocolates and the demand for customised chocolates (compared to this, in model1the customer demand for chocolates comprised solely of standard chocolates). In the manufacturer-dominant model, although the customers benefit from the provision of ordering for personalized chocolates through the retailer, there will be no inventory cost associated with such products at the retailers' end since customised chocolates are directly distributed to the customers; thus, made-to-order chocolatesdo not incur holding costs; the retailer only bears the inventory costs for standard chocolates (as is the case in model 1).

In this model an inventory for semi-finished products does exist, however this inventory is at the manufacturer's end (see Figure 2).The manufacturer's inventory cost for model2 takes into account the following: (a) The cost of finished productis divided into two components – the first pertains to the raw material cost for the semi-finished product (C_{su}^m)and the second is related to the semi-finished product inventory cost (C_{sh}^m). The subscripts denotes the parameters associated with semi-finished products. (b) The cost of customised product also consists of two parts – the first part is the raw materials cost of semi-finished product(C_{su}^m) and the second part is for costs pertaining to customisation (C_{cp}^m) ; customised chocolates are manufactured individually thereby increasing the labor, equipment and operating costs, so the cost of customised product cost is higher than finished products. (c) Subsequent to the introduction of the customised product, the setup cost of the finished product (C_{fp}^m) is decreased. (d) Customised chocolates are distributed by the third party logistics; C_n is the operation cost of the online channel. (e) Since customised products are directly distributed subsequent to production, the inventory cost is not considered; the shortage cost related to the customized products (C_{ss}^m) is added to the cost for the manufacture.

In this paragraph we analyse the profit of double-channel supply chain under manufacturer-dominant model**.** Here the inventory model of the retailer is no different compared to the traditional business model; however, the retailer can offer customized product to customer and increase income. The original finished products sales of the retailer will, to a certain extent, be affected by the sale of customized products. In this model the retailer's profit function is:

$$RP^2 = \frac{(P_f - W_f)D_f + (P_c - W_C)D_c - C_{fo}^r - C_{fh}^r - C_{fs}^r}{T} \quad (5)$$

After the introduction of customised production,the profit of double-channel supply chain under manufacture-dominant model is:

$$MP^2 = \frac{\sum_1^k (W_f - C_{fu}^m)Q_s^m + (W_C - C_{su}^m)D_c + (P_c' - C_n)D_c' - C_{sh}^m - C_{ss}^m - C_{sp}^m - C_{cp}^m - C_{fp}^m - C_{fh}^m - C_{fs}^m}{T} \quad (6)$$

5.6 Business Model 3: Retailer-dominant supply chains

Under the retailer-dominant supply chain, the customized product is manufactured by the retailer (Figure 3). In this model the retailer's inventory pattern for standard product remains the same. For enabling the on-demand manufacture of customised chocolates using 3D printing the retailer has to set up a semi-finished product inventory($I_s^r(t)$). As a result of the introduction of semi-finished products inventory, retailer's total inventory cost will be higher compared to models 1 and 2 since it would include the semi-finished products inventory holding cost(C_{sh}^r), shortage cost for semi-finished products(C_{ss}^r), and ordering cost for semi-finished products(C_{so}^r). At the same time this will create a shaping process cost(C_{cp}^r), but retailers' inventory of customised products can also be treated as a virtual inventory. The semi-finished product cost of each product will be W_s .

Under the retailer-dominant model the manufacturer will produce finished products and the raw materials for producing 3D printed chocolates (semi-finished products). For the semi-finished products, the inventory consumptionis divided into finished products consumption (Q_f^m)and retailers order(Q_s^m).

Retailers profit is the sum of profits from the sale of both standard products and customisedproducts. The profit function is:

$$RP^3 = \frac{(P_f - W_f)D_f + (P_c - W_s)(D_c + D_c') - C_{fh}^r - C_{fs}^r - C_{fo}^r - C_{cp}^r - C_{so}^r - C_{ss}^r - C_{sh}^r}{T} \quad (7)$$

Manufacturers profit is the income from standard products and wholesale income of semi-finished products. The profit function is:

$$MP^3 = \frac{\sum_1^k (W_f - C_{fu}^m)Q_f^m + \sum_1^k (W_s - C_{su}^m)Q_s^m - C_{fh}^m - C_{fp}^m - C_{fs}^m - C_{sp}^m - C_{sh}^m - C_{ss}^m}{T} \quad (8)$$

6. Findings and analysis

This section contains two sub-sections. Section 6.1 reports findings of profits comparison of three models when the degree of customisation (θ) is at the 0.18 level, considered a threshold using the 20/80 ratio, below which the customised products don't become a main stream products.

