

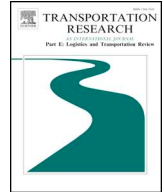


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Innovative “Bring-Service-Near-Your-Home” operations under Corona-Virus (COVID-19/SARS-CoV-2) outbreak: Can logistics become the Messiah? ☆

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ABSTRACT

The corona virus (COVID-19/SARS-CoV-2) outbreak has created serious disruptions to many business operations. Among them, many service operations, which require customers to travel and visit a place indoor, become almost infeasible to run in a crowded city like Hong Kong. Motivated by a recent reported real case on an innovative service operation in Hong Kong, we build analytical models to explore how logistics and technologies together can transform the “static service operations” to become the “bring-service-near-your-home” mobile service operations. We also highlight how the government may provide the subsidy to support the above mentioned mobile service operation (MSO) to make it financially viable. We specifically show that the government may adopt the fixed-cost-subsidy (FCS) scheme, operations-cost-subsidy (OCS) scheme or safety-technology-support (STS) scheme to help. We further uncover that the OCS scheme would bring a larger consumer surplus than the FCS scheme and is hence more preferable. In the extended models, we first study the case when service fee cannot be changed because of corona virus outbreak (CVO). We then explore the feasibility of adopting MSO in the long run as a financially self-sustainable service operation and derive the analytical conditions under which MSO is a win-win business model for both the service provider and consumers. Finally, we study the optimal safety technology investment problem.

1. Introduction

“May God Bless All People Around the World Against the COVID-19/SARS-CoV-2 Virus”.

1.1. Background and motivational real case

Imagine that we operate a private tutorial school in an indoor shopping mall for students (P.S.: mainly children) learning piano for professional public examinations in a city like Hong Kong. Teaching is commonly held in a way in which one teacher coaches one student inside a very small room with the piano. For this type of static service operation (SSO), during the normal period of time, the school is very popular and it is a very solid commercial service operation. However, during the recent corona virus (COVID-19/SARS-CoV-2) outbreak (CVO), students (as well as their parents if the students are children) deeply worry about attending the piano class in

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the music school because: (i) It is indoor and a lot of students come and go. (ii) Visiting the school requires traveling which usually involves public transport. (iii) Precaution measures may not be trusted as they cannot clearly see if the school has done a good job. As a result, most students will refuse to attend class anymore and the private tutorial school deeply suffers as the rental fee is very high in Hong Kong and the service provider will go bankrupt very soon if no solutions are found.

Table 1.1 shows the points that consumers commonly believe under the corona virus outbreak in a city like Hong Kong. All these points are very logical but they will create big troubles. In fact, the case described above is very common. Unlike many other classroom teaching (such as English or Mathematics), teaching piano is not going to be effective without practicing and trying in front of the piano. Moreover, many students do not have pianos at home in Hong Kong which makes it impossible to have online class/demonstration. The outbreak hence creates a huge problem as both the service provider (e.g., the private school) will go bankrupt and the consumers (e.g., students) will suffer. This is a terrible situation.

Recently, a newspaper in Hong Kong¹ reported a real case in which a private music school (just like the one we mentioned above) has innovatively changed its operations mode to be “mobile”. To be specific, the private school rents a long truck, renovates it and makes it a mobile classroom. The school hence becomes a mobile service operation (MSO)² and establishes the “bring-service-near-your-home” business model.

Being mobile, the private music school can directly move to the student’s home (or very near) and let students attend piano lessons conveniently. The hygiene level is kept at a high level. All students have to be tested with body temperature and must wear surgical masks. The psychological worries of students are hence much reduced. The response is very positive as the private music school claims that it can “continue to operate” and students can continue to learn piano without big disruptions. This is hence a highly desirable win-win scenario.

Table 1.1
Important and well-agreed points to note during corona virus outbreak for a city like Hong Kong.^a

Points	Details	Examples
Indoor mass gathering	Classroom teaching, especially indoor is dangerous	Church gathering, soccer matches, classroom teaching, private tutoring, etc.
Travelling	Avoid taking public transport with high density of passengers	Bus, school bus, metro, train, etc.
Precaution	Take defensive measures and increase the hygiene level	Wearing surgical masks, regular cleaning with diluted bleach water, alcohol, etc.

^a Many points are in fact governed by laws. For example, in Hong Kong, as a temporary and special measure, public gatherings of four or more people were banned during CVO (at the time when this paper was prepared).

1.2. Research questions and major findings

The corona virus outbreak (CVO) has created lots of disruptions to service operations. Motivated by the real case in Hong Kong in which “logistics” helps the private school to go “mobile” and recover the business operations, we aim to generalize the case and examine the following questions:

- (1) For both “static service operations” (SSOs) and bring-service-near-your-home “mobile service operations” (MSOs) during the corona virus outbreak, what are the optimal service pricing and hygiene level decisions? When will SSOs fail to operate? Under what situations can switching to be an MSO solve the problem?
- (2) If the government’s subsidy is needed, which are the proper subsidy schemes? Will it make a difference if the subsidy goes to different kind of costs (e.g., per unit operations cost or “lump-sum” fixed cost)?
- (3) Extending the analyses to cover more cases, e.g., (i) the case in which the service fee has to be fixed “before and after the outbreak”, (ii) the situation when MSO is used in the long run, (iii) the scenario with investment on safety technologies (such as air quality improvement and monitoring systems, blockchain and RFID systems, etc.), what are the corresponding managerial insights?

This paper aims to address the above proposed research questions via an analytical study. As we will show in the following analyses, our theoretical results indicate that the MSO business model is really an interesting idea and it can potentially overcome the huge challenge brought by CVO which may very likely lead to the failure of the service operations. Moreover, we find that governments can impose effective measures to support the service provider. Different measures have different effects. It is interesting to find that the commonly seen and well-proposed subsidy for the lump-sum fixed cost (called the FCS scheme) is in fact inferior to the

¹ <https://hk.lifestyle.appledaily.com/special/20200326/HGFBKHTSREXG5EOMMAAX74AAYY/> (Accessed 26 March 2020)

² In this paper, unless otherwise specified, the term “mobile service operation” (MSO) refers to the “bring-service-near-your-home” MSO.

sponsorship scheme which subsidizes the per unit operations cost (called the OCS scheme) because consumers will be benefited under the OCS scheme, but not the FCS scheme. Alternatively, the non-monetary sponsor scheme such as the safety-technology-support (STS) scheme may also serve the purpose. In the extended analyses, we prove that the qualitative conclusion under the endogenous service fee (i.e. revenue) case remains valid when the service fee is assumed to be “exogenous” (i.e., cannot be changed when the firm adopts MSO under CVO). We also derive the situations in which the MSO business model is financially viable in the long run. Last but not least, considering the scenario in which the service provider (i.e., the firm) can invest in safety technologies to reduce consumers’ worries under MSO, we analytically find the closed-form solution for the optimal safety technology investment level and highlight its relationship with, e.g., the unit operations cost under MSO.

As a remark, even though this study is motivated by the real Hong Kong case on a private music school teaching piano skills, this paper is not confined to just this example. As we will mention in [Section 5](#), the models and analyses can be generalized to cover many other real world relevant cases. The roles played by logistics are also critical as the innovative “bring-service-near-your-home” MSOs totally rely on having the long truck to help. Moreover, we trust the roles of technologies (both safety and health related technologies and information technologies) are critical, too.

1.3. Contribution statements and paper structure

To the best of our knowledge, this paper is the first analytical study which explores the innovative real case based “bring-service-near-your-home” MSO business model to deal with disasters such as CVO. Impacts on the society (i.e., business profit and consumers in the market) are examined. The findings provide important guidance to both (i) practitioners on when to adopt MSO and (ii) governments on whether and how to provide supports to service businesses during the hard time when disasters like CVO occur. Valuable managerial insights are also proposed.

This paper is organized as follows. [Section 1.2](#) includes the related literature. [Section 2](#) shows the basic analytical models. [Section 3](#) presents the analyses. [Section 4](#) extends this study in various critical directions, including the case when the service fee cannot be changed because of CVO, the situation in which MSO can be operated in the long-run, and the problem with optimal investment on safety technologies. [Section 5](#) concludes the whole piece of research study with a discussion on “generalization” and future research directions. To enhance exposition and readability, all proofs are relegated to [Appendix \(A1\)](#) and tables of abbreviations and notation are placed in [Appendix \(A2\)](#).

2. Literature review

This paper is related to various areas, namely service operations and logistics, operations under disasters, event studies related to disasters, and government roles in operations.

Service operations management is a very important topic ([Choi 2016](#)). There are different service operations schemes, including pure service operations and product-service operations ([Wang et al. 2015](#)). In the literature, for general service operations, [Liu et al. \(2019a\)](#) analytically examine the service operations platforms. The authors highlight the “value-added service” provided by the platforms. [Wang et al. \(2019\)](#) investigate the optimal “service order allocation” problem. The authors uncover the role played by risk attitudes. Most recently, [Choi et al. \(2020\)](#) examine the optimal pricing decision for “on-demand-service-platforms” such as Uber. The authors propose the use of blockchain as a technological tool to help implement the customized pricing scheme with respect to risk attitudes of individual consumer groups. In logistics service operations, [Shen et al. \(2019\)](#) analytically study the influence of logistics services for seasonal products. Most recently, [Ren et al. \(2020\)](#) explore third-party logistics services for “cross-border e-commerce” operations. The authors apply a novel machine intelligence approach to derive the optimal solution and test the results by using real data. This paper also considers service operations but the context relates to the innovative “bring-service-near-your-home” business model with the utilization of “logistics” (supported by technologies), which is totally different from the above examined studies in the literature.

