Online Grocery Retailing for Fresh Products with Order Cancellation and Refund Options

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This research studies an online grocery retail business. Customers of this business demand fresh products and efficient delivery, and at the same time want to keep options of cancelling the orders and getting refund. The business prepares the customer orders by two shifts while the customer orders are collected and the order cancellations occur. In this study, we derive the optimal joint inventory and pricing strategy with considerations of order cancellation and refund options. We use both theoretical and simulation approaches to reveal the impact of order cancellation and refund policy on the business performance. Our findings provide guidance and insights to on-line grocery businesses to maintain and improve their profitability while offering their customers the flexibility to cancel orders.

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I. INTRODUCTION

Online grocery business, also known as e-grocer, has gained substantial growth in the recent years. On one hand, the tech-savvy retailers and retail-savvy tech companies are constantly seeking new territories to expand their business. On the other hand, time-crunched consumers are raising their expectations on how much convenience the business world could provide them. "Around a quarter of American households currently buy some groceries online, up from 19 percent in 2014, and more than 70 percent will engage with online food shopping within 10 years. (Daniel 2017)" Online grocery shopping is becoming increasingly integrated into daily lives of common households, especially for women (who have traditionally been the primary food shoppers), dual-income households, single-parent households and elderly households with time and other resource constraints. Not only in the US, nowadays a greater number of populations in China buy groceries over Internet. Our study is mainly based on a seafood e-grocer in Beijing, China.

Research on online grocery business models (Palmer et al. 2000; Corbett 2001; Anckar, Walden, and Jelassi 2002; Tanskanen, Yrjölä, and Holmström 2002; Frohlich and Boyer 2003; Kempiak and Fox 2006; Ahmed and Fahad 2016) conclude that the two main e-grocer models are the store-based picking model (Bricks and Clicks Model), and the pure-play EGS (E-Grocery Shopping) model. The store-based picking model (Bricks and Clicks Model) allows their customers to place orders online, then pick up the orders at stores, which saves the customers time shopping in the stores. This is usually the model traditional brick and mortar grocery businesses first adopt when expanding their business online. Examples of the store-based picking model include Safeway and Walmart. The pure-play EGS model does not own any physical stores. It not only lets the customers place their grocery orders online, but also delivers the orders for them. Amazon Fresh and most farm-to-door business like FarmFreshToYou.com are examples of the pure-play EGS model. Even though the store-based picking model may also offer the delivery service, the hybrid nature of the business requires the store to separate the operations for display and picking and packing purposes. This leads to lower efficiency and higher operational cost (Palmer et al. 2000).

The pure-play EGS model is the e-grocer model studied in this paper. Particularly, we consider a pre-order online only grocery business that sells fresh products, and customers determine and pay each order separately. Fresh products, for example, fresh seafood, fresh vegetables, etc., have significant short shelf life comparing to other kinds of grocery items, and therefore cannot be stored by consumers long time before the consumptions. The freshness of the products is the major value the e-grocer provides to its consumers.

As many people still recall the spectacular failure of Webvan more than a decade ago (Wohlsen 2014), the recent e-grocer development still faces the question of survival and growth. The sustainability and profitability are even bigger concerns for an e-grocer selling fresh products. The short shelf life of fresh products limits both the supply preparation window and the order fulfillment window. For example, for the Chinese seafood e-grocer, the short shelf life of the products demands the planning cycle from obtaining the products to delivering the products to consumers to take less than one day. Besides, due to the lag between the order placement and the order delivery in the pre-order model (even though it is fairly short for fresh products), consumers desire the flexibility of cancelling their orders. This, for sure, will create more chaos in the order preparation process. However, e-grocers are concerned that a lack of the order cancellation option will negatively affect their market competitiveness and customer satisfaction. In this paper, we aim to provide guidance to e-grocers on maintaining their profitability while keeping the order cancellation and refund options for their customers in a pre-order setting.

Note that besides the pre-order model, there exists another commonly applied pure-play EGS model, called subscription model, where customers pay a set fee and receive deliveries routinely. As pointed out in Belavina, Girotra, and Kabra 2017, the subscription model generates more food waste, especially for highly perishable products. To reduce the food waste, E-grocers using a subscription model usually adopt strict order cancellation policies. For example, FarmFreshToYou.com, a California based fresh product e-grocer, requires their customers to cancel orders at least 4 days before the scheduled delivery date; i.e., the orders have to be cancelled prior to the preparation. This requirement alleviates the over-stocking/food waste risk from the business, yet creates inconvenience for the customers.

In our model, customer orders arrive randomly in each planning horizon. The order cancellation is allowed within a limited window, which partially overlaps with the demand arrival process but prior to the order shipment. Order cancellation may be fully or partially refunded. The e-grocer determines the selling prices of the products first that influences the consumer demand, then prepares the supply by two shifts. The two supply preparation shifts have different preparation costs and different amount of demand and order cancellation information. Order shipment occurs at the end of the planning horizon after the second shift of supply preparation and is considered a sunk cost. For the e-grocer we study, order shipment for the local market happens in late night/early morning when traffic is the lightest and transportation is the most efficient.

