Risk-Averse Ride-Hailing Platform Operations with Safety Risk-Averse Consumers under Pandemics: Roles of Blockchain Technology and Government Sponsors[1]

Tsan-Ming Choi

Centre for Supply Chain Research, University of Liverpool Management School, Chatham Building, Liverpool L69 7ZH, the United Kingdom; and Department and Graduate Institute of Business Administration, College of Management, National Taiwan University, Roosevelt Road, Taipei 10617, Taiwan, R.O.C. (Email: tsanmingchoi@link.cuhk.edu.hk; tmjchoi@gmail.com)

Jiuh-Biing Sheu, corresponding author

Department and Graduate Institute of Business Administration, College of Management, National Taiwan University, Roosevelt Road, Taipei 10617, Taiwan, R.O.C. (Email: jbsheu@ntu.edu.tw)

Abstract: Today, ride-hailing platform operations are popular. Facing pandemics (e.g., COVID-19), some customers feel unsafe for the ride-hailing service and possess a "safety risk-averse" (SRA) attitude. The proportion of this type of SRA customers is unfortunately unknown, which makes it difficult for the ride-hailing platform to decide its optimal service price. In this paper, understanding that blockchain technology (BT) based systems can help improve market estimation for the proportion of SRA customers, we conduct a theoretical study to explore the impacts that the BT-based system can bring to the platform, customers and drivers. We consider the case in which the platform is risk-averse (in profit) and serves a market with both SRA and non-SRA customers. We analytically prove that using BT, the optimal service price will be increased and BT is especially helpful for the case with a more risk-averse ride-hailing platform. However, whether it is more or less significant for the more risk-averse SRA customers depends on their degree of risk aversion. We uncover that when the use of BT is beneficial to the customers, it will also be beneficial to the drivers, and vice versa. We derive in closed-form the analytical conditions under which the use of BT can be beneficial to the ride-hailing

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platform, customers and drivers (i.e., achieving "all-win"). When all-win cannot be achieved automatically, we explore how governments can provide sponsors to help. We further extend the analysis to consider the general case in which BT incurs both a fixed cost as well as a cost increasing in demand. We prove that the main conclusion remains robust. In addition, we reveal that the required amount of government sponsor to achieve all-win is the same between the two different costing models explored in this paper.

Keywords: Risk; platform operations; blockchain; pandemics; risk aversion.

Managerial Relevance Statement: Nowadays, ride-hailing platform operations are popular. Facing pandemics (e.g., COVID-19), some customers feel unsafe for the ride-hailing service and possess a "safety risk-averse" (SRA) attitude. The proportion of SRA customers is unfortunately unknown, which makes it difficult for the ride-hailing platform to decide its optimal service price. In this paper, understanding that blockchain technology (BT) based systems can help improve market estimation, we conduct a theoretical study to explore the impacts that the BT-based system can bring to the platform, customers and drivers. We consider the case in which the platform is risk-averse and serves a market with both SRA and non-SRA customers. We analytically prove that using BT, the optimal service price will be increased and BT is especially helpful for the risk-averse cases with a more risk-averse ride-hailing platform. However, whether it is more or less significant for the more risk-averse SRA customers depends on their degree of risk aversion. We uncover that when the use of BT is beneficial to the customers, it will also be beneficial to the drivers, and vice versa. We derive in closed-form the conditions under which the use of BT can be beneficial to the ride-hailing platform, customers and drivers (i.e., achieving "all-win"). We explore how governments can provide sponsors to achieve all-win. We further extend the analysis to consider the general case in which BT incurs both the fixed cost as well as a cost increasing in demand. We prove that the main conclusion remains robust. In addition, we reveal that the required amount of government sponsor to achieve all-win is the same between the two different costing models explored in this paper. The above findings can bring important managerial guidance to ride-hailing platform managers on the pros and cons of using BT to deal with the pandemics such as COVID-19.

I. Introduction

A. Background

Ride-hailing platform operations are very popular nowadays. Companies such as Uber and Lyft are very influential and common in all major cities around the world. There is no doubt that the emergence of ride-hailing platforms brings lots of convenience to customers who wish to enjoy the on-demand "taxi" like travel services. However, challenges also exist. Among them, safety is definitely critical.

From news, we observe two types of safety risk are related to ride-hailing platform operations from the customer perspective. The first type is about personal safety with drivers who commit crimes. The second type is related to the pandemics such as COVID-19 [1, 2], in which "unclean" vehicles may spread the virus. For the first type on personal safety issues, back to 2019, Uber released a safety report[2], which shows that in 2017 and 2018, over 100 people died in car crashes, 19 people were killed in "physical assaults", and over 3000 sexual assault cases were reported. Another ride-hailing platform, Lyft, is also reported to face lawsuits related to sexual assaults of passengers. Recently, in 2022, the Chinese government criticized 11 ride-hailing platforms over safety problems in their operations, such as violations of safety rules (e.g., hiring unlicensed drivers) and improper handling of accidents[3]. During the COVID-19 pandemic, in August 2020, BBC reported that near 50% of customers who were active in Uber App were lost[4], with trip bookings went down by 70%. Another piece of news shows that Uber suffered a heavy loss of over 1 billion USD in its platform business from August to October 2020[5]. There is no doubt that both types of safety risk are substantial and critical.

It is a fact that in the market, some customers care a lot about the safety risk while some do not. We call those customers who worry about the safety risk the "safety risk-averse" (SRA) customers. For those who don't care, they are the non-SRA customers. The proportion of SRA customers in the market will definitely affect the ride-hailing platform's operations while it is in fact largely unknown.