Disasters happen from time to time. The recent global CVO is of course a big disaster. Traditionally, in operation management, a lot of studies focus on optimal disaster responses and humanitarian activities/services. For instance, [Balcik et al. \(2019\)](#) study the “collaborative prepositioning network design” in response to disasters in a region. [Kim et al. \(2019\)](#) explore the optimal choice of “logistics service providers” to prepare for disasters. [Liu et al. \(2019b\)](#) study the optimal “temporary facility location” problem to cope with disasters. The authors focus on the “casualty allocation planning” from the perspective of medical operations. [Mejia et al. \(2019\)](#) study the use of platforms to collect donation for helping emergency events such as disasters. Adopting the data analytics approach ([Schoenherr and Speier-Pero, 2015](#); [Choi et al. 2018](#); [Kuo and Kusiak 2019](#)), [Yan and Pedraza-Martinez \(2019\)](#) investigate the use of social media analytics to enhance “disaster management”. [Sheu and Choi \(2020\)](#) study the widely seen strategic hoarding problems when disasters happen. [Ye et al. \(2019\)](#) review the literature and cases on inventory management of “relief-resources”. Most recently, [Ivanov \(2020\)](#) conduct a simulation study to uncover how influences brought by CVO on the global supply chain system. This paper also examines operations under disasters and the specific emphasis is on the global CVO problem. However, it focuses on exploring how the “suppose-to-disrupted” service operations may be able to recover by an innovative change of business model with the use of transportation logistics and technologies. To the best of my knowledge, this has never been studied in the literature.

CVO is an event, which creates big challenges to operations ([Aras et al., 2020](#)). In the literature, disaster related event studies have been published over the past few decades. We review a few related studies that are published in recent years. For instance, [Jacob and Singhal \(2017\)](#) empirically study whether the market reacts negatively towards the “Rana Plaza disaster” in the Bangladeshi apparel

manufacturing industry by conducting an event study. The authors focus on exploring the stock market’s reaction using the standard empirical event study methodology in operations management. Singh et al. (2019) study using data from “tweets” on disasters. The authors focus on investigating the “event classification and location prediction” for disasters using data from social media. Liu et al. (2019b) examine analytically the optimal “casualty allocation” problem after the disaster event has happened. Most recently, Jeong et al. (2020) propose the adoption of “flying warehouses” for humanitarian activities when a disaster event happens. To be specific, the authors study the situation when disasters take place in an unrest area (e.g., with wars). Using road vehicles to deliver the needed commodities is very dangerous. As a result, they propose a solution by using the humanitarian “flying warehouse”. Similar to these studies, this paper also examines the case when there is a disaster event. However, both the scope and specific research questions are totally different.

Finally, this paper also studies how the government may provide the needed subsidy to support the service operations. In the logistics and operations literature, the roles of government have been rather well-researched. For example, a popular topic in which governments play a critical role over the past decade is about carbon emissions tax. Choi (2013) analytically investigates how the carbon emission taxation scheme can be designed to entice fashion retailers to source locally. Choi and Luo (2019) examine the emerging markets with sustainability issues. The authors propose the proper setting of government subsidy to over the data quality problem. Most recently, Huang et al. (2020) propose the use of a “green subsidy” to enhance the operations of a supply chain system under financial constraints. This paper also investigates how the government subsidy may help to support the service operations under CVO. In particular, we compare different types of subsidy schemes and show that sponsoring the “fixed cost”, despite being simple, is not a wise measure to consumers.

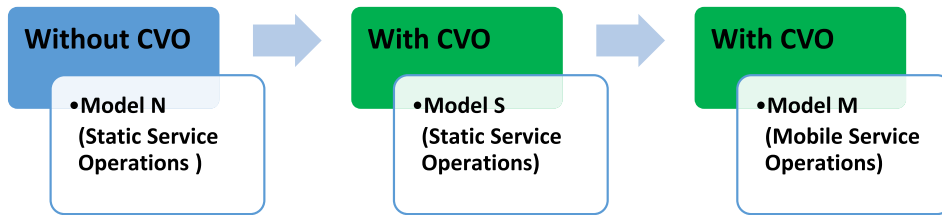


Fig. 3.1. The probable transition to Model M from Model N under CVO.

3. Models

In this paper, we examine a few models. Fig. 3.1 shows the transition from Model N to Model M (i.e., the “bring-service-near-your-home” MSO) as a probable solution to CVO for a service operation such as a music school (see Section 1).

3.1. Model N (Static service operations without CVO)

We start with the normal operation, called Model N. We consider a commercial service operation (called the “firm”), which is similar to the private music school as we mentioned in Section 1. Under normal situations, the firm operates inside an indoor mall. It offers a service to consumers and receives a revenue of p per each demand (i.e., the service fee). To operate, the school incurs a fixed cost F which includes the rental fee and staffing. Hygiene is an important factor and the firm achieves a hygiene level of h at a cost of $K_N(h)$. For analytical tractability as well as supported by prior studies, we model $K_N(h)$ as a quadratic function: $K_N(h) = \frac{k_N h^2}{2}$. In addition to hygiene level, travel distance is an issue. The firm serves a zone and the average distance for the consumer to visit the firm is l . Traveling to the firm incurs a disutility to the consumer. Assuming consumers possess a valuation v towards the service offered by the firm, and v follows a density function $f(v)$. The market population is normalized to be 1. Following the extant literature, we model $f(v)$ as a uniform distribution bounded between 0 and 1.

With the above description, the market demand faced by the firm is given as follows:

$$d_N = \int_{p+\eta l-h}^1 f(v)dv = 1 + h - p - \eta l, \tag{3.1}$$

where ηl represents the traveling disutility and $\eta > 0$.

The profit function Π_N is expressed in the following³:

$$\Pi_N = p(1 + h - p - \eta l) - K_N(h) - F. \tag{3.2}$$

We can also derive the consumer surplus CS_N as follows:

³ Note that for the service offering, we normalize the fundamental per demand service cost to be zero. This assumption is made because: (i) It allows “cleaner” analyses, (ii) having a non-zero cost does not affect any results qualitatively, and (iii) it is a common practice in the operations management literature to make this assumption for similar analyses.

$$CS_N = \int_{p+\eta l-h}^1 (v - (p + \eta l - h))f(v)dv = \frac{(1 + h - p - \eta l)^2}{2}. \tag{3.3}$$

With the above formulation, it is straightforward to find that the profit function Π_N is strictly concave when the hygiene cost is substantially high (i.e. $k_N > 1/2$) which implies that it will be too costly if one wants to increase the hygiene level to the upper limit. Throughout this paper, we assume this condition holds so that our closed-form analyses can be conducted without the need of exploring all those boundary cases. Solving the first order conditions yields the joint optimal revenue and hygiene level under Model N as follows:

$$h_N^* = \frac{1 - \eta l}{2k_N - 1}, \tag{3.4}$$

$$p_N^* = \frac{k_N(1 - \eta l)}{2k_N - 1}. \tag{3.5}$$

Putting (3.4) and (3.5) into the profit function and consumer surplus function gives the following:

$$\Pi_N^* = \Pi_N(h_N^*, p_N^*) = \frac{k_N(1 - \eta l)^2}{2(2k_N - 1)} - F, \tag{3.6}$$

$$CS_N^* = CS_N(h_N^*, p_N^*) = \frac{k_N^2(1 - \eta l)^2}{2(2k_N - 1)^2}. \tag{3.7}$$

From (3.6) and (3.7), we can clearly find the neat closed-form expressions of the profit and consumer surplus functions at the optimal decisions under Model N. In addition, please observe the high similarities (but not equivalence) between the analytical expressions of Π_N^* and CS_N^* .

3.2. Model S (Static service operations under CVO)

Now, under the corona virus outbreak, we consider the scenario in which the firm continues to operate using the original model, i.e. stations in the shopping mall indoor. We call the model under this scenario Model S. Consumers have some changes in their utility function. To be specific, they worry about visiting the firm and it is reflected by the change of two parameters:

First, during the travel distance l , consumers worry about being infected and hence the disutility in distance is now changed to be el in which $e > \eta$.

Second, there is an overall worry disutility factor w , which is called the consumers' psychological worry under SSO. It reflects the consumers' psychological worry of being infected in the firm, especially when it is an indoor environment.

In addition, under the CVO, the marginal cost for establishing the hygienic environment is higher under Model S than that under Model N. This point is reflected by the cost function $K_S(h) = \frac{k_S h^2}{2}$, in which $k_S > k_N$.