6.1 Profit comparison of three models at the level of 0.18

Each simulation cycle is defined as 120 days; production lasts 8 hours per day; retailers and manufacturers check stock status every day. The customer arrival is based on the Poisson Distribution with a mean 25 enquiries per day. According to the P_f , P_c , P_c' parameters provided in table 1, given ($\frac{p_f}{u_f} < \frac{p_c - p_f}{u_c - u_f} < 1$), φ (value can be calculated and determines whether a customer buys standard or customised p roducts (see Figure 6). The quantity that a customer purchases is random (0-10 items per enquiry). The simulation is run with 120 days and a cumulative consumer demand for standard chocolate products (D_f) and customised products from retailer ($D_c + Dc'$) can be obtained. According to channel preference（ß）, the customer demand for customised products from offline channels (D_c) or online channels (Dc') can then be determined.

Table 2 shows the profit of the retailer, the manufacture and the supply chain (including both the manufacturer and the retailer) of the three models when $\theta = 0.18$.

--Insert Table 2 about here--

In manufacturers-dominant model, because the profits of manufacturer's customised products are higher than the standard products, manufacturer's profits increase significantly. The sales of customised products affect negatively the sales of standard products for the retailer, leading to the slight fall of retailers' profit compared to that of the traditional model because the total sales is invariable and the manufacturer still uses the retailer as a distribution channel. When the retailer profits are negatively affected, it may reduce retailer's incentive to sell customised products. In this scenario, after the introduction of customized products, the manufacturer needs to consider how to motivatethe retailer to sell customisedproducts.

In retailer-dominant model, retailer's profits increased significantly. The manufacturer profits stand in between that of the traditional and manufacturer-dominant models in that the retailer places more orders on the manufacturer for semi-finished products for its own customised product production.

For both retailer and manufacturer-dominant models, the total supply chain profits are similar to each other but increase by around *20%*comparing to the traditional model. Based on above findings, we are able to draw a conclusion below:

Conclusion 1： When the ratio of customised and standard products (θ) is0.18, the supply chain profits tend to be similar for both retailers-dominant and manufacturers-dominant models, but whoever (e.g., retailer or manufacturer) adopts the 3D printing technology or finally processes the customised products gain higher profit.

6.2 Profit trend for manufacturer and retailer dominant models

For the manufacturer-dominant business model (Figure 7), with the increase of θ value, the manufacturer profits increase as the same rate as total supply chain profits while retailer profits stay almost stagnant and is not affected by the increase of manufacturer profits.

--Insert Figure 7 about here--

For the retailer dominant model (Figure 8), with the increase of θvalue the retailer profits increase as expected however the manufacturer profits are affected negatively and significantly. When $\theta = 0.24$, the manufacturer starts making a loss. This also leads to the decline of total supply china profits. This is mainly because the retailer exploits the whole value of customised products through the commercialization of the 3D chocolate printing technology. The role of the manufacturer reduces significantly in the supply chain, has to stop producing finished products and has to compete with many semi-finished product providers for business. When the market is dominated by customised products when $\theta > 0.24$, the manufacturer could be replaced or put it another way, the traditional chocolate production technology will be disrupted by the 3D technology.

--Insert Figure 8 about here--

Conclusion 2: With the increase of customised products comparing to standard products on the market (increase of θvalue), it is important for the manufacturer to adopt the technology first, otherwise if the retailer adopts the technology first, the manufacturer can be replaced.

Both conclusions provide a strong argument for both retailers and manufacturers to adopt this technology. For conclusion 1, the one who adopts the technology first gain higher profits. Conclusion 2states that if manufacturers allow retailers adopt the technology and dominate the customised products market, they will be squeezed out of market or disrupted by the 3D printing technology.