[2] https://www.consumerreports.org/ride-hailing/staying-safe-when-using-ride-hailing-services/
[3] https://technode.com/2022/08/23/chinese-regulator-slams-major-ride-hailers-over-safety-issues/
[4] https://www.bbc.co.uk/news/business-53687422
[5] https://www.theverge.com/2020/11/5/21551683/uber-q3-2020-earnings-revenue-loss-delivery

Thus, the ride-hailing platform would like to acquire good information regarding the proportion of SRA customers. One method that can help is to use the blockchain technology (BT) based systems. Note that despite being famous in FinTech [3, 4], BT actually has its applications in different industries and business operations [5, 6], including logistics [7], jewellery [8], and platforms [9, 10].

Owing to the inherent properties of BT, it is known that BT based systems have the benefits of keeping high quality data sets which cannot be amended and made-up. The data quality of BT-based systems is hence high [11] and would allow the ride-hailing platforms to more accurately estimate the proportion of SRA customers in the market. In addition, for customers, the presence of BT will also yield a benefit of "enhanced trust". This will be beneficial to both SRA and non-SRA customers.

Note that the use of BT based systems for ride related platforms has been proposed in the real world by companies such as RideX and Acrade City. Prior studies have also explored the use of BT to help on-demand ride-hailing platform operations under COVID-19 [12]. Thus, the use of BT in our problem context is supported by industrial practices and prior studies.

B. Research Questions and Major Findings

Motivated by the real-world observations that SRA customers exist in the market and the use of BT based systems may be helpful for the ride-hailing platform operations, we establish theoretical models to address the following important research questions:

1. How is the optimal pricing decision of the ride-hailing platform related to the proportion of SRA and the corresponding uncertainty?
2. If the BT based system is implemented, what will be the impacts to the ride-hailing platform, customers and drivers? When will an all-win situation be achieved in which the ride-hailing platform, customers and drivers are all benefited with the use of BT? If the use of BT benefits customers and drivers but not the ride-hailing platform, could a government sponsorship help?
3. If a general cost function with both the fixed cost and a demand increasing cost for operating BT-based system is considered, will the results remain robust?

To answer the above research questions, we build formal models and conduct a theoretical study. We analytically consider the case in which the platform is risk-averse and serves a market facing both SRA and non-SRA customers. We theoretically demonstrate that if the use of a BT-based system can reduce uncertainty regarding the estimation of proportion of SRA customers, the optimal service price will be increased. We prove that BT is especially helpful for the scenario with a more risk-averse ride-hailing platform. However, whether using BT is more significant for the more risk-averse SRA customers depends on their degree of risk aversion. To be specific, using BT will bring a higher (lower) value when the SRA customers are more risk-averse if they are already highly (mildly) risk-averse before the use of BT. We also find that when the use of BT is beneficial to the customers, it will also be beneficial to the drivers, and vice versa. We determine the analytical conditions under which the use of BT can be beneficial to the ride-hailing platform, customers and drivers (i.e., achieving the all-win situation). We explore how governments can provide sponsors to achieve all-win. We further extend the analysis to consider the case in which BT incurs a cost which is increasing in demand. We conclude by showing that the main conclusion remains valid. Moreover, we reveal that the required amount of government sponsor to achieve all-win is the same between the two different costing models explored in this paper. This implies that the implementation of government sponsorship scheme is easy, without too much worry of whether BT costs include only the fixed cost or the variable cost or both.

C. Contribution Statement and Paper's Organization

This paper's contribution is multi-fold. First, we bring new insights into the on-demand ride-hailing platform operations facing the pandemics (such as COVID-19) in the literature with the focal point on using BT. Second, we uncover the conditions under which all-win situations can be achieved with the use of BT and also propose an implementable government sponsorship scheme to help. Finally, our findings can bring important managerial guidance to ride-hailing platform managers on the pros and cons of using BT. To the best of our knowledge, this is the first study which analytically explores this important and timely topic.

The rest of this paper is arranged section by section as follows. We first review the closely related prior studies in the engineering management literature in Section 2. Then, we build the analytical main model in Section 3. We conduct the theoretical analysis for the case with BT (i.e., Model BT) in Section 4 and derive in closed-form the expected value of BT. We extend the model by considering a general cost function with both a fixed cost and a demand increasing variable cost of operating the BT-based system (i.e., Model EM) in Section 5. We present the conclusion with a discussion of core managerial implications in Section 6. To facilitate presentation, all technical proofs are placed in the supplementary online appendix (for online publication).

II. Literature Review

In the current digital era [13, 14], platform operations are commonly seen [15, 16, 17]. In the literature, Cachon et al. [18] analytically explore optimal surge pricing strategies for service platform operations. Bai et al. [19] examine how the use of on-demand platforms can balance demand and supply facing consumers who exhibit the impatient characteristics. Stafford [20] studies the systems security for platform-based information systems. Du et al. [21] examine the food delivery platform operations. The authors uncover the benefits of using the 3rd party as the delivery option. Hu et al. [22] study platform operations with the focal point on membership schemes. Most recently, He et al. [23] explore an interesting phenomenon called "off-platform" transaction in which the customer and service provider privately decide to have their transaction done without formally going through the platform. This lets them save the cost of paying the needed commissions to the platform at the expense of the platform's revenue loss. The authors reveal the service properties which would help platforms fight against this off-platform challenge. Li and Li [24] examine the platform entry strategies in the presence of an e-marketplace. The authors investigate whether it is wise to have integration of the critical logistics services. For recent reviews of platform operations and the related technology management studies, refer to [25, 26].