Theoretically, we provide the optimal joint inventory and pricing decisions to the fresh product e-grocer given any predetermined order cancellation and refund policy. By studying the impact of the order cancellation and refund option on the optimal decisions, we derive conditions under which the e-grocers could maintain and improve its profitability. We show that the e-grocer should always charge a lower price when order cancellation is allowed. The lower selling price, which induces larger consumer demand, may improve the profitability for two reasons: a larger demand may lead to a higher order cancellation revenue if the order cancelation is not fully refunded; and a larger demand helps the business to achieve the economies of scale during the first shift of the order preparation if the first preparation is strictly cheaper than the second one. In the numerical study, we further explore the impact of the refund policy on the market growth and the customers' order cancellation behavior by treating the refund proportion as a decision variable. The numerical results show that the selling price and the order preparation decisions are relatively robust in response to different market growth needs and different customer cancellation behaviors. The refund policy, on the other hand, should be adjusted responsively to market growth need and customers' sensitivity to a refund policy. A full refund policy may improve the profitability of the e-grocer if the market growth is tightly associated with the refund policy and customers strongly favor a higher level of refund, even though it means the e-grocer loses revenue from the cancelled orders.

The rest of the paper is organized as follows: Section 2 summarizes the literatures related to our work; Section 3 introduces the model; in Section 4, we present the main theoretical results; in Section 5, we conduct numerical studies to further examine the impact of order cancellation and refund options on the business performance; Section 6 concludes the paper.

II. LITERATURE REVIEW

Research related to online grocery shopping has paid much attention to consumer response (Morganosky and Cude 2001; Morganosky and Cude 2002; Wang and Tsai 2014), consumer behavior (Ramus and Nielsen 2005; Kempiak and Fox 2006; Hand et al. 2009; Gong, Stump, and Maddox 2013; Zhu and Semeijn 2015), as well as consumer expectations (Wilson-Jeanselme and Reynolds 2006; Scott and Scott 2008; Xia, Huang, and Zhu 2010). These works particularly concern with the acquisition of customers in online grocery retail market, and show that people are likely to buy groceries online in terms of convenience, product range and price. The disadvantages of online grocery shopping mentioned in these works could be concluded as mental barriers, e.g., the risk of receiving inferior quality groceries and the loss of the recreational aspect of grocery shopping. In the study conducted by Ramus and Nielsen 2005, it is reported that two groups of interviews *not* experienced with online grocery shopping perceived underlying risks due to the inherent time lag between ordering and delivery, which might cause losses in situations of urgency. It is an inevitable issue under present increasing online grocery market, and order cancellation option with refund has been adopted as a major approach to alleviate this kind of risk from e-grocer consumers. However, the order cancellation option creates more operations difficulties on the business side. In this paper, we explore the profitability of refund policy for consumer order cancellations in an online grocery business.

The stream of literature most relevant to our study is perishable inventory management with order cancellations, pricing strategy, and refund policy. From an inventory management point of view, order cancellations are considered as disruptions to the supply process. You and Wu (2007) develops a continuous time inventory model with order cancellations in advance sales period, and investigates the optimal ordering and pricing policy of two-period sales to achieve the maximum total profit. Jiang-Tao et al. (Jiang-Tao et al. 2008) establishes a production-sale model for deteriorating items with advance sales and spot sales, assuming the order cancellation rate is constant. Similarly, Son 2008, Thangam and Uthayakumar 2009, Zhang and Fu-Wen 2011, Zhao and Pang 2011, Fan 2012, Dye and Hsieh 2013, and You 2017 study order cancellation issues by deriving the optimal pricing and ordering policy, which aims to maximize the total profit. The difference of our study from the ones mentioned above lies in the different timeline. All of these papers listed above have one advance period with order cancellations plus one spot period without order cancellations. In our paper, the selling period and the order cancellation period overlaps with each other, at the same time, customer orders are prepared by two shifts with different amount of information. This difference implies a higher level of order cancellation disruption in our study by shifting the influence of the order cancellation from the early stage of the planning horizon towards the end of the planning horizon.

The order cancellation issue has also been studied in revenue management literatures. The techniques of revenue management are widely used in practices, e.g., airlines, hotels and fashion industry, which are characterized by limited capacity and high perishability. Gallego and Çahin 2010; Mcgill and Ryzin 1999; Watanabe and Moon 2011; Rusdiansyah et al. 2013 consider the online retailing problem with order cancellation and refund in this category. They focus on optimizing capacity allocation according to the forecasting of no-shows and partially refund for order cancellations. Although the problems in these papers have the similar perishability, the preparation costs have different features for online grocery retail business. The paper of Xie and Gerstner 2007 show that offering refunds for customer cancellations on a service request could be profitable without increasing the selling price. Namely the service provider could gain an extra revenue by allowing customers to cancel the services before delivery. While this paper, published in *Marketing Science*, only studies the impact of order cancellation on the demand side, we extend the study of order cancellation to the supply process of a e-grocer and prove that a lower price could benefit the e-grocer even no extra revenue is collected from order cancellation.