7. Pioneering efforts of and challenges facing Choc Edge

The commercialization of 3D chocolate printing pioneered by Choc Edge faces both great opportunities and challenges. It is a consensus among the businesses and entrepreneurs interviewed that 3D chocolate printing brings a completely different approach to create, make and distribute chocolate products in comparison to the traditional capital intensive mass production. It could be therefore considered a disruptive technological innovation, which causes a possible change of business model, to enhance product value and reduce production and logistic cost, in particular for small volume production of novel or seasonal products and one-off customised products. In addition, it allows retailers or manufacturers to engage in consumers in a way that they can co-create products and re-configure chocolate production supply chains. This opens up new ways of running chocolate retailing, manufacturing and innovative business models.

Due to the pioneering position of the Choc Edge, it faces a broad of choices to adopt this new technology and business models. According to interviews with Choc Edge’s key individuals/managers, there are several shifts of business models for Choc Edge which were the result of evolutionary thinking and deeper understanding of the market. The company had made significant efforts on technology and market development in the past two years (2012 and 2013) as well as business model experimentations.

At an early stage, they decided to be a 3D chocolate printer provider selling 3D printing machines to potential buyers through various channels (e.g., direct selling and eBay). This proved not to be successful as potential business and entrepreneurial buyers face difficulty in using this new machine and technology and translating it into business opportunities. Then they decided to promote and sell unique seasonal and personalized chocolate products produced by the 3D printer based on the idea that people or business would buy only after they see how the machine works and produces products so this business model is in part for demonstration purpose. This activity has enabled the Choc Edge team to build more in-depth knowledge on the production and business operation in supplying 3D printed chocolates and the associated logistics and supply chains issues. It also allows the team to realize the difficulty in supplying the 3D printed chocolates to global markets due to high packaging and postage costs.

Based on these experiences, Choc Edge adapted its business strategy again and positioned itself atotal business solution provider offeringbusiness and technological advice (e.g., design, printing trail service for the machine buyers) on top of selling the machines i.e., a servitization strategy. This business model has enabled Choc Edge to increase sales of machines and target broad range of buyers including retailers, chocolate manufacturers, and individual entrepreneurs.

With the findings of this study, Choc Edge is able to present a case to both the targeted retailers and chocolate manufacturers to persuade them to adopt this technology in the UK. This has resulted in a number of purchases of the machine by the research teams of both retailers and manufacturers which could potentially lead to the fully fledged adoption in the UK.Now Choc Edge is attempting to create a situation where the retailers and manufacturers compete to be an early adopter of this technology giving them a first mover advantage. This is especially imminent for manufacturers because according to the two conclusions drawn in section 6, it is a matter of survival for manufacturers and it is an issue of whether or not to achieve first mover advantage for retailers.

However, there are challenges facing Choc Edge while commercializing 3D chocolate printing technology. Overall, the adoption of 3D printing technology is currently in small-scale, predominantly in high value industrial sectors such as aerospace, medical and creative industries. Although there are increased sales and adoption of low-cost 3D printers, these printers are predominantly used for prototyping or hobbyist applications. The business models for implementing this technology in a scalable retailing or manufacturing environment and selling 3D printed products to mainstream customers are lacking. As a pioneer and start-up, Choc Edge has to pursue both technical development and business model innovation simultaneously with limited man-power and financial resources. 3D chocolate printing requires specific temperature control and chocolate material properties to perform good layer-by-layer material dispensing and building process so as to make 3D chocolate in acceptable shape and tasty quality. Choc Edge will need to develop more advanced and automated system in order to improve productivity and efficiency of the 3D chocolate printings. In addition, it will have to develop easy-to-use software for chocolate printing and design customisation. These developments will require significant manpower and financial resources.