Among platform operations, one very important sector is on ride-hailing. In the literature, Wang et al. [27] analytically investigate the optimal pricing policies for ride-hailing platform operations. Yu et al. [28] reveal the trade-off in imposing rules on ride-hailing platform services. Choi and Shi [12] analytically explore via a queuing model the optimal "on-demand-ride-hailing-service platform" operations under the pandemic. The authors study how technologies can be used to improve the service operations facing the pandemic. Liu et al. [29] study ride-hailing platform operations using the artificial intelligence approach. They reveal the optimal schemes to dispatch vehicles. Tripathy et al. [30] examine the "driver collusion" challenges for on-demand ride-hailing platforms such as Uber. This paper is similar to the above reviewed studies in which the focal point is on ride-hailing platform operations. However, both the specific model and focal points are very different. In particular, we examine the market with an uncertain proportion of SRA customers and explore how the use of BT-based system can help improve market estimation by reducing the uncertainty. To the best of our knowledge, this problem has not been examined in the ride-hailing operations literature before.

Ride-hailing platform operations involve risk. In the literature, Liu et al. [31] conduct an empirical study to uncover the customers' security attitudes towards ride-hailing services. Under COVID-19 pandemic, Monahan and Lamb [32] discuss the "social-justice implications" of ride-hailing service operations for public transportation systems. Yang et al. [33] empirically explore during the normal days, the safety perception of passengers, especially female, for ride-hailing services. All the above risk related studies are empirical in nature. Partially motivated by these empirical findings, we build theoretical models and study the optimal ride-hailing platform operations by an analytical modelling approach. We also highlight the use of BT-based systems as a way to improve service operations.

BT has been widely explored in the literature such as finance [34], crowdsourcing [35], logistics [36, 37], and systems security [38]. Since this paper also relates to the proposal of using BT-based systems to enhance ride-hailing platform operations, we examine some related studies. Choi and Luo [11] study how using BT can improve quality of data to achieve sustainable business operations. The authors also study the government policies which can support the use of BT to improve social welfare.

Choi et al. [39] investigate via a queuing model the use of BT for on-demand platforms facing risk-sensitive customers. The authors consider the case in which the customers can be risk seeking, risk-averse and risk neutral. Choo et al. [40] discuss the challenges and research potential of using BT to develop an ecosystem for business operations. Cai et al. [41] analytically uncover how the use of BT-based systems can overcome cheating problems in platform operations. Most recently, Wang et al. [42] explore the use of BT for developing an "anonymous ride-hailing scheme for autonomous taxi network". The authors pay attention to the use of BT for passengers privacy issues. This paper follows Choi and Luo [11] to consider the use of BT to improve data quality, but the problem domain is very different. This paper is also related to Choi et al. [39] in considering risk sensitive customers. However, in this paper, we focus on safety related risk while Choi et al. [39] examine the waiting time volatility related risk. The specific models are also totally different.

III. Main Model

In this paper, we analytically examine ride-hailing platforms such as Uber, Didi, and Lyft. The ride-hailing platform recruits professional drivers. Each driver receives a per demand income c, and the operating expense incurred for the driver is m. In the market, there are two types of customers who would like to take a ride as "passengers". The first type is called SRA customers who are averse to safety. Here, under the pandemics such as COVID-19, safety refers to not just the personal safety, but also the infection risk. The second type is the non-SRA customers who have no worries towards safety risk on taking the ride-hailing service. For the SRA customers, they have a safety fear which is denoted by a single parameter ξ in the model, where $\xi > 0$. Without loss of generality, the total market population is normalized to be 1. This is a standard approach in the literature which helps simplify the mathematical derivation and results.

We consider the situation in which the proportion of SRA customers in the market is denoted by $\tilde{\alpha}$ (and hence the proportion of non-SRA customers is $1-\tilde{\alpha}$). In our model, $\tilde{\alpha}$ is modelled as a random variable following a general distribution with mean $\bar{\alpha}$ and variance σ^2. In this paper, we use the ~ as a notation to represent random variables.

The ride-hailing platform charges a fee p for the service. Customers in the market possess a heterogenous valuation v towards the ride-hailing service. Following the standard literature [12], we model v as a uniformly distributed random variable with the support of 0 and 1.

For a given $\tilde{\alpha}$, we can derive the demand for ride-hailing services $\tilde{D}$ as follows:

$$\tilde{D} = \tilde{\alpha}(1-p-\xi)+(1-\tilde{\alpha})(1-p) = (1-p)-\tilde{\alpha}\xi . \tag{1}$$

It is easy to derive the expected demand $\bar{D}$ and variance of demand $\hat{D}$ to be the following:

$$\bar{D} = E[\tilde{D}] = (1-p)-\xi\bar{\alpha} , \tag{2}$$

$$\hat{D} = V[\tilde{D}] = \xi^2\sigma^2 . \tag{3}$$

Note that in this paper, for analytical tractability, we focus on the simpler models in which we do not consider queueing based consumer arrival models. This in fact follows some important studies in the area [43, 44]. Nevertheless, in Section VI, we admit limitations and propose that future research can be conducted to examine the more sophisticated models.

With (1) to (3), we can derive the ride-hailing platform's profit $\tilde{\Pi}_{PF}$, expected profit $\bar{\Pi}_{PF}$ and variance of profit $\hat{\Pi}_{PF}$ as follows:

$$\tilde{\Pi}_{PF} = (p-c)((1-p)-\tilde{\alpha}\xi) , \tag{4}$$

$$\bar{\Pi}_{PF} = (p-c)((1-p)-\bar{\alpha}\xi) , \tag{5}$$

$$\hat{\Pi}_{PF} = (p-c)^2\xi^2\sigma^2 . \tag{6}$$

For the ride-hailing platform, it possesses a risk-averse atttiude. Note that risk-aversion is rather commonly seen in logistics [45, 46] and business operations [47]. We consider its objective function U_{PF} to be a mean-standard-deviation form, with a risk-averse coefficient k, where $k > 0$:

$$U_{PF} = \bar{\Pi}_{PF} - k\sqrt{\hat{\Pi}_{PF}} . \tag{7}$$

Note that in (7), the objective function captures the risk-averse attitude of the ride-hailing platform in which $\sqrt{\hat{\Pi}_{PF}}$ denotes the level of profit risk. This mean-standard-deviation framework is widely applied in the literature, including prior studies in the on-demand platform literature [39]. The idea is to capture the profit risk by the variation of profit and the payoff by the expected profit. This approach is very commonly used and is closely related to the mean-variance approach [48] [49] [50]. It is crystal clear that a larger *k* represents a more risk-averse ride-hailing platform. Thus, *k* reflects the degree of risk aversion of the ride-hailing platform.