With the above two factors, following Model N, we have the demand model under Model S:

$$d_S = \int_{p+el-h+w}^1 f(v)dv = 1 + h - p - el - w. \tag{3.8}$$

The profit function Π_S is expressed in the following:

$$\Pi_S = p(1 + h - p - el - w) - K_S(h) - F. \tag{3.9}$$

We can also analytically derive the consumer surplus CS_S under Model S as follows:

$$CS_S = \frac{(1 + h - p - el - w)^2}{2}. \tag{3.10}$$

With the above formulation, it is easy to show that Π_S is concave. Solving the first order conditions gives the joint optimal revenue and hygiene level under Model S to be the following:

$$h_S^* = \frac{1 - el - w}{2k_S - 1}, \tag{3.11}$$

$$p_S^* = \frac{k_S(1 - el - w)}{2k_S - 1}. \tag{3.12}$$

Putting (3.11) and (3.12) into the profit function Π_S and consumer surplus function CS_S , we have:

$$\Pi_S^* = \Pi_S(h_S^*, p_S^*) = \frac{k_S(1 - el - w)^2}{2(2k_S - 1)} - F, \tag{3.13}$$

$$CS_S^* = CS_S(h_S^*, p_S^*) = \frac{k_S^2(1 - el - w)^2}{2(2k_S - 1)^2}. \tag{3.14}$$

Comparing the analytical results between Model N and Model S, it is clear that the closed-form expressions of Π_S^* and CS_S^* are in

fact very similar to Π_N^* and CS_N^* in terms of format. Of course, owing to differences in parameters, they are not the same. In particular, the presence of consumers' psychological worry under SSO (i.e., w) and high travel disutility (i.e., el) all create a substantial difference between them.

3.3. Model M (Using Logistics: Mobile service operations under CVO)

Similar to Model S, we now consider the scenario when the firm starts to be "mobile", i.e., rather than waiting in the indoor fixed location, the firm offers its service by using a long truck. In other words, the "bring-service-near-your-home" business model is adopted in which "logistics" (i.e., the "mobile truck") plays a key role. The model for this scenario is represented by Model M. The long truck is well-equipped with all the necessary and helpful technological facilities to support the service offering in a way which reduces the worries of the consumers. For example, an air-quality monitoring system can be installed to show in real time the air-quality level. The hygiene measures can also be well-displayed on a computerized system to let customers see how hygiene measures are imposed systematically⁴, e.g., via the smart phones. As such, the consumers' psychological worry under MSO (i.e., Model M) is denoted by y , where $w > y$.

Different from Model N and Model S, as it is the firm, which travels to the consumer place, there is no distance related cost for the consumers. However, a related cost is present for the firm (as it needs to travel now) and we denote it as t , which is defined as cl and $c > 0$.

In addition, under the CVO in the long truck environment, the marginal cost for establishing the hygienic environment is in general different from that under Model S or Model N. We hence have the hygiene related cost as follows: $K_M(h) = \frac{k_M h^2}{2}$, where $k_M > 0$ and it should be higher than k_N due to CVO. Moreover, the fixed cost under Model M is denoted by G , which refers to the cost associated with using the long truck, etc. It is in general different from F .

With the above details, the demand function under Model M is given below:

$$d_M = \int_{p-h+y}^1 f(v)dv = 1 + h - p - y. \tag{3.15}$$

The profit function Π_M and consumer surplus CS_M under Model M are expressed as follows:

$$\Pi_M = (p - t)(1 + h - p - y) - K_M(h) - G, \tag{3.16}$$

$$CS_M = \frac{(1 + h - p - y)^2}{2}. \tag{3.17}$$

Note that Π_M is concave. Thus, the joint optimal revenue and hygiene level under Model M can easily be determined to be the following:

$$h_M^* = \frac{1 - y - t}{2k_M - 1}, \tag{3.18}$$

$$p_M^* = \frac{k_M(1 - y - t)}{2k_M - 1} + t. \tag{3.19}$$

With (3.18) and (3.19), we can find the optimal profit and the consumer surplus function at the optimal decisions under Model M below:

Table 3.1
Optimal decisions and the corresponding profits and consumer surplus under Model $i \in (N, S, M)$.

	Model N	Model S	Model M
h_i^*	$\frac{1 - \eta l}{2k_N - 1}$	$\frac{1 - el - w}{2k_S - 1}$	$\frac{1 - y - t}{2k_M - 1}$
p_i^*	$\frac{k_N(1 - \eta l)}{2k_N - 1}$	$\frac{k_S(1 - el - w)}{2k_S - 1}$	$\frac{k_M(1 - y - t)}{2k_M - 1} + t$
Π_i^*	$\frac{k_N(1 - \eta l)^2}{2(2k_N - 1)} - F$	$\frac{k_S(1 - el - w)^2}{2(2k_S - 1)} - F$	$\frac{k_M(1 - y - t)^2}{2(2k_M - 1)} - G$
CS_i^*	$\frac{k_N^2(1 - \eta l)^2}{2(2k_N - 1)^2}$	$\frac{k_S^2(1 - el - w)^2}{2(2k_S - 1)^2}$	$\frac{k_M^2(1 - y - t)^2}{2(2k_M - 1)^2}$

⁴ Note that these are some technologies facilities that are proposed to be implemented. However, they may not be present in the motivational case discussed in Section 1.

$$\Pi_M^* = \Pi_M(h_M^*, p_M^*) = \frac{k_M(1-y-t)^2}{2(2k_M-1)} - G, \quad (3.20)$$

$$CS_M^* = CS_M(h_M^*, p_M^*) = \frac{k_M^2(1-y-t)^2}{2(2k_M-1)^2}. \quad (3.21)$$

Table 3.1 shows a summary of the firm's optimal decisions and the corresponding profits and the consumer surplus values under Model N, Model S and Model M. Note that under a model, when we add the profit and consumer surplus (at the corresponding optimal decisions) up, we have the social welfare under the respective model.

From Table 3.1, we can see that the optimal profits and the consumer surplus functions (at the optimal decisions) exhibit very similar structure. However, there are also subtle differences which highlight the special features of the scenario under exploration. For example, under Model S, the presence of psychological worry is reflected by the presence of w . Under Model M, owing to the mobile nature of the service operation, a transportation cost t is present.

One point to note is, comparing the hygiene levels under Model N and Model S, it is surprising to note that we have: $h_N^* > h_S^*$. This means that under CVO, owing to the difficulty of service operations, the firm will set the optimal hygiene level lower than that under the normal market situation. This creates a very bad situation as consumers might expect the firm to lift the hygiene level while as reflected by our analysis, it is in fact not optimal for the firm to do so. We summarize this result in Lemma 3.1.

Lemma 3.1. *Under the static service operation (SSO), the presence of CVO will lead to a lower optimal hygiene level (i.e., $h_N^* > h_S^*$) even though the firm knows that the hygiene level is important.*

Lemma 3.1 is an important and clear result that highlights the negative impact of CVO on the optimal hygiene level offered by the firm.

4. Analyses

4.1. When will the SSO fail under CVO?

After deriving the results in Section 2 (esp. Table 3.1), we first examine when the SSO will fail and hence the firm will go bankrupt⁵ under Model S (i.e. static service operations under CVO).

Since there are a lot of factors in the optimal profit function, we focus on the most critical factor, i.e., consumers' psychological worry under SSO w , and examine whether we can derive the condition based on it.

Define (4.1) and (4.2). We have Proposition 4.1.

$$\hat{w}_S = 1 - el - \sqrt{\frac{2F(2k_S - 1)}{k_S}}, \quad (4.1)$$

$$\hat{e}_S = \frac{1}{l} \left(1 - w - \sqrt{\frac{2F(2k_S - 1)}{k_S}} \right), \quad (4.2)$$

$$\hat{F}_S = \frac{k_S(1 - el - w)^2}{2(2k_S - 1)}. \quad (4.3)$$

Proposition 4.1. *The firm will go bankrupt with the static service operation (SSO) business model under CVO if and only if any one of the following three equivalent conditions happens: (i) $w > \hat{w}_S$; (ii) $e > \hat{e}_S$; (iii) $F > \hat{F}_S$.*

Proposition 4.1 presents a very neat and intuitive result. In particular, Proposition 4.1(i) shows that if the consumers' psychological worry under SSO is too large (i.e., above \hat{w}_S), demand is insufficient to justify for the fixed cost F . The firm hence goes bankruptcy. Similarly, Proposition 4.1(ii) shows the case associated with consumers' worry about being infected during the travel trip to the firm. If this worry is too large, the effect is the same as the consumers' psychological worry under SSO (w) and will lead to a low demand which "kills" the service operation. Proposition 4.1(iii) is the most direct as it indicates that if the fixed operations cost is too high, the firm cannot continue to operate with the much reduced demand under CVO. Further note that all the three conditions in Proposition 4.1 are equivalent, and the only difference is the "term" being extracted to highlight the respective factor.

Note that in reality, in a city like Hong Kong, a service provider like the one we mentioned in Section 1 would find it extremely difficult to continue operations as the consumers' psychological worry under SSO (w) and worry of infection during travel are simply too high. If the service operation cannot continue, it will create a loss to consumers and lead to the firm's bankruptcy. A negative social welfare hence results. Unfortunately, in this case, even if the government is willing to sponsor the fixed cost (e.g., the rental fee), the sponsorship probably cannot help as consumers simply worry too much and will not come. Without substantial demand, the firm's business operation cannot continue.

⁵ Here and in the rest of this paper, "going bankrupt" means the firm's profit at the optimal decisions is negative. Obviously, the business can no longer survive.

4.2. When should the MSO be chosen to help under CVO?

When either condition in [Proposition 4.1](#) holds, we note that SSO (i.e., Model S) cannot continue under CVO and the firm will go bankrupt if no changes are made. In this sub-section, we explore the conditions under which the “bring-service-near-your-home” MSO (i.e., Model M) can help.