In parallel, they have to respond to diversified business enquires and opportunities. According to interviews with the company senior managers, a few large chocolate manufacturers and supermarkets have expressed great interest in this technology. However, forming an effective collaborative relationship with these large corporations proves to be difficult for Choc Edge at the moment. The decision process for big companies and retailers in adopting new technology is long and requires a lot of efforts from Choc Edge in term of technology demonstration and business negotiations. Furthermore, 3D chocolate printing technology creates a new value proposition by providing a high level of shape customisation, involving consumers in the product design, and enriching their personalized consumer experience (Cohen et al., 2009). This will require the buyers of 3D chocolate printers to have sufficient technical and service capability to create and produce personalized products in a cost effective way. They need to understand how to engage consumers in the chocolate design and printing process to offer value-added consumer experience. This could change the business models or operations for these 3D printing adopters. Such business innovations will require significant planning as well as experimentation work. Choc Edge team has spent significant time in exchanging views and discussing these business innovations with existing and potential machine buyers. Choc Edge faces a challenge in carrying on their own business innovation as well as assisting in their consumers in implementing new business innovations.

8. Conclusion

In this paper, we set out to use computer simulation for modeling supply chain constituents and their profitability functions with the aim of experimenting economic viability of the new 3D food printing-enabled business models in the processed food industry. We have achieved this by simulating two models of 3D enabled chocolate printing supply chains dominated by chocolate manufacturers and retailers respectively.We have shown that these two models are feasible solutions for manufacturesand retailers to adopt and compared the profits under each scenario/model. The simulation results show that 1) whoever between retailers and chocolate manufacturer adopts the 3D chocolate printing technology first gain higher profits than the other; 2) chocolate manufacturers risk being left out market if retailers adopt this technology, successfully commercialise it when $\theta > 0.24$ (ratio of customised and standard products) and assume a dominant position on the market.

We believe this is the first of its kind simulating 3D enabled food supply chain/business models, therefore we fill the gap in the literature. Our findings also show that 3D printing technology could be a disruptive innovation to chocolate manufacturers. The study has significant practical implications for chocolate manufacturers and retailers to consider and evaluate the adoption of this technology. The findings provide some insights and analytical results for Choc Edge to discuss with and persuade their potential customers on new business and supply chain innovations so that new business opportunities can be captured.

Future studies could design further models based upon these two basic ones in order to capture all the models in the industry. For example, when retailers or manufacturers see the other party take the advantage of this technology and attempt to catch up, the scenarios become more complex. Hence, simulation of the complex scenarios may be carried out and is more close to the real world.

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Fig 1. Supply chain of a traditional chocolate production