With the above formulation, we can further derive the consumer surplus as follows. To be specific, we first define CS_{SRA} and $CS_{non-SRA}$ as the consumer surplus for the SRA customers and non-SRA customers, respectively. Then, by definition, we have:

$$CS_{SRA} = \int_{p+\xi}^{1} (v-p-\xi) f(v) dv = \frac{(1-(p+\xi))^2}{2}, \tag{8}$$

$$CS_{non-SRA} = \int_{p}^{1} (v-p) f(v) dv = \frac{(1-p)^2}{2}. \tag{9}$$

With (8) and (9), we can define the (expected) consumer surplus for the whole market as follows:

$$\begin{aligned} CS &= \bar{\alpha} CS_{SRA} + (1-\bar{\alpha}) CS_{non-SRA} \\ &= \frac{\bar{\alpha}(1-(p+\xi))^2}{2} + \frac{(1-\bar{\alpha})(1-p)^2}{2}. \end{aligned} \tag{10}$$

For the hired drivers, as the service agents, their expected profit function $\bar{\Pi}_{DR}$ is given below:

$$\bar{\Pi}_{DR} = (c-m)((1-p)-\bar{\alpha}\xi). \tag{11}$$

To enhance presentation, the main notation and abbreviations used in this paper are summarized in Table 1 (Appendix A1). Note that some of the defined notation and abbreviations are used in other sections as well as the appendix.

With the analytical mean-standard-deviation objective function derived above, after checking its structural properties, we can derive the optimal service price and present Lemma 1.

Lemma 1. *In the main model (without the use of BT): (a) The optimal service price* $p^* = \frac{1-\bar{\alpha}\xi - k\xi\sigma + c}{2}$ *. (b)* p^* *is increasing in c, and decreasing in* $\bar{\alpha}$*,* σ*,* ξ *and* k*. (c) To ensure a* *profitable business, the ride-hailing paltform cannot be too risk-averse (i.e., $k < \ddot{k}$, where $\ddot{k} = \dfrac{1 - c - \bar{\alpha}\xi}{2\xi\sigma}$).*

Lemma 1(a) gives the closed-form analytical expression for the optimal service price. Lemma 1(b) presents the structural properties of the optimal service price. In particular, we note that the optimal service price is increasing the driver's income *c*, while decreasing in the expected proportion of SRA customers ($\bar{\alpha}$) as well as the market uncertainty regarding the proportion of SRA customers (σ). The optimal service price is also related to the SRA customer's safety risk and the ride-hailing platform's risk-averse level. To be specific, when we have a more risk-averse case, i.e., when the SRA customers's safety risk is higher or the ride-hailing platform is more risk-averse, the optimal service price becomes smaller.

IV. Using Blockchain Technology: Model BT

For the ride-hailing platform, an accurate estimate of the proportion of SRA customers is critical to set an optimal price for the service. With the advance of technologies, the use of BT-based system is known to be helpful in this regard [11]. To be specific, we consider the situation in which the use of BT can reduce the uncertainty regarding the proportion of SRA customers (i.e., σ). In addition, in the presence of BT (i.e., under Model BT), customers will have more understanding of the ride-hailing platform operations, i.e., the operational transparency is enhanced. This will bring an enhanced trust utility, denoted by *b*. In the main model, we consider the case in which BT incurs a fixed cost (e.g., the fixed rental fee for using BT offered by the BT solution service provider) *T*. It is obvious that if the expected benefit brought by BT for the platform is larger than *T*, then it will be beneficial for the ride-hailing platform to implement BT. In the following, we proceed with the analysis.

In the presence of a BT-based system, the ride-hailing platform can better estimate the proportion of SRA customers with a reduced variance δ^2, where $\delta < \sigma$. In this case, we can easily derive the demand for ride-hailing services $\tilde{D}^{BT}$ as follows:

$\tilde{D}^{BT} = \tilde{\alpha}(1+b-p-\xi)+(1-\tilde{\alpha})(1+b-p)= (1+b-p)-\tilde{\alpha}\xi$.

It is straightforward to derive the ride-hailing platform's profit, expected profit and variance of profit to be the following:

$\tilde{\Pi}_{PF}^{BT} = (p-c)((1+b-p)-\tilde{\alpha}\xi)-T$,

$\bar{\Pi}_{PF}^{BT} = (p-c)((1+b-p)-\bar{\alpha}\xi)-T$,

$\hat{\Pi}_{PF}^{BT} = (p-c)^2\xi^2\delta^2$.

Similar to (7), the mean-standard-deviation objective function for the ride-hailing platform under Model BT is given below:

$U_{PF}^{BT} = \bar{\Pi}_{PF}^{BT} - k\sqrt{\hat{\Pi}_{PF}^{BT}}$.

Maximizing U_{PF}^{BT} yields the optimal service price, which is given by: $p^{BT*} = \dfrac{1+b-\bar{\alpha}\xi-k\xi\delta+c}{2}$.

Observe that p^{BT*} is independent of the fixed cost *T*.

Lemma 2. *Comparing Model BT and the main model: (a)* $p^{BT*} > p^*$ *. (b) To ensure a profitable business, the ride-hailing platform cannot be too risk-averse (i.e.,* $k < \ddot{k}^{BT}$ *, where* $\ddot{k}^{BT} = \dfrac{\sqrt{(1+b-c-\bar{\alpha}\xi)^2-4T}}{2\xi\delta}$*).*

Lemma 2 gives a good and clean result. It highlights the fact that under the main model when only a fixed cost is incurred for deploying the BT-based systenm, using BT implies a higher price. This is a neat result, which mainly derives from the fact that there is a reduction of market uncertainty as well as an enhanced trust utility is gained.