To be specific, we define three critical thresholds as follows:

$$\hat{y}_M = 1 - t - \sqrt{\frac{2G(2k_M - 1)}{k_M}}, \quad (4.4)$$

$$\hat{c}_M = \frac{1}{l} \left(1 - y - \sqrt{\frac{2G(2k_M - 1)}{k_M}} \right), \quad (4.5)$$

$$\hat{G}_M = \frac{k_M(1 - y - t)^2}{2(2k_M - 1)}. \quad (4.6)$$

Proposition 4.2. *The firm will survive with the “bring-service-near-your-home” mobile service operation (MSO) business model under CVO if and only if any one of the following three equivalent conditions happens: (i) $y \leq \hat{y}_M$; (ii) $c \leq \hat{c}_M$; (iii) $G \leq \hat{G}_M$.*

[Proposition 4.2](#) shows the analytical conditions under which Model M (i.e., mobile service operations under CVO) can save the firm’s life. [Proposition 4.2\(i\)](#) indicates that if the consumers’ psychological worry under Model M is not too large (i.e., less than \hat{y}_M), then the firm’s mobile service operation can attract enough demand to justify its business operation. [Proposition 4.2\(ii\)](#) highlights from the cost perspective that if the transportation operations cost associated Model M is not too large, the operations can become sustainable. Finally, [Proposition 4.2\(iii\)](#) is a direct result, which shows that if the fixed operations cost for Model M is not too large, the firm can survive. Similar to [Proposition 4.1](#), the conditions in [Proposition 4.2](#) are equivalent. However, despite the fact that they are equal, they actually may have different implications to, e.g., government subsidy schemes, as we will discuss later on in [Section 3.3](#). Moreover, observe that the three thresholds are in fact inter-related. For example, when G is larger, both \hat{y}_M and \hat{c}_M are smaller which means the conditions in [Proposition 4.2](#) (i) and (ii) are more stringent because the bounds are tighter. The effect is the same as having a larger G in the condition of [Proposition 4.2](#) (iii).

4.3. Impacts on consumers

In [Section 3.1](#) and [Section 3.2](#), we focus on the service provider, i.e., the firm, and highlight the conditions in which Model M (i.e., the “bring-service-near-your-home” MSO) can help. How about consumers? How much can the consumers be benefited? In our analysis, we model the case in which under CVO, the firm cannot continue to operate under Model S. In other words, the consumer surplus will become zero. If the firm can survive under Model M, the consumer surplus becomes $\frac{k_M(1-y-t)^2}{2(2k_M-1)^2}$. Thus, with CVO, consumers are always benefited under Model M if the firm cannot operate under Model S. The amount of benefit depends on various factors. To be specific, consumers benefit more if y is smaller and t is smaller. These are also the conditions under which the firm would benefit more. As such, the consumers and the firm (i.e. service provider) both treasure the case if the transportation operations cost t and the psychological worry of consumers under Model M (y) are lower.

4.4. Government subsidy schemes

Under CVO, our analyses above indicate that if the firm fails to sustain under Model S, moving to Model M is a strategy that benefits consumers. To be specific, the social welfare under this case when MSO is adopted becomes:

$$SW_M^* = \Pi_M^* + CS_M^* = \left(\frac{k_M(1-y-t)^2}{2(2k_M-1)} \right) \left(\frac{3k_M-1}{2k_M-1} \right) - G.$$

However, what if $SW_M^* > 0$ (which means MSO is in fact good for the society) while the firm still cannot survive under Model M because, e.g., the fixed cost G is too high (or in general, the conditions in [Proposition 4.2](#) do not hold)? Can the government provide a subsidy scheme to help? In the following, we explore several different schemes:

The operations cost subsidy (OCS) scheme: Under the OCS scheme, the government provides a sponsor s_c to lower the value of c to be the same as \hat{c}_M (or even lower if the subsidy is generous). This subsidy is given per each demand. For instance, for each customer, the government provides a subsidy which is transferred as a revenue to the firm directly.

The fixed cost subsidy (FCS) scheme: Under the FCS scheme, the government provides a sponsor s_G to lower the value of G to be the same as \hat{G}_M (or even lower if the subsidy aims to help the firm make a profit), e.g., helping the firm to pay part of the rental fee for using the long truck. This subsidy is independent of demand size.

Comparing between the two subsidy schemes proposed above, we have [Proposition 4.3](#).

Proposition 4.3. (a) *From the service provider’s perspective, if the conditions in [Proposition 4.2](#) do not hold, both the OCS scheme and FCS scheme can help the firm to survive under MSO.* (b) *From the consumers’ perspective, the OCS scheme outperforms the FCS scheme in bringing a larger consumer surplus under MSO.*

Proposition 4.3 (a) gives a few interesting insights. First of all, in terms of financially helping the firm, both the OCS and FCS schemes can successfully help and make MSO a feasible operation. Thus, the two schemes may appear to be the same. However, if we look at the issue from the perspective of consumers, we see the difference. The OCS scheme actually “outperforms” the FCS scheme as it brings a larger consumer surplus. This is a very interesting finding for the government’s reference.

To effectively implement OCS, it is important for the government to monitor and avoid cheating. One simple measure is via the personal identity (ID) document of each consumer. For example, the firm can get the subsidy from the government with the real details of each customer’s official ID document. To make things even more transparent and secure, technologies such as blockchain⁶ (Choi et al. 2019) can also be applied to make sure all data records are well-kept, transparent and traceable. This is a technological solution to overcome the potential cheating problem.

In addition to the OCS scheme and FCS scheme, the government may also provide the safety-technology-support (STS) scheme. Under the STS scheme, the government provides technological and protection devices (i.e., not monetary sponsors) to the firm to help lift the “safety level”. This helps to hence reduce γ to a level sufficiently low (e.g., as low as $\hat{\gamma}_M$). For CVO, examples of STS include (i) high quality masks, protection gowns and gloves, as well as (ii) technological devices which can help improve and show air-quality, etc. The effect of STS scheme can be similar the OCS scheme as consumer surplus can be enhanced. Table 4.1 shows the performances of different government subsidy schemes. It is crystal clear to note that the widely proposed FCS scheme is in fact an inferior one.

Table 4.1
Performances of different government subsidy schemes (Can the schemes improve the firm’s profit and consumer surplus?).

Schemes	The firm’s profit	Consumer surplus
OCS	Yes	Yes
FCS	Yes	No
STS	Yes	Yes

5. Extended models

5.1. Service fee doesn’t change (“Exogenous” service fee)

In the above sections, we consider the case when the firm can price differently under different models. However, it may not be true in many real cases. For example, for many service providers like private tuition schools, it is quite common for them to offer the same price under the normal market environment and during CVO. To a certain extent, increasing price under CVO is “crazy” and may be regarded as “cheating”. Lowering price under CVO may give an impression to consumers that the business is very poor (and hence needs promotion); this may create another negative effect as consumers may worry about the firm will go bankrupt (and hence decline to pay the monthly service fee, etc. or even request refund).

As such, in this sub-section, we look at the simple case when the service revenue p is fixed. The only decision of the firm is to set the optimal hygiene level under Model N, Model S and Model M. Table 5.1 shows the result. To differentiate from the models and analyses under the endogenous service fee case (Section 2 and Section 3), note that we use a “bar” to denote the results in this extended analysis with an “exogenous” service fee (i.e., the service fee does not change when the firm adopts MSO under CVO).

Table 5.1
Optimal hygiene levels, profits, consumer surplus under Model $i \in (N, S, M)$.

	Model N	Model S	Model M
Optimal hygiene level (\bar{h}_i^*)	$\bar{h}_N^* = \frac{p}{k_N}$	$\bar{h}_S^* = \frac{p}{k_S}$	$\bar{h}_M^* = \frac{p-t}{k_M}$
Optimal profit ($\bar{\Pi}_i^*$)	$p(1 - p - \eta l) + \frac{p^2}{2k_N} - F$	$p(1 - p - w - el) + \frac{p^2}{2k_S} - F$	$(p - t)(1 - p - y) + \frac{(p-t)^2}{2k_M} - G$
Consumer surplus at \bar{h}_i^* (\bar{CS}_i^*)	$\frac{(k_N(1 - \eta l) + (1 - k_N)p)^2}{2k_N^2}$	$\frac{(k_S(1 - w - el) + (1 - k_S)p)^2}{2k_S^2}$	$\frac{(k_M(1 - y) - t + (1 - k_M)p)^2}{2k_M^2}$

⁶ Note that blockchain is a “distributed ledger” technology not just for finance (e.g., bitcoin, Choi 2020b). It is also a critical technology for logistics and supply chain management (see Choi et al. 2019).

Similar to the case when the service fee is endogenous, we define various critical thresholds in the following:

$$\bar{w}_S = 1 - p \left(1 - \frac{1}{2k_S} \right) - \left(\frac{F}{p} \right) - el, \tag{5.1}$$

$$\bar{e}_S = \frac{1}{l} \left(1 - p \left(1 - \frac{1}{2k_S} \right) - \left(\frac{F}{p} \right) - w \right), \tag{5.2}$$

$$\bar{F}_S = p(1 - p - w - el) + \frac{p^2}{2k_S}, \tag{5.3}$$

$$\bar{G}_M = (p - t)(1 - p - y) + \frac{(p - t)^2}{2k_M}, \tag{5.4}$$

$$\bar{y}_M = 1 - p - \frac{G^2}{p - t} + \frac{p - t}{2k_M}, \tag{5.5}$$

$$\bar{c}_M = \frac{1}{l} \{ p + k_M(1 - p - y) - \sqrt{2k_M(G + [k_M(1 - p - y)]^2)} \}. \tag{5.6}$$

We have [Proposition 5.1](#).