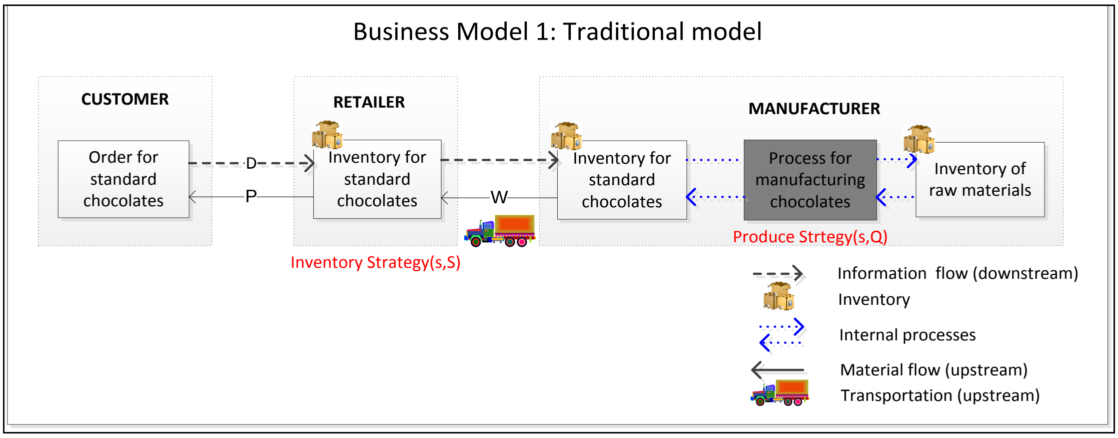

Fig 2. Manufacturer-dominant double-channel supply chain structure

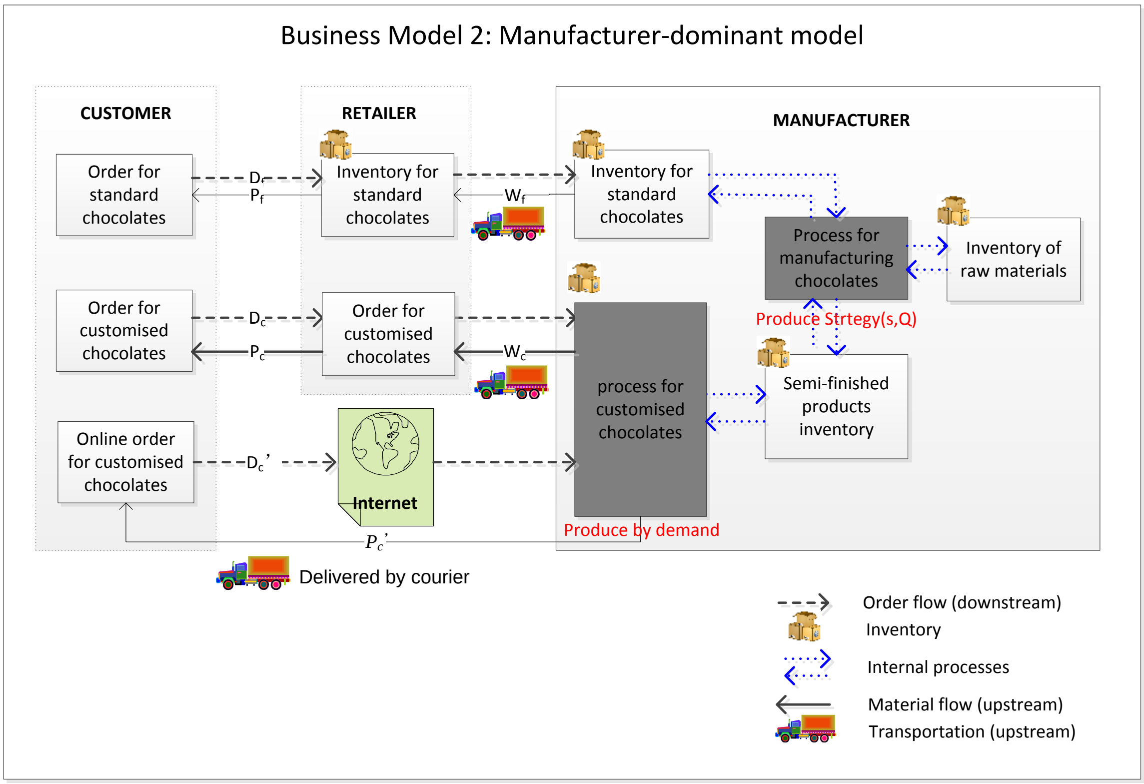

Fig 3. Retailer-dominant supply chain structure

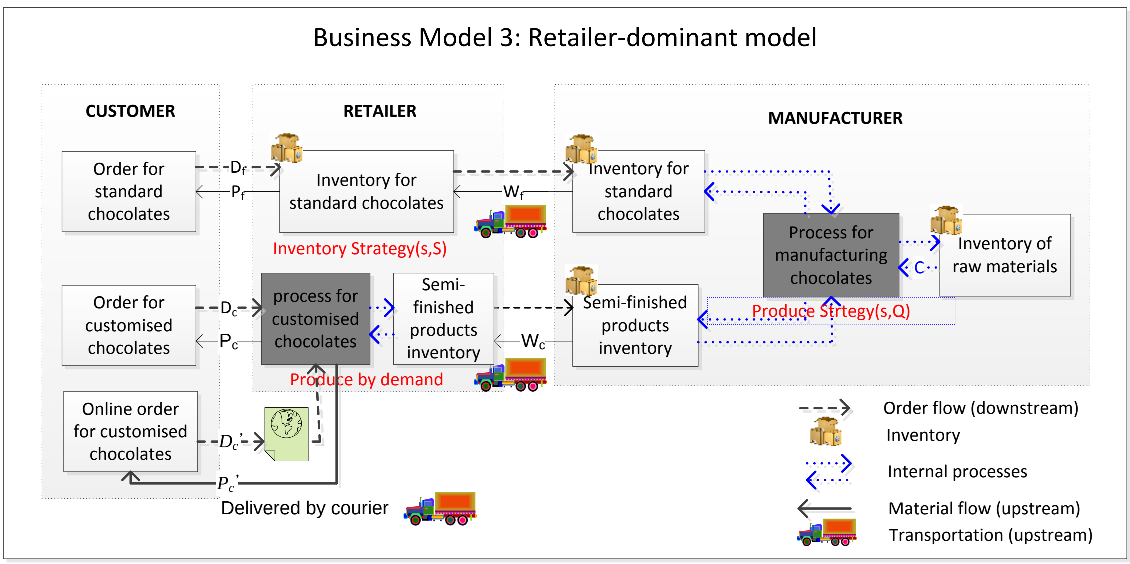

Fig 4.ExtendSim model of the retailer-dominant business model (model 1)

showing the processes pertaining to the retailer (top) and the manufacturer (bottom)