It is worth noting that the refund policy for product returns cannot be applied directly to the order cancellation situation in this study. Product returns are often caused by low quality or poor fit. Refunds for returns provide insurance against dissatisfaction, and allowing firms to charge higher prices and earn higher profits (Fruchter and Gerstner 1999). Previous researches (Mann and Wissink 1989; Moorthy and Srinivasan 1995; Chu, Gerstner, and Hess 1998; Shieh 2010) have shown that offering refunds for product returns can be profitable. However, order cancellations for e-grocers typically occur before the ordered items are delivered or shipped. E-grocers offer refunds only on cancellations made well before the delivery moment.

III. MODEL

We consider a pre-order online fresh grocery retail business with order cancellation options and two supply preparation shifts. Due to the perishable nature of the fresh products, the problem is single-period with planning horizon starting from determining the selling price and accepting consumer orders, and ending when all orders are shipped. Any cost occurs between order shipment and order delivery is considered as a sunk cost. During the planning horizon, the following four events occur: online consumer order collection, consumer order cancellation, first shift of supply preparation, and second shift of supply preparation. The timeline of these four events is shown in Figure 1.

Table 1 below summarizes all the symbols used in our model.

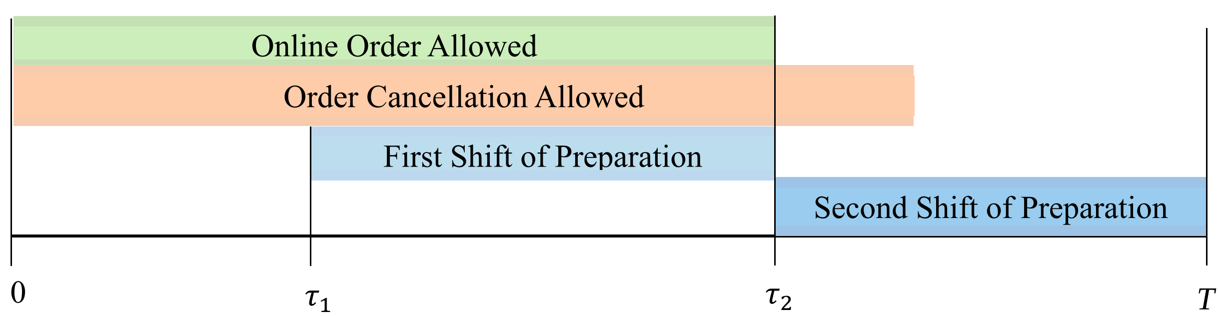

FIGURE 1. SEQUENCE OF EVENTS

TABLE 1. SUMMARY OF THEORETICAL MODEL SYMBOLS

Symbol	Meaning of the Symbol
T	The length of the planning horizon
τ_1	The time when the first shift of supply starts to be prepared
τ_2	The time when the second shift of supply starts to be prepared
c_0	Unit preparation cost of the first shift of supply
c_1	Unit preparation cost of the second shift of supply ($c_1 \geq c_0$)
x	Preparation quantity of the first shift of supply
p	Selling price
$D(p)$	Demand function $D(p) = \lambda - \mu p$
λ	Demand function parameter that indicates the market potential
μ	Demand function parameter that indicates the price sensitivity
δ	Refund proportion $0 \leq \delta \leq 1$
ϵ	Percentage of order cancellation – random variable when *x* is determined $\epsilon \in [0,1]$
$F(\cdot)$	Cumulative distribution function of ϵ
$f(\cdot)$	Density function of ϵ
β	$\beta = \frac{c_{0/c_1} - \int_0^{F^{-1}(c_0/c_1)} \epsilon dF(\epsilon)}{1 - \delta E(\epsilon)}$

3.1 Order Preparations

Besides the time difference, the two supply preparation shifts differ in two other aspects: preparation cost and available information. When the first shift of supply preparation starts at τ_1, the unit preparation cost, denote as c_0, is relatively low. When the quantity of the first shift preparation, denote as x , is determined, both the demand information and the order cancellation information, however, are only partially revealed. While the second shift of supply is prepared from τ_2 , accurate demand information and order cancellation information can be gradually observed. Yet, the second shift of supply comes with a relatively higher preparation cost, denote as c_1 ($c_1 \geq c_0$). Note that the capacity or time constraint is not explicitly modeled in our study, but indirectly reflected in the preparation costs. A higher preparation cost implies a more limited capacity or a tighter time constraint. Since the second supply preparation is eventually determined based on perfect information, only the first supply preparation quantity x needs to be optimized. We assume there is an ample supply. Therefore, lost sales can always be avoided in this problem. However, the first supply preparation and order cancellation could lead to over-stock/food waste. Any leftover supply is discarded with zero salvage value.