The ride-hailing platform's expected profit at the optimal price with the use of BT is given below:

$$\bar{\Pi}_{PF,BT}^{*} = \left(\frac{1+b-c-\bar{\alpha}\xi}{2}\right)^2 - \left(\frac{k\xi\delta}{2}\right)^2 - T . \tag{12}$$

Define the expected value of BT (EVBT) for the platform as follows:

$EVBT_{PF}^{BT} = \bar{\Pi}_{PF,BT}^{*} - \bar{\Pi}_{PF}(p^*)$

$$= \frac{b(b+2(1-c-\bar{\alpha}\xi))}{4} + \frac{k^2\xi^2\left(\sigma^2-\delta^2\right)}{4} - T \ . \tag{13}$$

Note that under Model BT, even though implementing the BT-based system only incurs a fixed cost *T*, the optimal service price is still increased after using BT (see Lemma 2) because there is an enhanced trust utility to consumers with the use of BT. We have Lemma 3.

Lemma 3. *Under Model BT: (a) $EVBT_{PF}^{BT}$ is increasing in k, b, and σ while decreasing in T. $EVBT_{PF}^{BT}$ is increasing (resp. decreasing) in ξ if it is larger (resp. smaller) than $\frac{b\bar{\alpha}}{2k^2\left(\sigma^2-\delta^2\right)}$. (b) It is beneficial to implement blockchain technology (BT) for the ride-hailing platform (BT) if and only if* $\sigma^2-\delta^2 > \frac{4T-b(b+2(1-c-\bar{\alpha}\xi))}{k^2\xi^2}$, i.e., *the reduction of variance regarding the proportion of SRA customers ($\tilde{\alpha}$) by using BT is sufficiently large. (c) Using BT will more likely be a beneficial measure if T is smaller and k is larger.*

Lemma 3 gives several concise results. First, Lemma 3(a) shows the structural properties of $EVBT_{PF}^{BT}$. In particular, we know that the value of implementing BT relates to several important factors. It is intuitive to learn that it is increasing in the original market uncertainty level σ and decreasing in the BT fixed cost *T*. It is interesting to note that it also relates to the risk aversion level of SRA customers (i.e., ξ) and the ride-hailing platform (i.e., *k*). In particular, if the ride-hailing platform is more risk-averse (i.e., a larger *k*), then $EVBT_{PF}^{BT}$ is larger. However, for the risk aversion level of SRA customers (i.e.,)ξ, it depends. If ξ is sufficiently large, $EVBT_{PF}^{BT}$ is larger when ξ goes up. On the contrary, $EVBT_{PF}^{BT}$ becomes smaller when ξ increases if ξ is small. This finding means that BT is especially helpful for the case with a more risk-averse ride-hailing platform, while it will be especially helpful for the more risk-averse SRA customers if the perceived safety risk level (before using BT) is already sufficiently high (and the SRA customers are truly risk-averse). Lemma 3(b) proves the theoretical results that if the use of BT can yield a sufficiently large reduction of market uncertainty (towards the proportion of SRA customers), using BT is beneficial. Here, the necessary and sufficient condition relates to the threshold $\frac{4T-b(b+2(1-c-\bar{\alpha}\xi))}{k^2\xi^2}$. Lemma 3(c) further presents analysis of this threshold to show when the use of BT is more likely to be beneficial.

As a special case, we examine the case when the use of BT can completely remove uncertainty. Of course, this is a theoretical case while it does indicate the perfect value of BT in our model setting. We hence call the respective value of using BT the expected perfect value of BT (EPVBT). From (13), it is easy to derive that the EPVBT for the platform is:

$$EPVBT_{PF}^{BT}=\frac{b(b+2(1-c-\bar{\alpha}\xi))}{4}+\frac{k^2\xi^2\sigma^2}{4}-T\ .$$

Obviously, $EPVBT_{PF}^{BT}$ gives the upper bound for the value that BT can bring to the platform. All the structural properties of $EPVBT_{PF}^{BT}$ remain similar to $EVBT_{PF}^{BT}$ and hence the findings of Lemma 3 is valid (with $\delta=0$).

We further analyze the impact brought by the implementation of BT-based system on the optimal service price, customers and drivers. We first define two critical thresholds and then give Lemma 4:

$$b_1=\sqrt{4(1-c-\bar{\alpha}\xi)^2+T-k^2\xi^2(\sigma^2-\delta^2)}-2(1-c-\bar{\alpha}\xi)\ ,$$

$$b_2=k\xi(\sigma-\delta)\ .$$

Lemma 4. *Comparing Model BT and the main model: (a) It is beneficial for the ride-hailing platform to use blockchain technology if and only if* $b>b_1$*, (b) For the customers and drivers, using blockchain technology is beneficial if and only if* $b>b_2$*. Thus, using blockchain technology is an all-win strategy if* $b>\max(b_1,b_2)$.

Lemma 4 tells us that when the unit benefit brought by using BT for consumer utility is sufficiently high, using BT is beneficial to the ride-hailing platform, drivers and customers. It is interesting to note that the conditions for the customers and drivers are the same which are independent of *T* and *c*. However, for the ride-hailing platform, the condition critically depends on *T* and *c*. Overall, Lemma 4 gives a very important theoretically finding: It shows the analytical situations (and hence conditions) under which using BT can achieve an all-win case for the ride-hailing platform operations.

Suppose that there is a case in which $b_2 < b < b_1$ holds, which means using BT is (i) good for the consumers and drivers, but (ii) bad for the ride-hailing platform. In this situation, the government who puts emphasis on people can consider providing a sponsor to the ride-hailing platform to entice it to adopt BT. Lemma 5 shows the result.