Proposition 5.1. *Under the “exogenous” service fee case in which the service fee cannot be changed when the firm adopts MSO under CVO: (a) The firm will fail and go bankrupt with static service operations under CVO if and only if any one of the following three equivalent conditions happens: (i) $w > \bar{w}_S$; (ii) $e > \bar{e}_S$; (iii) $F > \bar{F}_S$. (b) The firm will survive with “bring-service-near-your-home” mobile service operations under CVO if and only if any one of the following three equivalent conditions happens: (i) $y \leq \bar{y}_M$; (ii) $c \leq \bar{c}_M$; (iii) $G \leq \bar{G}_M$.*

From [Proposition 5.1](#), it is obvious that the major conclusions under the case with endogenous service revenue (i.e., pricing) decisions (i.e., [Section 2](#) and [Section 3](#)) remain valid if the service fee is “exogenous” (i.e., cannot be changed when the firm adopts MSO under CVO). This of course also includes the government subsidy schemes in which the OCS and STS schemes outperform the FCS scheme as they not only can help to make MSO financially viable for the firm, but also benefit the consumers.

5.2. Does MSO work in the long run?

The CVO will not last forever. Is going “mobile” a long term sustainable solution? In other words, if the “bring-service-near-your-home” MSO business model is adopted for the long run in which the CVO type of disasters may or may not occur again, is it still beneficial to operate under the MSO mode? We examine this issue in this sub-section.

To be specific, we explore two cases under the situation when the market has a chance to become normal while also a chance of facing a disruption like another CVO. We represent the chance of having a disaster like CVO to be ϕ and the chance of having “no disaster” is $1 - \phi$, where $0 < \phi < 1$. We then explore two models, namely Model SX and Model MX (P.S.: SX and MX represent S-Extended, and M-Extended, respectively).

Under Model SX, we consider the SSO mode of business model. We first define the following threshold which is helpful for us to further define two sub-models (Model SX-1 and Model SX-2):

$$\hat{F}_{SX} = \frac{k_S(1 - el - w)^2}{2(2k_S - 1)}. \tag{5.7}$$

Model SX-1: If $F > \hat{F}_{SX}$, the firm will operate when the disaster does not appear and will stop operating when the disaster appears.

Model SX-2: If $F \leq \hat{F}_{SX}$, the firm will operate no matter whether the disaster appears or not. In other words, the firm will continue to run under the SSO mode no matter whether the disaster is present.

Note that Model SX-1 captures the case when the firm finds that it will lose money if it continues to run under disaster. This case appears when the fixed operations cost is too high. As such, it is optimal to choose not to operate when disaster occurs. On the contrary, Model SX-2 captures the case when the firm will continue to operate even when the disaster appears. This is the case when the fixed operations cost is sufficiently low.

Under Model MX, we consider the MSO mode of business model which is also financially viable under the disaster. As such, we only have one case in which the firm will operate both “with and without disaster”.

Under each model, we consider the situation when the firm will set the optimal service revenue (i.e., pricing) and hygiene level under the respective state of the world, i.e., “with disaster” or “without disaster”. In other words, under Model SX-2, if there is no disaster, the optimal service revenue and hygiene level decisions will be the same as the ones under Model N. When the disaster is present, then the respective optimal decisions will become the same as the ones under Model S.

Under Model MX, the case is a bit different. When the disaster comes, then the optimal decisions under Model MX are the same as the ones under Model M. When the disaster is absent, then the profit function of the firm is given as follows:

$$\Pi_{NM} = (p - t)(1 + h - p) - K_{NM}(h) - G, \tag{5.8}$$

where $K_{NM}(h) = \frac{k_{NM}h^2}{2}$ is the cost for achieving the hygiene level h , and $k_{NM} > 0$.

Maximizing (5.8) yields the corresponding optimal decisions as follows: $h_{NM}^* = \frac{1-t}{2k_{NM}-1}$, and $p_{NM}^* = \frac{k_{NM}(1-t)}{2k_{NM}-1} + t$.

Table 5.2 shows the expected optimal profits and the expected consumer surplus (at optimal decisions) under different models (Model SX-1, Model SX-2, Model MX).

Table 5.2

Optimal expected profits and expected consumer surplus under Model $j \in \{SX - 1, SX - 2, MX\}$.

	Π_j^*	CS_j^*
Model SX-1	$(1 - \phi) \left(\frac{k_N(1-\eta)l^2}{2(2k_N-1)} - F \right)$	$(1 - \phi) \frac{k_N^2(1-\eta)l^2}{2(2k_N-1)^2}$
Model SX-2	$\frac{\phi k_S(1-el-w)^2}{2(2k_S-1)} + (1 - \phi) \left(\frac{k_N(1-\eta)l^2}{2(2k_N-1)} - F \right)$	$\frac{\phi k_S^2(1-el-w)^2}{2(2k_S-1)^2} + (1 - \phi) \frac{k_N^2(1-\eta)l^2}{2(2k_N-1)^2}$
Model MX	$\frac{\phi k_M(1-y-t)^2}{2(2k_M-1)} + \frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - G$	$\frac{\phi k_M^2(1-y-t)^2}{2(2k_M-1)^2} + \frac{(1-\phi)k_{NM}^2(1-t)^2}{2(2k_{NM}-1)^2}$

We define a few important thresholds in the following, which relate to the conditions with respect to G and y for us to show the theoretical results in Lemma 5.1.

$$\hat{G}_1 = \frac{\phi k_M(1-y-t)^2}{2(2k_M-1)} + \frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - (1-\phi) \left(\frac{k_N(1-\eta)l^2}{2(2k_N-1)} - F \right), \tag{5.9}$$

$$\hat{G}_2 = \frac{\phi k_M(1-y-t)^2}{2(2k_M-1)} + \frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - \left[\frac{\phi k_S(1-el-w)^2}{2(2k_S-1)} + (1-\phi) \left(\frac{k_N(1-\eta)l^2}{2(2k_N-1)} - F \right) \right], \tag{5.10}$$

$$\hat{y}_1^\Pi = 1-t - \sqrt{\left(\frac{2(2k_M-1)}{\phi k_M} \right) \left\{ (1-\phi) \left(\frac{k_N(1-\eta)l^2}{2(2k_N-1)} - F \right) - \left(\frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - G \right) \right\}}, \tag{5.11}$$

$$\hat{y}_2^\Pi = 1-t - \sqrt{\left(\frac{2(2k_M-1)}{\phi k_M} \right) \left\{ \frac{\phi k_S(1-el-w)^2}{2(2k_S-1)} + (1-\phi) \left(\frac{k_N(1-\eta)l^2}{2(2k_N-1)} - F \right) - \left(\frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - G \right) \right\}}. \tag{5.12}$$

From Table 5.2, we can easily derive Lemma 5.1, which shows the analytical conditions in which Model MX (MSO) outperforms Models SX-1 and SX-2.

Lemma 5.1. *In the long run: (a) When $F > \hat{F}_{SX}$: Model MX (i.e., MSO) is the optimal service operations model if and only if $y < \hat{y}_1^\Pi$ (or equivalently $G < \hat{G}_1$). (b) When $F \leq \hat{F}_{SX}$: Model MX (i.e., MSO) is the optimal service operations model if and only if $y < \hat{y}_2^\Pi$ (or equivalently $G < \hat{G}_2$).*

Lemma 5.1 gives a simple rule to decide whether it is optimal to continue running the business under the MSO mode. To be specific, first, depending on the fixed operations cost under SSO (i.e., F), the firm may choose Model SX-1 or Model SX-2 if it votes for SSO as the operations mode. This is why we have two cases (part (a) and part (b)). For each case, by checking either the consumers' psychological worry under MSO in the presence of the disaster (i.e., y) or the fixed operations cost under MSO (i.e., G), if it is lower than the respective threshold, it will be optimal to adopt Model MX, i.e., operating the business under the MSO mode.

In a similar vein, we define the following:

$$\hat{y}_1^{CS} = 1-t - \sqrt{\left(\frac{2(2k_M-1)^2}{\phi k_M^2} \right) \left((1-\phi) \frac{k_N^2(1-\eta)l^2}{2(2k_N-1)^2} - \frac{(1-\phi)k_{NM}^2(1-t)^2}{2(2k_{NM}-1)^2} \right)},$$

$$\hat{y}_2^{CS} = 1-t - \sqrt{\left(\frac{2(2k_M-1)^2}{\phi k_M^2} \right) \left(\frac{\phi k_S^2(1-el-w)^2}{2(2k_S-1)^2} + (1-\phi) \frac{k_N^2(1-\eta)l^2}{2(2k_N-1)^2} - \frac{(1-\phi)k_{NM}^2(1-t)^2}{2(2k_{NM}-1)^2} \right)}.$$

Lemma 5.2 gives the conditions under which adopting Model MX is also optimal for consumers.

Lemma 5.2. *In the long run: (a) When $F > \hat{F}_{SX}$: The consumers are benefited under Model MX (i.e., MSO) if and only if $y < \hat{y}_1^{CS}$. (b) When $F \leq \hat{F}_{SX}$: The consumers are benefited under Model MX (i.e., MSO) if and only if $y < \hat{y}_2^{CS}$.*

Lemma 5.2 gives the conditions in which adopting the MSO business model will benefit the consumers as well. Define: $\hat{Y}_1 = \min(\hat{y}_1^\pi, \hat{y}_1^{CS})$ and $\hat{Y}_2 = \min(\hat{y}_2^\pi, \hat{y}_2^{CS})$. Combining the results from **Proposition 5.2**.