In this study, we simplify the relations among the events by letting τ_2 represent both the end of the online order collection and the beginning of the second shift preparation. This relation can be relaxed without affecting the main results of this paper as long as the second shift of supply can eventually be prepared based on perfect information. In Section 4, we do not consider τ_1 and τ_2 as decision variables, but treat them as fixed parameters. Instead, we focus on deriving the optimal joint inventory and pricing decisions and analyzing the order cancellation and refund options under different parameter settings. When τ_1 and τ_2 changes, the cost difference as well as the demand and order cancellation uncertainties will be affected. We illustrate these impacts on the business performance in the numerical study.

3.2 Demand Function and Order Cancellation

We assume the total expected demand, denote as $D(p)$, depends on the selling price decision p according to a linear function: $D(p) = \lambda - \mu p$, where λ measures the total market potential, and μ indicates the price sensitivity.

Each order cancellation is associated with a partial or full refund δp, where δ is the proportion of the refund and $\delta \leq 1$. When $\delta < 1$, the e-grocer charges a penalty $(1-\delta)p$ to their customers for each cancelled order. This order cancellation penalty is also referred to as order cancellation fee. Let ϵ denote the fraction of order cancellations with range $[0, 1]$. At the moment the initial shift of supply is prepared, ϵ is a random variable with known distribution function $F(\cdot)$, and density function $f(\cdot)$.

In Section 4, we treat the refund proportion δ as a system parameter, and focus on deriving the optimal pricing and inventory decisions, and discussing the impact of order cancellation and refund options on these two decisions. To simplify the analysis, the order cancellation fraction ϵ is assumed to be independent of the amount of demand in the theoretical analysis.

In Section 5, we further explore of the impact of the refund policy using numerical studies by considering it as a decision variable. Moreover, in Section 5, we consider the impact of refund proportion δ on the demand population and the order cancellation fraction. When a refund policy that is more favorable to the consumers is chosen, it is likely to attract more demand, and encourage higher level of order cancellations.

3.3 Objective Function

Let $\Pi(p, x)$ denote the total expected profit. Then

$$\Pi(p, x) = \mathrm{E}\{R(p) - c_0 x - \delta R(p)\epsilon - c_1(D(p) - \epsilon D(p) - x)^+\},$$

where $R(p) \triangleq pD(p)$ represent the total expected revenue, excluding order cancellations, $c_0 x$ represents the cost of the first shift of the supply preparation, $\delta R(p)\epsilon$ is the amount of revenue returned to customers who cancel their orders. Define the function $(\cdot)^+ \triangleq \max\{0, \cdot\}$. Then $c_1(D(p) - \epsilon D(p) - x)^+$ evaluates the cost of the second shift of supply preparation.

IV. MAIN RESULTS

4.1 Optimal Decisions

Proposition 1. *The total expected profit $\Pi(p, x)$ is jointly concave in (p, x).*

Proof: To prove $\Pi(p, x)$ is jointly concave in (p, x), we only need to prove every component contained in $\Pi(p, x)$ is jointly concave in in (p, x).

Due to the linear structure of $D(p) = \lambda - \mu p$, $R(p)$ is concave in p. Let $G(p, x) \triangleq \mathrm{E}(D(p) - \epsilon D(p) - x)^+ = \int_0^{1-\frac{x}{D(p)}} (D(p) - \epsilon D(p) - x) dF(\epsilon)$. It is left to show $G(p, x)$ is jointly convex in (p, x).

$\frac{\partial G(p,x)}{\partial p^2} = \frac{x^2\mu^2}{D(p)^3} f\left(1 - \frac{x}{D(p)}\right) \geq 0$, $\frac{\partial G(p,x)}{\partial x^2} = \frac{x^2\mu^2}{D(p)} f(1 - \frac{x}{D(p)}) \geq 0$, $\frac{\partial G(p,x)}{\partial x \partial p} = \frac{\partial G(p,x)}{\partial p \partial x} = \frac{x\mu}{D(p)^2} f(1 - \frac{x}{D(p)})$. *Then.* $\frac{\partial G(p,x)}{\partial p^2} \frac{\partial G(p,x)}{\partial x^2} -$

$\frac{\partial G(p,x)}{\partial x \partial p}\frac{\partial G(p,x)}{\partial p \partial x} = 0$. *Therefore,* $\Pi(p,x)$ *is jointly concave in* (p,x). □

Proposition 1 implies that the joint optimal solution (p^*,x^*) uniquely exists.

Proposition 2. *The expected profit* $\Pi(p,x)$ *is sub-modular in* (p,x), *which implies that the* x^* *decreases in* p^*.