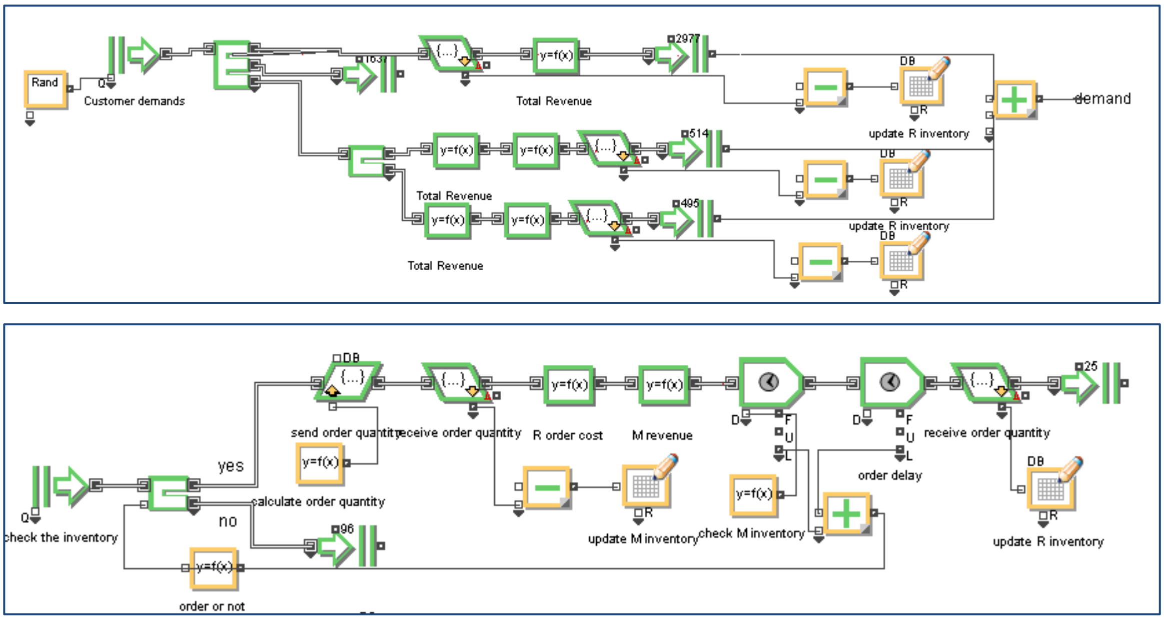

Fig 5. Simulation logic of retailer-dominant business model (model 3)