Lemma 5. *Under Model BT, when $b_2 < b < b_1$ holds: (a) the government can provide a sponsor of S in which $S = 2(\sigma - \delta)k\xi[k\sigma\xi + 2(1 - c - \bar{\alpha}\xi)] - T$ to entice the ride-hailing platform to implement blockchain technology, which will be beneficial to customers, drivers and the ride-hailing platform (i.e., all-win is achieved). (b) The required sponsor S is increasing in σ and k, decreasing in c, T and δ.* (c) *The required sponsor S is increasing in ξ if $\bar{\alpha} \le k\sigma / 2$; otherwise, if $\bar{\alpha} > k\sigma / 2$, then we have:*

$$\frac{\partial S}{\partial \xi}\begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \Leftrightarrow \xi \begin{pmatrix} < \\ = \\ > \end{pmatrix} \frac{1-c}{2\bar{\alpha} - k\sigma}.$$

Lemma 5(a) tells us the analytical value for the required government sponsor to achieve all-win. Note that the required sponsor *S* is increasing in the market uncertainty σ and the degree of risk aversion of the ride-hailing platform. This is an interesting and important finding because it tells us that from the government perspective, it should be prepared to sponsor more for the market when its volatility is higher and the case when the ride-hailing platform is more risk averse.

As a remark, from Lemma 5(c), we see that the impact brought by ξ on S is more subtle. It first relates to the condition on the expected proportion of SRA customers in the market $\bar{\alpha}$. If $\bar{\alpha}$ is sufficiently small (i.e., $\bar{\alpha} \le k\sigma / 2$*),* then required sponsor *S* is increasing in ξ. Otherwise, whether required sponsor *S* is increasing or decreasing in ξ is governed by the condition which relates to the size of ξ. If the size of ξ is sufficiently small (big), then *S* is increasing (decreasing) in ξ.

V. Extended Modelling Analyses: Model EM

In Model ET we built and analysed above, we assume that the use of BT incurs a fixed cost *T*. However, in many cases, owing to the special features of BT, its operations cost is in fact related to the number of users (i.e., demand). In fact, when more people use BT, the corresponding cost will increase. In this extended model (called Model EM), we consider this case.

To be specific, we consider the situation in which using BT incurs a cost $\tilde{K}$, which is defined as follows:

$$\tilde{K} = T + a\tilde{D}, \tag{14}$$

where $a > 0$.

Obviously, (14) indicates that the BT deployment cost includes both a fixed cost and a variable cost increasing in demand.

With (14), we can derive the optimal service price with the use of blockchain under the extended model.

Lemma 6. *Under Model EM: (a) The optimal price* $p^{EM*} = \dfrac{1+a+b+c-\bar{\alpha}\xi-k\xi\sigma}{2}$ *, which is increasing in a, b and c, and decreasing in* $\bar{\alpha}$*,* σ*,* ξ *and* k*. (b) To ensure a profitable business, the ride-hailing paltform cannot be too risk-averse (i.e.,* $k < \ddot{k}^{EM}$*, where* $\ddot{k}^{EM} = \dfrac{\sqrt{(1+b-a-c-\bar{\alpha}\xi)^2-4T}}{2\xi\delta}$*). (c)* $p^{EM*} > p^{BT*} > p^*$*. (d) (i)* $\ddot{k}^{BT} > \ddot{k}^{EM}$ *always holds; (ii)* $\ddot{k} > \ddot{k}^{BT} > \ddot{k}^{EM}$ *if* $T < \dfrac{b(b+2(1-c-\bar{\alpha}\xi))}{4}$*; (iii)* $\ddot{k} < \ddot{k}^{EM} < \ddot{k}^{BT}$ *if* $T > \dfrac{(b-a)(b-a+2(1-c-\bar{\alpha}\xi))}{4}$.

Lemma 6(a) and Lemma 6(b) are very similar to the results of Lemma 2(a) and Lemma 2(b), respectively. This shows that the structural properties of the optimal service prices for the cases with BT under two different cost structures are in fact similar. Lemma 6(c) compares the optimal service prices and indicates that a monotonic pattern is observed: It is highest under the extended model in which the cost of BT is demand-increasing, followed by the case with BT (fixed cost) and then the case without BT. This is logical as under Model EM, the cost incurred by BT is highest among all the three cases, and hence the highest service price is set. Lemma 6(d) shows the comparisons among the "feasibility" risk-aversion thresholds among all three cases (i.e., the main model without BT, the main model with BT, and the extended model). The case is more tricky. First, from Lemma 6(d)(i), we see that $\ddot{k}^{BT} > \ddot{k}^{EM}$ is always true which implies that under Model EM with a larger cost for using BT, the "feasibility" risk-aversion threshold is smaller which means the ride-hailing platform has to be even less risk-averse in order to have a profitable business. Second, from Lemma 6(d)(ii) and Lemma 6(d)(iii), we can see that whether the the "feasibility" risk-aversion threshold is larger or smaller before using BT depends on *T*. If *T* is sufficiently small, we have $\ddot{k} > \ddot{k}^{BT} > \ddot{k}^{EM}$, which means the "feasibility" risk-aversion threshold is smaller after using BT. On the contrary, if *T* is sufficiently big, we have $\ddot{k} < \ddot{k}^{EM} < \ddot{k}^{BT}$, which implies that the "feasibility" risk-aversion threshold is larger after using BT. We can hence see the critical role played by *T* in affecting the degree of risk-aversion the ride-hailing platform can possess in making its own operations economically viable.