Proof: In $\Pi(p,x)$, *only* $G(p,x)$ *contains both p and x. Therefore, to prove* $\Pi(p,x)$ *is sub-modular in* (p,x), *we only need to prove* $G(p,x)$ *is super-modular in* (p,x). *As shown in the proof of Proposition 1,* $\frac{\partial G(p,x)}{\partial x \partial p} = \frac{\partial G(p,x)}{\partial p \partial x} = \frac{x\mu}{D(p)^2} f\left(1-\frac{x}{D(p)}\right) > 0$. *Therefore,* $\Pi(p,x)$ *is sub-modular in* (p,x). □

With a higher selling price, demand will be lower. Therefore, the quantity of the first supply preparation will be reduced.

Proposition 3. $\frac{x^*}{D(p^*)} = 1 - F^{-1}(\frac{c_0}{c_1})$.

Proof: The optimal solution (p^*,x^*) satisfies the *first order condition of* $\Pi(p,x)$*:*

$$\frac{\partial \Pi(p,x)}{\partial x} = -c_0 - c_1\frac{\partial G(p,x)}{\partial x} = -c_0 + c_1 F\left(1-\frac{x}{D(p)}\right) = 0.$$

Therefore, $\frac{x^*}{D(p^*)} = 1 - F^{-1}(\frac{c_0}{c_1})$. □

Proposition 3 implies that once the selling price is determined, the initial preparation quantity is a faction of the expected total demand, where the fraction only depends on the cost difference between the first and second supply preparations, and the order cancellation distribution. The amount of the refund proportion δ does not directly affect the first supply preparation quantity. The first shift preparation quantity is determined to achieve the tradeoff between preparation cost and available information of order cancellation, i.e., the risk of over stocking. If there is no cost difference between the two supply preparations, i.e., $c_0 = c_1$, then $x^* = 0$, i.e., all the supply will be prepared after the demand and order cancellation information is realized. If $c_0/c_1 \to 1$, then $x^* = D(p^*)$, i.e., all the customer orders will be prepared initially according to the expected demand quantity, as the second order preparation cost is relatively too high.

Proposition 4 below presents the explicit form of the optimal pricing decision. The solution reveals that the preparation costs influence the pricing decision in two ways: 1) When the cost of the second supply preparation gets higher, a higher price is charged to offset the cost; 2) when the cost ratio c_0/c_1 gets lower, a lower price is charged to attract more demand, so that the cost advantage of the first order preparation can be better achieved.

Proposition 4. *(i)* $p^* = \frac{\lambda + c_1\mu\beta}{2\mu}$, *where* $\beta = \frac{c_0/c_1 - \int_0^{F^{-1}(c_0/c_1)} \epsilon dF(\epsilon)}{1-\delta \mathrm{E}(\epsilon)}$; *(ii)* $\beta \le 1$ *and increases in* c_0/c_1; *(iii)* p^* *increases in* c_0/c_1.

Proof:

(i) *The optimal solution* (p^*,x^*) satisfies the *first order condition of* $\Pi(p,x)$*:*

$$\frac{\partial \Pi(p,x)}{\partial p} = \left(1-\delta \mathrm{E}(\epsilon)\right)(\lambda - 2\mu p) + c_1\mu F\left(1-\frac{x}{D(p)}\right) - c_1\mu\int_0^{1-\frac{x}{D(p)}} \epsilon dF(\epsilon) = 0.$$

From Proposition 3, we have that $F\left(1-\frac{x^*}{D(p^*)}\right) = \frac{c_0}{c_1}$. *Then*

$$\left(1-\delta \mathrm{E}(\epsilon)\right)(\lambda - 2\mu p^*) + c_1\mu\frac{c_0}{c_1} - c_1\mu\int_0^{F^{-1}\left(\frac{c_0}{c_1}\right)} \epsilon dF(\epsilon) = 0,$$

$$p^* = \frac{c_1\mu\left[\frac{c_0}{c_1} - F^{-1}\left(\frac{c_0}{c_1}\right)f(F^{-1}(\frac{c_0}{c_1}))\right]}{2\mu(1-\delta \mathrm{E}(\overline{\epsilon}))} + \frac{\lambda}{2\mu} = \frac{\lambda + c_1\mu\beta}{2\mu}.$$

(ii) We first prove $\beta = \frac{c_0/c_1 - \int_0^{F^{-1}(c_0/c_1)} \epsilon dF(\epsilon)}{1-\delta \mathrm{E}(\overline{\epsilon})}$ *increases in* c_0/c_1.

Let $\gamma(z) \triangleq z - \int_0^{F^{-1}(z)} \epsilon dF(\epsilon)$. *To prove* β *increases in* c_0/c_1, *we only need to show* $\gamma'(z) > 0$. $\gamma'(z) = 1 - \frac{1}{f(F^{-1}(z))}F^{-1}(z)f(F^{-1}(z)) = 1 - F^{-1}(z) > 0, if\ F^{-1}(z) < 1$.