Proposition 5.2. *In the long run: (a) When $F > \hat{F}_{SX}$: Model MX (i.e., MSO) is the optimal service operations model for both the firm and consumers if and only if $y < \hat{Y}_1$. (b) When $F \leq \hat{F}_{SX}$: Model MX (i.e., MSO) is the optimal service operations model for both the firm and consumers if and only if $y < \hat{Y}_2$.*

From **Proposition 5.2**, we can clearly see how the MSO business model can be a win-win model for both the firm and consumers. As the condition goes to the consumers' psychological worry under MSO (i.e., y), the government can provide technological support (e.g., the STS scheme) to help the firm so that consumers will feel more secure. This will yield a smaller “ y ” which also means the win-win situation is more likely to occur with the adoption of MSO.

5.3. Safety technology investment

In the above sections, we understand that “ y ” (the consumers' psychological worry under Model M) is very critical. In particular, from **Proposition 5.2**, we can see that in long-term service operations, the “bring-service-near-your-home” MSO business model is beneficial to both the firm and consumers if y is sufficiently small. However, are there any specific measures that can be imposed to achieve a sufficiently small y ?

In this extended analysis, we consider the case when the firm can lower “ y ” by investing in safety technologies which include air quality control systems, body temperature monitoring systems, and even a RFID (Choi 2011) supported blockchain system to keep track of customer flows and their behaviors. The use of blockchain can also help provide the needed information transparency by allowing customers to observe some information which can be shown (e.g., on their mobile phones) to foster trust and reduce worries. Note that there are two types of blockchain systems, namely public and private. In our proposal here, we propose the use of private blockchain systems because the firm can choose “what to display” and “what not to display”. This relates to customers' privacy and is hence a very critical aspect for properly running the MSO.

Suppose that to reduce y by a factor of α , the required investment on safety technologies (including blockchain) is quadratic: $K_Y(\alpha) = k_Y \alpha^2 / 2$, where $k_Y > 0$. We call α the safety technology investment. Thus, under Model M, for a given y , we have: $\Pi_M^* = \frac{k_M(1-y-t)^2}{2(2k_M-1)} - G$. In the presence of safety technology investment, the revised profit function under Model M becomes:

$$\tilde{\Pi}_M^*(\alpha) = \frac{k_M(1 - (1 - \alpha)y - t)^2}{2(2k_M - 1)} - G - K_Y(\alpha). \tag{5.13}$$

Checking the structural properties indicates that $\partial^2 \tilde{\Pi}_M^*(\alpha) / \partial \alpha^2 < 0$. Thus, solving the first order condition $\partial \tilde{\Pi}_M^*(\alpha) / \partial \alpha = 0$ for α yields the unique optimal α s follows:

$$\alpha_M^* = \frac{k_M(1 - t - y^2)}{(2k_M - 1)k_Y - 2k_M y^2}. \tag{5.14}$$

From (5.14), we can see that there exists an optimal safety technology investment level, which is a function of the hygiene cost coefficient k_M as well as the safety technology investment cost coefficient k_Y . In addition, the unit operations cost under Model M (i.e., t) is also a factor. In particular, a larger t implies a smaller optimal safety technology investment level. This finding may relate to the fact that when the profit margin is lower (i.e., $p - t$ is smaller as t is larger), it is less beneficial to invest more on safety technologies.

6. Conclusion

6.1. Concluding remarks

Today, service operations face many challenges. One of them is brought by global disasters such as the current CVO problem. In this paper, motivated by a real service operations business model in Hong Kong under CVO, we have constructed stylized analytical models to explore whether logistics (e.g., the use of a long truck, supported by technologies) can be the “Messiah” to support the innovative “bring-service-near-your-home” MSOs, which may save the service provider's business life. We have analytically illustrated how the consumers' worry about the disease will lead to the failure of the service operation under SSO. We then show how the MSO can be a solution. In case when MSO is not financially viable, as it is still beneficial to consumers if MSO can be offered (as SSO definitely cannot run owing to the danger of being infected as well as the very big consumers' psychological worry), we suggest the government to provide subsidy to the firm to support MSO. There are three government subsidy schemes and we have shown that the OCS scheme outperforms the FCS scheme as it can bring benefits to both the firm and consumers. Moreover, an alternative non-monetary scheme, termed as the STS scheme, may also be applied. In the extended analyses, we first consider the case when service fee (i.e. revenue) is “exogenous” (i.e., cannot be changed when the firm adopts MSO under CVO). We have shown that the main conclusions under the endogenous service fee case remain valid. After that, we have explored the issue of whether it is wise for the firm to consider implementing the MSO business model in the long run, i.e., not just for the case when the disaster comes. We have

derived the analytical conditions which support this idea. Finally, we have derived the optimal safety technology investment level for the case when the consumers’ psychological worry can be reduced at a cost. In short, when the right conditions are met, we find that using the innovative “bring-service-near-your-home” MSO business model is a good idea to help the firm survive under disasters such as CVO.

6.2. Generalization

In this paper, since the motivation example follows a recent real case in Hong Kong, the context is very close to it and our focal point is based on that case. However, if we observe different industrial practices in the real world, we will find that MSO business models actually do commonly exist. For instance, in Hong Kong, we have mobile libraries, mobile Chinese medical service trucks, mobile insurance and financial service trucks, and even Red Cross has the mobile trucks to serve as the blood-donation stations. As a consequence, the MSO business models do exist in the world before we have the disasters. However, when we face a disaster like CVO, using transportation logistics to provide MSO is still a solid proposal. We argue that across different industries, such as fashion tailors, boutiques (Choi et al. 2017), hair stylists, fashion beauty and massage, medical doctors, drawing classes, etc. which involve personal face-to-face advice or interactions (e.g., measurements by tailors or diagnosis by medical doctors), the MSO business model may work under CVO type of disasters.

6.3. Future studies

In this paper, several important factors are not yet considered for the “bring-service-near-your-home” service operations. For example, during CVO, some countries have imposed strict rules in which consumers simply cannot leave homes. Thus, the MSO model may not be directly applicable to them⁷ and further studies are needed to find an alternative solution. Operational risk (Choi et al. 2008; Chiu and Choi 2016; Xue et al. 2016; Aras et al., 2020; Zhang et al. 2020b) is an important topic for service operations under disasters such as CVO, which deserves deeper exploration in the future (Chiu et al. 2018; Sun et al. 2018; Guo and Liu 2020). As service operations under disaster may involve many psychological effects such as worries, in this paper, we simply model them using relatively simple mathematical models. Further studies can investigate them from a multi-methodological approach (Choi et al. 2016; Li et al. 2019), e.g., with the collection of behavioral data from human subjects to fit into the analytical models. Last but not least, this paper focuses on highlighting the role played by logistics to support MSO. The more complete and general multi-echelon service supply chain systems are not yet examined. As a result, in the future, research can be conducted on the bigger supply chain systems (Chiu et al. 2011). Impacts brought by different supply chain members’ bargaining (Shi et al. 2020), elastic logistics (Choi 2020a) and stochastic capacities (Zhang et al. 2020a) may also open new avenues for further investigations.

Appendix (A1). All proofs and important derivations

Derivations of optimal decisions and consumer surplus

As there are multiple models and the derivations are similar, we choose the more complex model, Model M, as the illustration. From (3.16), we have: $\Pi_M = (p - t)(1 + h - p - y) - K_M(h) - G$.

Taking derivatives yields: $\partial\Pi_M/\partial p = 1 + t + h - y - 2p$, $\partial\Pi_M^2/\partial p^2 = -2$, $\partial\Pi_M^2/\partial p\partial h = 1$, $\partial\Pi_M/\partial h = (p - t) - k_N h$, $\partial\Pi_M^2/\partial h^2 = -k_M$.

The Hessian matrix is: $\begin{bmatrix} -2 & 1 \\ 1 & -k_M \end{bmatrix}$.

It is easy to find that if $k_M > 1/2$, then Π_M is concave.

Solving the first order conditions:

$$\partial\Pi_M/\partial p = 0 \Rightarrow p = \frac{1 + t + h - y}{2}, \tag{A1}$$

$$\partial\Pi_M/\partial h = 0 \Rightarrow h = (p - t)/k_N. \tag{A2}$$

Solving (A1) and (A2) yields $h_M^* = \frac{1 - y - t}{2k_M - 1}$ and $p_M^* = \frac{k_M(1 - y - t)}{2k_M - 1} + t$.

For the consumer surplus CS_M , it can be derived as follows:

$$\begin{aligned} CS_M &= \int_{p+y-h}^1 (v - (p + y - h))f(v)dv \\ &= \left(\frac{v^2}{2} - (p + y - h)v \right) \Big|_{(p+y-h)}^1 \\ &= \frac{(1 + h - p - y)^2}{2} \end{aligned} \tag{A3}$$

⁷ As a remark, even for China and other markets in which tight controls are imposed during CVO, there will be times when some cities will have relaxed control if the CVO is less severe. At that time, consumers can come out but they may still worry about visiting these static service operations. Thus, the “bring-service-near-your-home” MSO business model may still be applicable at that time.

Putting the optimal hygiene levels and revenue into the profit function and consumer surplus function, we have Table A1. Similarly, we can do the same for the analyses under Model N and Model S. This gives all the optimal decisions under each model and the whole Table 3.1.

Table A1
Optimal profit and consumer surplus under Model M.