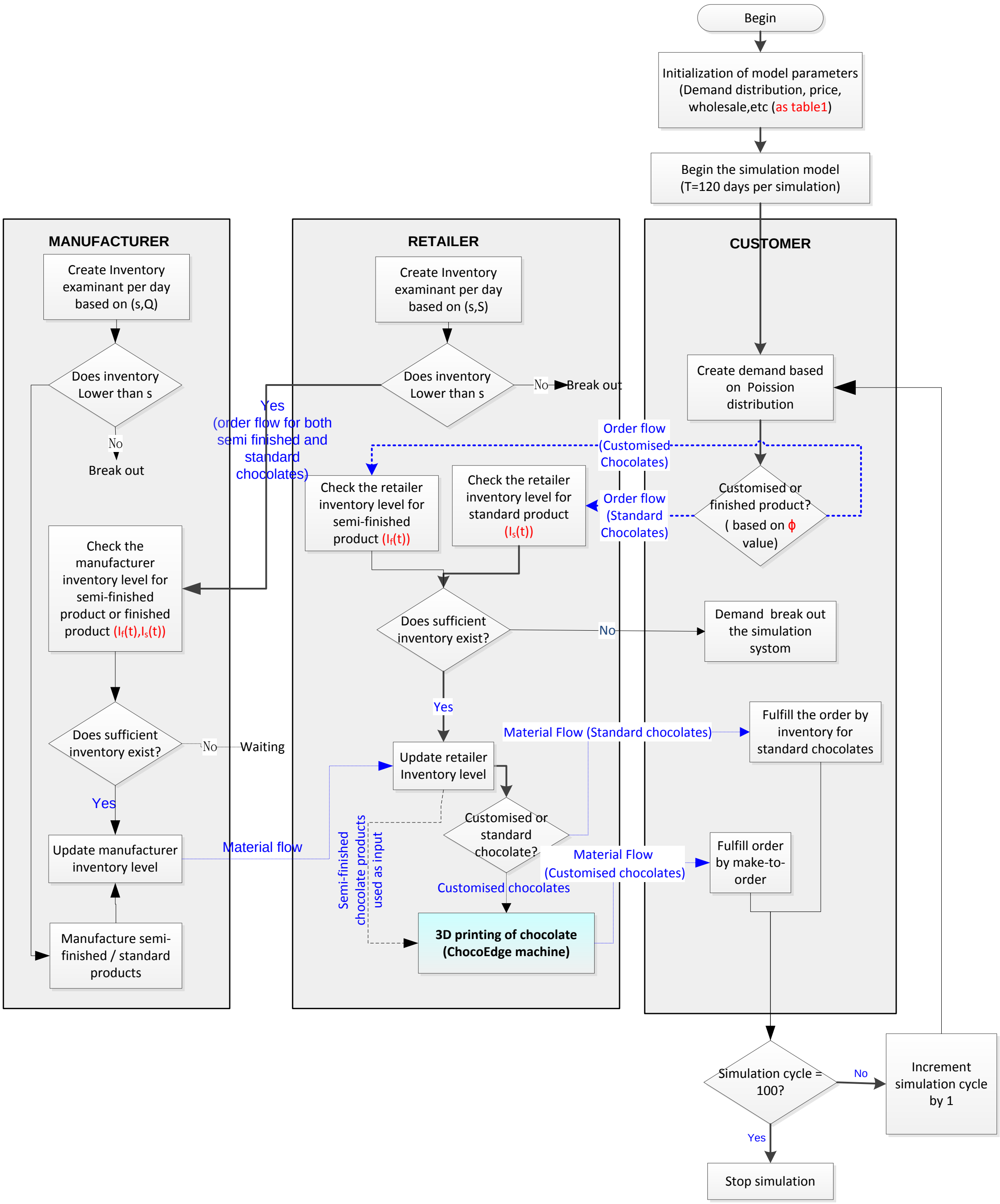

Fig. 6 **market demands of standard products and customised products**

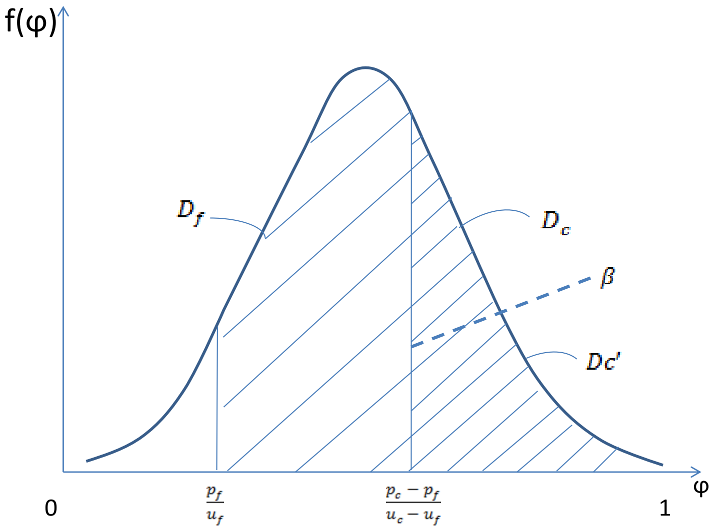

Fig. 7 Profit trend with the change of θ (manufacturer-dominant model)