$F^{-1}(\cdot)$ *is the inverse distribution function of* $\epsilon \in [0,1]$. *Then* $F^{-1}(\cdot) < 1$.

When $c_0 = c_1$, c_0/c_1 *takes its largest value 1.*

$\beta = \frac{1-\int_0^{F^{-1}(1)} \epsilon dF(\epsilon)}{1-\delta \mathrm{E}(\epsilon)} = \frac{1-\mathrm{E}(\epsilon)}{1-\delta \mathrm{E}(\epsilon)} \leq 1$, *since* $\delta \leq 1$. □

4.2 Order Cancellation and Refund Option Discussion

To analyze the value of the order cancellation option and the refund proportion choice, we compare our results in Section 4.1 to the optimal decision in the a benchmark system with no order cancellation and $c_0 = c_1$. In this benchmark system, since there is no cost advantage from earlier supply preparation, all orders will be prepared until demand information is fully observed. The only decision in this system is the selling price p. Let $\overline{\Pi}(p)$ be the total expected profit for the benchmark system. Then

$$\overline{\Pi}(p) = R(p) - c_1 D(p).$$

Denote the optimal pricing decision for the benchmark system as $\overline{p}$.

Proposition 5. *(i) The optimal price for the benchmark system* $\overline{p} = \frac{\lambda + c_1\mu}{2\mu}$; *(ii)* $p^* \leq \overline{p}$.

Proof: (i) The optimal price $\overline{p}$ *satisfies the following first order condition:*

$$\lambda - 2\mu p + c_1\mu = 0,$$

$$\overline{p} = \frac{\lambda + c_1\mu}{2\mu}.$$

(ii) $\beta \leq 1$ *implies that* $p^* \leq \overline{p}$. □

Proposition 5 implies that the price will be chosen at a lower level when order cancellation is allowed or there is a cost advantage from the initial supply preparation. This will in turn generate larger amount of demand.

From the proof of Proposition 5, we can see that the impacts of order cancellation, refund proportion, and preparation cost difference on the pricing decision are fully captured by the term of β. Below we analyze the order cancellation and refund impact and the cost impact, respectively, by studying the term of β in two special cases:

Case 1. When $c_0 = c_1$, and $\delta < 1$, $\beta = \frac{1-\mathrm{E}(\epsilon)}{1-\delta \mathrm{E}(\epsilon)} < 1$.

In this case, the impact of cost difference is removed. β measures the ratio of the fraction of orders to be fulfilled $(1 - \mathrm{E}(\epsilon))$ and the fraction of revenue to be kept $(1 - \delta \mathrm{E}(\epsilon))$. $\beta < 1$ implies that the fraction of revenue to be kept is strictly higher than the fraction of orders to be fulfilled. This is because the orders cancelled by the customers are only partially refunded, i.e., there is an extra revenue from cancelled orders. This provides incentives to attract more demand at the beginning which may induce more order cancellations and order cancellation revenue later on. To increase the overall number of customer orders, a lower selling price needs to be charged comparing to the case where order cancellation is not allowed. Moreover, β decreases in $1 - \delta \mathrm{E}(\epsilon)$, which implies that a larger amount of demand will be attracted from a lower price when a larger portion of revenue can be kept from the cancelled orders.

Case 2. When $c_0 < c_1$, and $\delta = 1$, $\beta = \frac{c_0/c_1 - \int_0^{F^{-1}(c_0/c_1)} \epsilon dF(\epsilon)}{1-\mathrm{E}(\epsilon)} < 1$.

In this case, no additional revenue can be collected from order cancellation since full refund is issued. However, there is a cost benefit from the initial supply preparation. Therefore, a lower selling price will still be charged to attract more demand at the beginning to enlarge the cost advantage from initial supply preparation.

The above discussion provides two directions to maintain profitability while an e-grocer consider offering the order cancellation and refund options to their customers. The business could make an effort to lower the initial preparation cost c_0. This allows the business to choose a refund policy more favorable to their customers. If the business could not be able to lower the initial preparation cost c_0, then the business has to count on getting compensation from order cancellations by keeping the refund fee high.

Note that the argument above is also aligned with the idea of push/pull strategy. An e-grocer is basically adopting a push/pull strategy while allowing two shifts of supply preparations. The amount of order cancellations depends on the decision of the push stage, and has an influence on the outcome of the pull stage. When a low selling price is charged at the push stage, a large amount of demand will be induced, which raises the chance of order cancellations and the risk of leftovers. If the e-grocer can enjoy substantial amount of cost saving from economies of scale at the push stage, the higher risk of order cancellation is less harmful to the business. Otherwise, the business has to protect itself from charging an order cancellation fee. The benefit from either the economies of scale or the order cancellation fee desires a larger demand quantity or a lower price.