Under Model EM, the ride-hailing platform's expected profit at the optimal price with the use of BT is given below:

$$\bar{\Pi}_{PF}^{EM*} = \left(\frac{1+b-a-c-\bar{\alpha}\xi}{2}\right)^2 - \left(\frac{k\xi\delta}{2}\right)^2 - T \,. \tag{15}$$

Define the expected value of BT (EVBT) for the platform under Model EM as follows:

$$\begin{aligned} EVBT_{PF}^{EM} &= \bar{\Pi}_{PF}^{EM*} - \bar{\Pi}_{PF}(p^*) \\ &= \frac{(b-a)(b-a+2(1-c-\bar{\alpha}\xi))}{4} + \frac{k^2\xi^2\left(\sigma^2-\delta^2\right)}{4} - T \,. \end{aligned} \tag{16}$$

We have Lemma 7.

Lemma 7. *Under Model EM: (a)* $EVBT_{PF}^{EM}$ *is increasing in k,* b, *and* σ *while decreasing in T.* $EVBT_{PF}$ *is increasing (resp. decreasing) in* ξ *if it is larger (resp. smaller) than* $\dfrac{(b-a)\bar{\alpha}}{2k^2\left(\sigma^2-\delta^2\right)}$. *(b) It is beneficial to implement blockchain technology (BT) for the ride-hailing platform (BT) if and only if*

$\sigma^2-\delta^2>\frac{4T-(b-a)(b-a+2(1-c-\bar{\alpha}\xi))}{k^2\xi^2}$, i.e., *the reduction of variance regarding the proportion of SRA customers ($\tilde{\alpha}$) by using BT is sufficiently large. (c) Using BT will more likely be a beneficial measure if T is smaller and k is larger.*

Lemma 7 is very similar to Lemma 3, which confirms the robustness of findings under the two different costing models for BT.

We further explore the impact brought by the deployment of BT-based system on the optimal service price, customers and drivers in the ride-hailing platform operations. We define two critical thresholds and present Lemma 8:

$$b_1^{EM}=a-2(1-c-\bar{\alpha}\xi)+\sqrt{4(1-c-\bar{\alpha}\xi)^2+T-k^2\xi^2(\sigma^2-\delta^2)}\,, \tag{17}$$

$$b_2^{EM}=a+k\xi(\sigma-\delta)\,. \tag{18}$$

Lemma 8. *Under Model EM: (a) It is beneficial for the ride-hailing platform to use blockchain technology if and only if* $b>b_1^{EM}$ *, (b) For the customers and drivers, using blockchain technology is beneficial if and only if* $b>b_2^{EM}$. Thus, *using blockchain technology is an all-win strategy if* $b>\max(b_1^{EM},b_2^{EM})$. *(c) when* $b_2^{EM}<b<b_1^{EM}$ *holds: (i) The government can provide a sponsor of S in which* $S=2(\sigma-\delta)k\xi[k\sigma\xi+2(1-c-\bar{\alpha}\xi)]-T$ *to entice the ride-hailing platform to implement blockchain technology, which will be beneficial to customers, drivers and the ride-hailing platform (i.e., all-win is achieved), (ii) the required sponsor is the same under Model BT and Model EM, i.e., it is independent of the BT cost models.*

Lemma 8(a) and Lemma 8(b) confirm that the findings under Model EM are consisitent with the ones under the main model with Model BT. Lemma 8(c) gives the most interesting result: For the case when using BT is good for the consumers and drivers but bad for the ride-hailing platform, similar to Lemma 5, the government can provide a sponsor to encourage the ride-hailing platform to implement BT. Here, the required sponsor under Model EM is exactly the same as the one under Model BT. In other words, the government sponsorship is independent of the specific BT costs that we have considered in this paper. This will make the sponsorship scheme easy to implement in practice.

VI. Conclusion

Today, in the platform age, ride-hailing platform operations with enterprises such as Uber and Lyft are very popular. However, critical operational challenges exist and technologies can play a role.

In this study, facing the pandemics like COVID-19, we consider the scenario in which for some customers, services offered by the ride-hailing platforms are far from safe. These customers possess the “safety risk-averse” (SRA) attitude (e.g., infection risk as well as general safety risk). However, in the market, the proportion of SRA customers is in general stochastic. This makes it a very difficult problem for the ride-hailing platforms to scientifically decide their optimal service pricing decisions.

In real-world operations, and supported by the engineering management and operations management literature, we know that the use of BT based information systems can enhance data quality. This would better allow the ride-hailing platform to learn about the market and hence it can more accurately estimate the proportion of SRA customers.

Motivated by the challenges faced by ride-hailing platforms under the COVID-19 pandemic and the potential applications of BT, we conduct a theoretical study to explore the impacts that the BT-based system can bring to the platform, customers and drivers. We consider the case in which the platform is risk-averse and serves a market with both SRA and non-SRA customers. We analytically prove that using BT, the optimal service price will be increased. We uncover that using BT is especially helpful for the risk-averse case with a more risk-averse ride-hailing platform. However, whether it is especially helpful and significant for the case with the more risk-averse SRA customers depends on their specific degree of risk aversion. When the use of BT is beneficial to the customers, it will also be beneficial to the drivers, and vice versa. We reveal the analytical conditions under which the use of BT can be beneficial to the ride-hailing platform, customers and drivers (i.e., achieving “all-win”). Furthermore, we explore how governments or policy makers can provide sponsors to achieve all-win.

We further extend the analysis to consider the case in which BT incurs a total cost which includes both a fixed cost and a variable cost increasing in demand. We prove that the main conclusion remains robust. In addition, we reveal that the required amount of government sponsor to achieve all-win is the same between the two different costing models explored in this paper.

Based on the theoretically derived findings, we have the following managerial insights and practical implications.

Optimal service price: For the platform managers, using BT will mean an increased optimal service price. The interesting thing is that even under the use of BT with a fixed cost, the optimal service price is increased. Another finding is that when the cost of BT is larger (i.e., under the case with both the fixed cost and demand-increasing variable cost), the optimal service price is even higher. This fits our intuition. However, a higher service price does not necessarily mean that customers suffer as consumer surplus can be higher or lower depending on other parameters (such as the unit benefit (enhanced trust utility) brought by using BT).