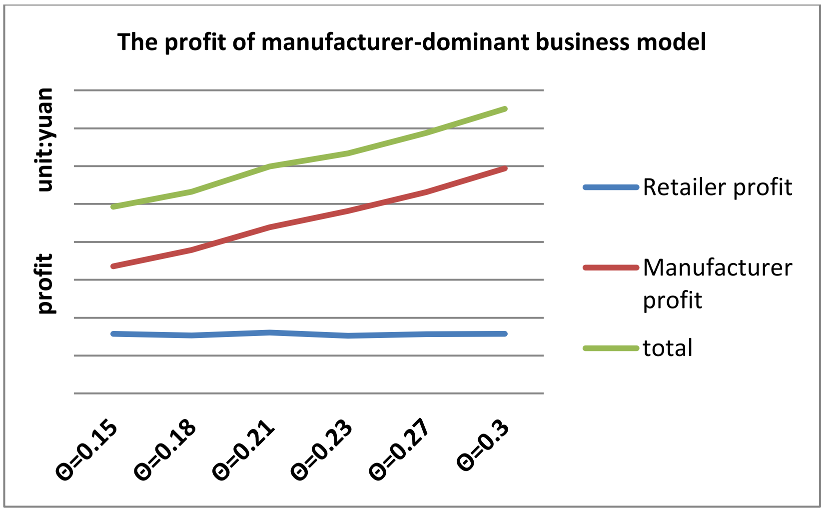

Fig. 8 Profit trend with the change of θ (retailer-dominant model)

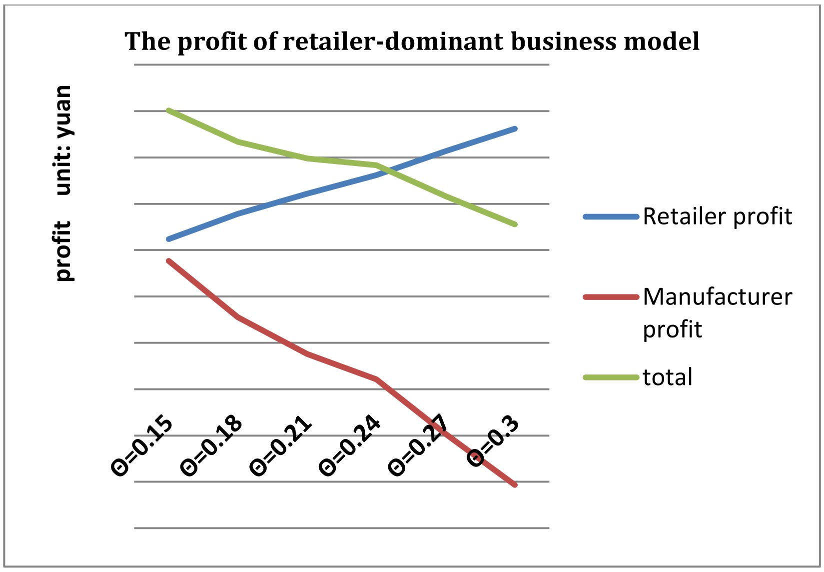

Table 1. Simulation parameters table

	Retailer		Manufacturer	
standard products	P_f	60	C_{fh}^m	0.04
	C_{fh}^r	0.04	C_{fs}^m	15
	C_{fs}^r	15	C_{fp}^m	3000
	C_{fo}^r	300	C_{fu}^m	12
	W_f	45		
customised products	P_c	100	P_c'	100
	W_s	25	C_{sh}^m	0.01
	C_{sh}^r	0.04	C_{ss}^m	20
	C_{ss}^r	20	C_{sp}^m	1500
	C_{cp}^r	1000	C_{su}^m	12
	C_{so}^r	300	C_{cp}^m	1000
	W_c	85	C_n	3

Unit: Chinese Yuan; Approximately 1 Yuan= 0.1British pound

Table 2. Profits of the manufacturer, the retailer and the supply chain ($\theta = 0.18$)

	Retailer Profit	Manufacturer profit	Supply chain profit
Traditional supply chain	392	540	932
Manufacturer-dominant supply chain	325	793	1118
Retailer-dominant supply chain	537	632	1169