V. NUMERICAL STUDY

In this section, we rely on the Monte Carlo simulation approach to further analyze the order cancellation and refund options. Unlike the theoretical study, where impact of order cancellation and refund policy is analyzed based on aggregated order collection and cancellations, we consider the customer arrival, order cancellation and preparation as continuous processes in the numerical study. Furthermore, in this section, we consider the refund proportion δ as an additional decision variable, and assume it has two more impacts on the system: 1) the potential market size λ gets higher when a larger refund proportion δ is chosen; 2) the order cancellation rate gets higher with a larger refund proportion δ.

The Monte Carlo simulation approach presented in this section not only generates more managerial insights, but also aims to serve the industrial practice purpose.

5.1 Monte Carlo Simulation Formulation

A Monte Carlo simulation is coded on Mathworks Matlab R2017b (https://www.mathworks.com/) to model the continuous process. Assume that customer order arrivals follow a non-stationary Poisson process. The allowed ordering and cancellation period T_0 is segmented into n sub-periods and we assume the Poisson arrival rates a_i, $i = 1, \cdots, n$, is known in all sub-periods. It is unnecessary that the sub-periods are of equal length. The length of sub-period i is t_i, $i = 1, \cdots, n$. In practice, the average number of arrivals in each sub-period can easily be obtained by analyzing historical data. We also assume that for each customer order, the possible cancellation also follows a memoryless process that the time of cancellation after the order placement follows an exponential distribution. If the simulated cancellation time falls outside of the allowed cancellation period, the order is sustained. The percentage of cancellation is ϵ. It is straightforward to show that the numbers of sustained orders, denote as d_i, at the end of the sub-periods follow the following distributions.

$$d_1 = \text{Binomial}\left(\text{Poisson}(a_1), \frac{t_1}{2T_0}\right),$$

$$d_i = \text{Binomial}\left(d_{i-1}, \frac{t_i}{T_0}\right) + \text{Binomial}(\text{Poisson}(a_i), \frac{t_i}{2T_0}).$$

Assume that demand d_{n-k} is observed at the end of sub-period $n-k$, $k \geq 2$, and the supply preparation quantity x of the first shift is determined at the end of sub-period $n-k$ as a ratio r of the of the observed demand d_{n-k}, i.e., $x = rd_{n-k}$. The allowed ordering period ends at the end of sub-period n – 1. During the last sub-period, sub-period n, no more ordering is allowed but existing orders can be cancelled. The final demand is therefore $d_n = \text{Binominal}\left(d_{n-1}, \frac{t_n}{T_0}\right)$. The second shift production quantity is $\max(d_n - x, 0)$.

The process can therefore be simulated using Monte Carlo simulation instead of discrete event simulation. d_n is the final number of sustained orders and $\sum_i a_i - d_n$ is the number of cancelled orders. The total revenue, cost, and profit can be calculated in accordance with customer orders, cancellations, and supply preparation decisions. Since a large number of replicates can easily be simulated using Monte Carlo simulation, optimal solutions can be obtained using optimization-via-simulation to maximize the expected profit.

Assume that the potential market size λ is a function of the refund rate δ.

$$\lambda = \lambda_0 + \delta\lambda_1$$

A high ratio of λ_1/λ_0 implies that the market is highly sensitive to the cancellation refund policy.

Also assume that the order cancellation percentage ϵ is a function of the refund rate δ:

$$\epsilon = \delta\epsilon_0$$

That is, we assume $\epsilon = 0$ if the refund rate is 0% and the maximum possible cancellation percentage ϵ_0 is achieved if the refund rate is 100%.

Table 2 below summarizes the set of symbols used in the simulation in addition to the ones listed in Table 1.

TABLE 2. SUMMARY OF SIMULATION MODEL SYMBOLS

Symbol	Meaning of the Symbol
T_0	The deadline of order cancellation
n	Number of sub-periods from time 0 to T_0
a_i	Poisson arrival rates a_i in sub-period i, $i = 1, \cdots, n$
t_i	The length of sub-period i, , $i = 1, \cdots, n$
d_i	The number of sustained orders at the end of sub-period i, $i = 1, \cdots, n$
r	$r = x/d_{n-k}$, the ratio between the first order preparation quantity and the number of sustained orders at the end of sub-period $n-k$ when x is determined, $k \geq 2$
λ_0	Minimum market size when $\delta = 0$
λ_1	Additional market size coefficient associated with refund proportion δ
ϵ_0	Maximum possible cancellation percentage when $\delta = 1$

5.2 Simulation Results

In the numerical studies, we optimize the following three decisions variables with the objective of maximizing the total expected profit:

- Selling price p
- Refund proportion δ
- First shift order preparation ratio r when demand is observed at the decision point.

The optimization is conducted under the following 8 scenarios to explore the impacts of three factors: cancellation rate, cost difference, and the market sensitivity to refund policy.