	Model M
Π_M^*	$\frac{k_M(1-y-t)^2}{2(2k_M-1)} - G$
CS_M^*	$\frac{k_M^2(1-y-t)^2}{2(2k_M-1)^2}$

Proof of Proposition 4.1. The firm will go bankrupt with the static service operation (SSO) under CVO when $\Pi_S^* = \frac{k_S(1-el-w)^2}{2(2k_S-1)} - F < 0$.

By definition, we have: $\hat{w}_S = 1 - el - \sqrt{\frac{2F(2k_S-1)}{k_S}}$, $\hat{e}_S = \frac{1}{l} \left(1 - w - \sqrt{\frac{2F(2k_S-1)}{k_S}} \right)$, $\hat{F}_S = \frac{k_S(1-el-w)^2}{2(2k_S-1)}$.

It is straightforward to prove that: $\Pi_S^* < 0$ if and only if one of the following three equivalent conditions holds: (i) $w > \hat{w}_S$; (ii) $e > \hat{e}_S$; (iii) $F > \hat{F}_S$. \square

Proof of Proposition 4.2. The firm will survive with the mobile service operation (MSO) under CVO when $\Pi_M^* = \Pi_M(h_M^*, p_M^*) = \frac{k_M(1-y-t)^2}{2(2k_M-1)} - G \geq 0$. By definition, we have: $\hat{y}_M = 1 - t - \sqrt{\frac{2G(2k_M-1)}{k_M}}$, $\hat{c}_M = \frac{1}{l} \left(1 - y - \sqrt{\frac{2G(2k_M-1)}{k_M}} \right)$, $\hat{G}_M = \frac{k_M(1-y-t)^2}{2(2k_M-1)}$. It is straightforward to prove that $\Pi_M^* \geq 0$ if and only if any one of the following three equivalent conditions is true: (i) $y \leq \hat{y}_M$; (ii) $c \leq \hat{c}_M$; (iii) $G \leq \hat{G}_M$. \square

Proof of Proposition 4.3. (a) It is obvious that by sponsoring G under the FCS scheme or sponsoring c under the OCS scheme can make $\Pi_M^* = 0$ (the break-even point). This completes the proof for Part (a). However, by definition, we have $CS_M^* = \frac{k_M^2(1-y-t)^2}{2(2k_M-1)^2}$ which is a function independent of G. As a result, using the FCS scheme does not improve consumer surplus. On the contrary, CS_M^* depends on t, which is defined as: $t = cl$. Thus, under the OCS scheme, by providing subsidy on c, the value t will be smaller which increases CS_M^* . Thus, the OCS scheme outperforms the FCS scheme. \square

Proof of Proposition 5.1. The analysis is similar to Proposition 4.1 and Proposition 4.2.

First, note that by definition, we have: $\bar{w}_S = 1 - p \left(1 - \frac{1}{2k_S} \right) - \left(\frac{F}{p} \right) - el$, $\bar{e}_S = \frac{1}{l} \left(1 - p \left(1 - \frac{1}{2k_S} \right) - \left(\frac{F}{p} \right) - w \right)$, $\bar{F}_S = p(1-p-w-el) + \frac{p^2}{2k_S}$, $\bar{G}_M = (p-t)(1-p-y) + \frac{(p-t)^2}{2k_M}$, $\bar{y}_M = 1 - p - \frac{G^2}{p-t} + \frac{p-t}{2k_M}$, $\bar{c}_M = \frac{1}{l} \{ p + k_M(1-p-y) - \sqrt{2k_M(G + [k_M(1-p-y)]^2)} \}$.

Second, the key is to note that:

- (a) $\bar{\Pi}_S^* < 0$ if and only if any one of the following three equivalent conditions holds: (i) $w > \bar{w}_S$; (ii) $e > \bar{e}_S$; (iii) $F > \bar{F}_S$.
- (b) $\bar{\Pi}_M^* \geq 0$ if and only if any one of the following three equivalent conditions holds: (i) $y \leq \bar{y}_M$; (ii) $c \leq \bar{c}_M$; (iii) $G \leq \bar{G}_M$.

As a remark, for “ $c \leq \bar{c}_M$ ”, the analysis includes a “completing square” step: Since $\bar{\Pi}_M^* = (p-t)(1-p-y) + \frac{(p-t)^2}{2k_M} - G$, $\bar{\Pi}_M^* = 0 \Leftrightarrow (p-t)(1-p-y) + \frac{(p-t)^2}{2k_M} - G = 0$, which means:

$$\begin{aligned} & \frac{1}{2k_M} (2k_M(p-t)(1-p-y) + (p-t)^2) - G = 0 \\ \Leftrightarrow & \frac{1}{2k_M} ((p-t) + k_M(1-p-y))^2 - G - [k_M(1-p-y)]^2 = 0 \\ \Leftrightarrow & ((p-t) + k_M(1-p-y))^2 = 2k_M(G + [k_M(1-p-y)]^2) \\ \Leftrightarrow & t = p - k_M(1-p-y) - \sqrt{2k_M(G + [k_M(1-p-y)]^2)} \\ \Leftrightarrow & cl = p - k_M(1-p-y) - \sqrt{2k_M(G + [k_M(1-p-y)]^2)} \end{aligned}$$

$$\Leftrightarrow c = \bar{c}_M.$$

This completes the proof. \square

Proof of Lemma 5.1. First of all, note the following definitions:

$$\hat{G}_1 = \frac{\phi k_M(1-y-t)^2}{2(2k_M-1)} + \frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - (1-\phi)\left(\frac{k_N(1-\eta l)^2}{2(2k_N-1)} - F\right),$$

$$\hat{G}_2 = \frac{\phi k_M(1-y-t)^2}{2(2k_M-1)} + \frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - \left[\frac{\phi k_S(1-el-w)^2}{2(2k_S-1)} + (1-\phi)\left(\frac{k_N(1-\eta l)^2}{2(2k_N-1)} - F\right)\right],$$

$$\hat{y}_1^\Pi = 1-t - \sqrt{\left(\frac{2(2k_M-1)}{\phi k_M}\right)\left\{(1-\phi)\left(\frac{k_N(1-\eta l)^2}{2(2k_N-1)} - F\right) - \left(\frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - G\right)\right\}},$$

$$\hat{y}_2^\Pi = 1-t - \sqrt{\left(\frac{2(2k_M-1)}{\phi k_M}\right)\left\{\frac{\phi k_S(1-el-w)^2}{2(2k_S-1)} + (1-\phi)\left(\frac{k_N(1-\eta l)^2}{2(2k_N-1)} - F\right) - \left(\frac{(1-\phi)k_{NM}(1-t)^2}{2(2k_{NM}-1)} - G\right)\right\}}.$$

- (a) When $F > \hat{F}_{SX}$: We compare the optimal profit functions under Model MX (i.e., MSO) and Model SX-1. Then, we can see that $\Pi_{MX}^* > \Pi_{SX-1}^*$ if and only if $y < \hat{y}_1^\Pi$ (or equivalently $G < \hat{G}_1$).
- (b) When $F \leq \hat{F}_{SX}$: We compare the optimal profit functions under Model MX (i.e., MSO) and Model SX-2. Then, we can see that $\Pi_{MX}^* > \Pi_{SX-2}^*$ if and only if $y < \hat{y}_2^\Pi$ (or equivalently $G < \hat{G}_1$). \square

Proof of Lemma 5.2. By definition, we have the following:

$$\hat{y}_1^{CS} = 1-t - \sqrt{\left(\frac{2(2k_M-1)^2}{\phi k_M^2}\right)\left((1-\phi)\frac{k_N^2(1-\eta l)^2}{2(2k_N-1)^2} - \frac{(1-\phi)k_{NM}^2(1-t)^2}{2(2k_{NM}-1)^2}\right)},$$

$$\hat{y}_2^{CS} = 1-t - \sqrt{\left(\frac{2(2k_M-1)^2}{\phi k_M^2}\right)\left(\frac{\phi k_S^2(1-el-w)^2}{2(2k_S-1)^2} + (1-\phi)\frac{k_N^2(1-\eta l)^2}{2(2k_N-1)^2} - \frac{(1-\phi)k_{NM}^2(1-t)^2}{2(2k_{NM}-1)^2}\right)}.$$

- (a) When $F > \hat{F}_{SX}$: Note that $CS_{MX}^* > CS_{SX-1}^*$ if and only if $y < \hat{y}_1^{CS}$.
- (b) When $F \leq \hat{F}_{SX}$: Observe that $CS_{MX}^* > CS_{SX-2}^*$ if and only if $y < \hat{y}_2^{CS}$. \square

Proof of Proposition 5.2. Observe that $\hat{Y}_1 = \min(\hat{y}_1^\Pi, \hat{y}_1^{CS})$ and $\hat{Y}_2 = \min(\hat{y}_2^\Pi, \hat{y}_2^{CS})$. Directly using the results from Lemma 5.1 and 5.2 yields Proposition 5.2. \square

Appendi (A2). Definitions

See Table A2-A3.

Table A2
Definitions of some important abbreviations.

Abbreviation	Details
MSO	Mobile service operation
SSO	Static service operation
Model N	The static service operations model under the normal market environment
Model S	The static service operations model under CVO
Model M	The mobile service operations model under CVO
Model SX-1	The static service operations model for the long run (type 1)
Model SX-2	The static service operations model for the long run (type 2)
Model MX	The mobile service operations model for the long run
CVO	Corona virus outbreak
OCS	Operating cost subsidy
FCS	Fixed cost subsidy
STS	Safety-technology-support

Table A3
Notation of some key parameters utilized in the modeling analysis.