- high ϵ_0, high c_1/c_0 ratio, high λ_1/λ_0 ratio
- high ϵ_0, high c_1/c_0 ratio, low λ_1/λ_0 ratio
- high ϵ_0, low c_1/c_0 ratio, high λ_1/λ_0 ratio
- high ϵ_0, low c_1/c_0 ratio, low λ_1/λ_0 ratio
- low ϵ_0, high c_1/c_0 ratio, high λ_1/λ_0 ratio
- low ϵ_0, high c_1/c_0 ratio, low λ_1/λ_0 ratio
- low ϵ_0, low c_1/c_0 ratio, high λ_1/λ_0 ratio
- low ϵ_0, low c_1/c_0 ratio, low λ_1/λ_0 ratio

When ϵ_0 is high, there is a higher chance of order cancellation associated with any refund policy. A high c_1/c_0 ratio indicates a higher level cost advantage from the first shift of supply preparation. And a higher λ_1/λ_0 ratio implies a higher potential of market growth when a larger amount of refund is issued for cancelled orders.

In our cases, the e-grocer has observed approximately 85% of order arrivals at the decision point of determining r in accordance with the given non-stationary Poisson arrival pattern. Part of the observed order arrivals have already been cancelled. The sustained demand d_{n-k} at the decision point and future arrivals can still be partially cancelled before T_0. A thousand replicates are simulated in each iteration of the optimization-via-simulation process. Optimal solutions are summarized in the following Table 3.

TABLE 3. SIMULATION RESULTSS

Case	p^*	δ^*	r^*
$\epsilon_0 = 0.72, \quad \frac{c_1}{c_0} = 1.8, \quad \frac{\lambda_1}{\lambda_0} = 1$	$2.49c_0$	0.73	1.16
$\epsilon_0 = 0.72, \quad \frac{c_1}{c_0} = 1.8, \quad \frac{\lambda_1}{\lambda_0} = 0.25$	$2.46c_0$	0.45	1.16
$\epsilon_0 = 0.72, \quad \frac{c_1}{c_0} = 1.2, \quad \frac{\lambda_1}{\lambda_0} = 1$	$2.50c_0$	0.73	1.15
$\epsilon_0 = 0.72, \quad \frac{c_1}{c_0} = 1.2, \quad \frac{\lambda_1}{\lambda_0} = 0.25$	$2.48c_0$	0.47	1.16
$\epsilon_0 = 0.36, \quad \frac{c_1}{c_0} = 1.8, \quad \frac{\lambda_1}{\lambda_0} = 1$	$2.52c_0$	1	1.16
$\epsilon_0 = 0.36, \quad \frac{c_1}{c_0} = 1.8, \quad \frac{\lambda_1}{\lambda_0} = 0.25$	$2.49c_0$	0.58	1.17
$\epsilon_0 = 0.36, \quad \frac{c_1}{c_0} = 1.2, \quad \frac{\lambda_1}{\lambda_0} = 1$	$2.50c_0$	1	1.16
$\bar{\epsilon}_0 = 0.36, \quad \frac{c_1}{c_0} = 1.2, \quad \frac{\lambda_1}{\lambda_0} = 0.25$	$2.49c_0$	0.58	1.16

The results demonstrate that, in practice, the pricing decision is relatively robust since the price is dominated by the market's overall price sensitivity and the e-grocer's cost, primarily determined by the first shift as most inventory units are prepared in the first shift. Inventory decision in the first production shift is also relatively robust as the majority of the demand can be revealed before the decision is made. A higher c_1/c_0 ratio leads to a slightly larger quantity of preparation in the first shift in some cases as it is more expensive to prepare the product in the second shift. Depending on the scale of the order quantity facing the e-grocer, a one percent difference can be a significant number.

The optimal cancellation refund policy, on the other hand, is largely affected by the potential maximum order cancellation rate as well as the market's sensitivity towards the refund policy. Overall, a relatively high refund proportion δ is favorable in order to help the e-grocer achieve potential market growth. In case of a market highly sensitive to the refund proportion choice, an extremely high refund proportion δ is desired. In cases where the cancellation probabilities are low, it can be optimal to have a 100% refund rate to help the e-grocer access full market potential.

VI. CONCLUSION REMARKS

E-grocer, as one of the trendiest types of business in recent years, attracts great attention and increasing popularities among consumers. However, the perishability of the products and high level of convenience requirement from consumers present new challenges to this type of business.

In this study, we use both theoretical and simulation approaches to analyze the joint inventory and pricing decisions for a pre-order online fresh grocery business with order cancellation and refund considerations. Our theoretical results suggest that a lower selling price should be charged by the e-grocer when the order cancellation option is offered to the consumers. The lower selling price, which induces larger amount of demand, may benefit the business from economies of scales during the earlier stage of the supply process, and generate more revenue from the cancellation fee. In the numerical study, we explore a more complex relation among three decisions: selling price, order preparation, and refund proportion for order cancellations. The results suggest the business to keep relatively stable pricing and inventory decision, but adjust the refund policy more responsively when market has different reactions to order cancellation and refund options.

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