Notation	Meaning
p	Unit service fee (revenue)
F	Unit fixed operations cost under SSO
G	Unit fixed operations cost under MSO
l	The average distance for the consumer to visit the firm
η	The unit traveling disutility under Model N
e	The unit traveling disutility under Model S, where $e > \eta$
w	The consumers' psychological worry under Model S
y	The consumers' psychological worry under Model M
c	The operations cost coefficient (with respect to the needed travel for the firm) under Model M
t	The unit operations cost under Model M, which is defined as $t = cl$

References

- Aras, O., Choi, T.M., Olson, D., Salman, S., 2020. Role of analytics for operational risk management in the era of big data. *Decision Sci.* <https://doi.org/10.1111/dec.12451>.
- Balcik, B., Silvestri, S., Rancourt, M.E., Laporte, G., 2019. Collaborative prepositioning network design for regional disaster response. *Prod. Oper. Manage.* 28 (10), 2431–2455.
- Chiu, C.H., Choi, T.M., 2016. Supply chain risk analysis with mean-variance models: a technical review. *Ann. Oper. Res.* 240, 489–507.
- Chiu, C.H., Choi, T.M., Tang, C.S., 2011. Price, rebate, and returns supply contracts for coordinating supply chains with price-dependent demands. *Prod. Oper. Manage.* 20 (1), 81–91.
- Chiu, C.H., Choi, T.M., Dai, X., Shen, B., Zheng, J.H., 2018. Optimal advertising budget allocation in luxury fashion markets with social influences: A mean-variance analysis. *Prod. Oper. Manage.* 27 (8), 1611–1629.
- Choi, T.M., 2011. Coordination and risk analysis of VMI supply chains with RFID technology. *IEEE Trans. Ind. Inf.* 7 (3), 497–504.
- Choi, T.M., 2013. Local sourcing and fashion quick response system: the impacts of carbon footprint tax. *Transport. Res. Part E: Logist. Transport. Rev.* 55, 43–54.
- Choi, T.M., 2016. *Service Supply Chain Systems: A Systems Engineering Approach*. CRC Press, the UK.
- Choi, T.M., 2020a. Facing market disruptions: Values of elastic logistics in service supply chains. *Int. J. Prod. Res.* <https://doi.org/10.1080/00207543.2020.1722861>.
- Choi, T.M., 2020b. Supply chain financing using blockchain: Impacts on supply chains selling fashionable products. *Ann. Oper. Res.* <https://doi.org/10.1007/s10479-020-03615-7>.
- Choi, T.M., Cheng, T.C.E., Zhao, X., 2016. Multi-methodological research in operations management. *Prod. Oper. Manage.* 25 (3), 379–389.
- Choi, T.M., Chow, P.S., Shen, B., Wan, M.L., 2017. Service analysis of fashion boutique operations: An empirical and analytical study. *IEEE Trans. Syst., Man, Cybernet. – Syst.* 47 (11), 2896–2907.
- Choi, T.M., Guo, S., Liu, N., Shi, X., 2020. Optimal pricing in on-demand-service-platform-operations with hired agents and risk-sensitive customers in the blockchain era. *Eur. J. Oper. Res.* 284 (3), 1031–1042.
- Choi, T.M., Li, D., Yan, H., 2008. Mean-variance analysis of a single supplier and retailer supply chain under a returns policy. *Eur. J. Oper. Res.* 184 (1), 356–376.
- Choi, T.M., Luo, S., 2019. Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes. *Transport. Res. Part E: Logist. Transport. Rev.* 131, 139–152.
- Choi, T.M., Wallace, S.W., Wang, Y., 2018. Big data analytics in operations management. *Prod. Oper. Manage.* 27 (10), 1868–1883.
- Choi, T.M., Wen, X., Sun, X., Chung, S.H., 2019. The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era. *Transport. Res. Part E: Logist. Transport. Rev.* 127, 178–191.
- Guo, S., Liu, N., 2020. Influences of supply chain finance on the mass customization program: risk attitudes and cash flow shortage. *Int. Trans. Oper. Res.* <https://doi.org/10.1111/itor.12708>.
- Huang, S., Fan, Z.P., Wang, N., 2020. Green subsidy modes and pricing strategy in a capital-constrained supply chain. *Transport. Res. Part E: Logist. Transport. Rev.* 136, 101885.
- Ivanov, D., 2020. Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transport. Res. Part E: Logist. Transport. Rev.* 136, 101922.
- Jacob, B.W., Singhal, V.R., 2017. The effect of the Rana Plaza disaster on shareholder wealth of retailers: Implications for sourcing strategies and supply chain governance. *J. Oper. Manage.* 49–51, 52–66.
- Jeong, H.Y., Yu, D.J., Min, B.C., Lee, S., 2020. The humanitarian flying warehouse. *Transport. Res. Part E: Logist. Transport. Rev.* 136, 101901.
- Kim, S., Ramkumar, M., Subramanian, N., 2019. Logistics service provider selection for disaster preparation: a socio-technical systems perspective. *Ann. Oper. Res.* 283, 1259–1282.
- Kuo, Y.H., Kusiak, A., 2019. From data to big data in production research: the past and future trends. *Int. J. Prod. Res.* 57 (15–16), 4828–4853.
- Li, G., Li, L., Choi, T.M., Sethi, S.P., 2019. Green supply chain management in Chinese firms: Innovative measures and the moderating role of quick response technology. *J. Oper. Manage.* <https://doi.org/10.1002/joom.1061>.
- Liu, W., Yan, X., Wei, W., Xie, D., 2019a. Pricing decisions for service platform with provider's threshold participating quantity, value-added service and matching ability. *Transport. Res. Part E: Logist. Transport. Rev.* 122, 410–432.
- Liu, Y., Cui, N., Zhang, J., 2019b. Integrated temporary facility location and casualty allocation planning for post-disaster humanitarian medical service. *Transport. Res. Part E: Logist. Transport. Rev.* 128, 1–16.
- Mejia, J., Urrea, G., Pedraza-Martinez, A.J., 2019. Operational transparency on crowdfunding platforms: Effect on donations for emergency response. *Prod. Oper. Manage.* 28 (7), 1773–1791.
- Ren, S., Choi, T.M., Lee, K.M., Lin, L., 2020. Intelligent service capacity allocation for cross-border-E-commerce related third-party-forwarding logistics operations: A deep learning approach. *Transport. Res. Part E: Logist. Transport. Rev.* 134, 101834.
- Schoenheerr, T., Speier-Pero, C., 2015. Data science, predictive analytics, and big data in supply chain management: Current state and future potential. *J. Bus. Logist.* 36 (1), 120–132.
- Shen, B., Xu, X., Guo, S., 2019. The impacts of logistics services on short life cycle products in a global supply chain. *Transport. Res. Part E: Logist. Transport. Rev.* 131, 153–167.
- Sheu, J.B., Choi, T.M., 2020. Strategic hoarding, panic buying, and post-disaster retail market recovery. Working paper, The Hong Kong Polytechnic University.
- Shi, X., Chan, H.L., Dong, C., 2020. Value of bargaining contract in a supply chain system with sustainability investment: An incentive analysis. *IEEE Trans. Syst., Man, Cybernet. – Syst.* 50 (4), 1622–1634.
- Singh, J.P., Dwivedi, Y.K., Rana, N.P., Kumar, A., Kapoor, K.K., 2019. Event classification and location prediction from tweets during disasters. *Ann. Oper. Res.* 283, 737–757.

- Sun, X., Chung, S.H., Chan, F.T.S., Wang, Z., 2018. The impact of liner shipping unreliability on the production–distribution scheduling of a decentralized manufacturing system. *Transport. Res. Part E: Logist. Transport. Rev.* 114, 242–269.
- Wang, D., Liu, W., Shen, X., Wei, W., 2019. Service order allocation under uncertain demand: Risk aversion, peer competition, and relationship strength. *Transport. Res. Part E: Logist. Transport. Rev.* 130, 293–311.
- Wang, Y., Wallace, S.W., Shen, B., Choi, T.M., 2015. Service supply chain management: A review of operational models. *Eur. J. Oper. Res.* 247, 685–698.
- Xue, W., Choi, T.M., Ma, L., 2016. Diversification strategy with random yield suppliers for a mean–variance risk-sensitive manufacturer. *Transport. Res. Part E: Logist. Transport. Rev.* 90, 90–107.
- Yan, L., Pedraza-Martinez, A.J., 2019. Social media for disaster management: Operational value of the social conversation. *Prod. Oper. Manage.* 28 (10), 2514–2532.
- Ye, Y., Jiao, W., Yan, H., 2019. Managing relief inventories responding to natural disasters: Gaps between practice and literature. *Prod. Oper. Manage.* <https://doi.org/10.1111/poms.13136>.
- Zhang, J., Choi, T.M., Cheng, T.C.E., 2020a. Stochastic production capacity: A bane or a boon for quick response supply chains. *Nav. Res. Logist.* 67 (2), 126–146.
- Zhang, J., Sethi, S.P., Choi, T.M., Cheng, T.C.E., 2020b. Supply chains involving a mean-variance-skewness-kurtosis newsvendor: Analysis and coordination. *Prod. Oper. Manage.* <https://doi.org/10.1111/poms.13159>.