Achieving all-win with BT deployment: Whether using BT is good or not to customers, ride-hailing platform and drivers depends on many factors such as the unit benefit brought by using BT (b). Achieving an all-win situation may not be automatic though. In other words, in general, when using BT is beneficial to the ride-hailing platform, it need not benefit the drivers and customers. It is interesting to note that the drivers and customers will both be benefited by the use of BT under the same condition. In other words, when using BT is good for the drivers, it will also be good for the customers (and vice versa). As such, for policy makers, the way to achieve all win only requires to provide the right incentive (i.e., sponsor) to make sure the ride-hailing platform will vote for using BT if it is beneficial to customers (and hence also the drivers). This makes the policy easier to implement.

Degrees of risk-aversion: We reveal an insight that using BT is especially beneficial to the more risk-averse ride-hailing platform. In other words, if the ride-hailing platform's manager is more risk averse, using BT is especially significant. However, for the SRA customers, whether it is especially significant for the case with the more risk-averse SRA customers depends on their specific degree of risk aversion. In particular, if the existing SRA customers are already substantially risk-averse (i.e., their fear to safety is sufficiently high), then the benefit of using BT is especially prominent to them.

Comparisons of two different costing models: When we compare the two costing models, under the case when government sponsor S is needed to achieve the all-win situation, it is most interesting to find that the required sponsor amount is the same under the two examined costing models. This implies that for the implementation of government sponsorship scheme, it is in fact easy to do so and policy makers of governments do not need to worry too much about the costing structure. When we compare the optimal service prices, it is rather natural and intuitive to find that the one under Model EM is higher because when the cost is larger (with both the fixed cost and demand-increasing variable cost), the price will also be higher. For the feasibility risk averse coefficient to ensure a profitable business of the ride-hailing platform operations, we have $\ddot{k}^{BT} > \ddot{k}^{EM}$ which implies that the ride-hailing platform has to be less risk-averse under Model EM (compared to Model BT with only a fixed cost) in order to have a profitable business.

Similar to other analytical studies, we admit a few non-trivial limitations which call for further research. To be specific, in this paper, we focus on the analytical models with which we do not consider the specific arrival patterns of customers. Future research can consider this factor by making it a queueing model based study. In this study, we focus our analysis on safety risk while not putting emphasis on environmental sustainability related issues [51, 52, 53, 54]. It will be interesting to consider the environmental impacts associated with the deployment of BT in future studies. Furthermore, we do not consider market competition. In the future, exploring platform level competition can enrich the findings.

Appendix (A1)

Table 1. The notation and abbreviation table

Notation/Abbreviation	**Meaning**
SRA	Safety risk averse
Non-SRA	Not safety risk averse
BT	Blockchain technology
Model BT	The model under which BT is used and incurs a fixed cost T
Model EM	The model under which BT is used and incurs both a fixed cost T and a demand-increasing cost
PF	Platform
DR	Drivers
c	Unit income of drivers
m	Unit operating cost of drivers
ξ	Safety fear by customers, which reflects the degree of SRA attitude
$\tilde{\alpha}$	The proportion of SRA customers
$\bar{\alpha}$	The mean of $\tilde{\alpha}$
σ^2	The variance of $\tilde{\alpha}$ (without the use of BT)
$\tilde{D}$	The demand for ride-hailing services, which is random (without the use of BT)
$\bar{D}$	The mean of $\tilde{D}$ (without the use of BT)
$\hat{D}$	The variance of $\tilde{D}$ (without the use of BT)
$\tilde{\Pi}_{PF}$	The profit function of the ride-hailing platform (without the use of BT)
$\bar{\Pi}_{PF}$	The mean of $\tilde{\Pi}_{PF}$
$\hat{\Pi}_{PF}$	The variance of $\tilde{\Pi}_{PF}$ (without the use of BT)
U_{PF}	The mean-standard-deviation form of objective function for the ride-hailing platform (without the use of BT)
k	The risk-averse coefficient for the ride-hailing platform
CS_{SRA}	The consumer surplus for the SRA customers (without the use of BT)
$CS_{non-SRA}$	The consumer surplus for the non-SRA customers (without the use of BT)
CS	The consumer surplus (without the use of BT)
$\bar{\Pi}_{DR}$	The expected profit of drivers
p^*	The optimal service price (without the use of BT)
$\ddot{k}$	The feasibility risk-averse coefficient threshold (without the use of BT)
$\tilde{D}^{BT}$	The demand for ride-hailing services, which is random (under Model BT)
δ^2	The variance of $\tilde{\alpha}$ under Model BT
b	The enhanced trust utility to customers with the use of BT
T	The fixed cost incurred with the deployment of BT (e.g., the rental service fee for the BT solution provider)
$\tilde{\Pi}_{PF}^{BT}$	The profit function of the ride-hailing platform (under Model BT)
$\bar{\Pi}_{PF}^{BT}$	The mean of $\tilde{\Pi}_{PF}^{BT}$
$\hat{\Pi}_{PF}^{BT}$	The variance of $\tilde{\Pi}_{PF}^{BT}$
U_{PF}	The mean-standard-deviation form of objective function for the ride-

	hailing platform under Model BT
p^{BT*}	The optimal service price (under Model BT)
$\ddot{k}^{BT}$	The feasibility risk-averse coefficient threshold (under Model BT)
$EVBT_{PF}^{BT}$	The expected value of BT for the ride-hailing platform under Model BT
$EPVBT_{PF}^{BT}$	The expected perfect value of BT for the ride-hailing platform under Model BT
S	The government sponsor
$\tilde{K}$	The BT cost function under Model EM
p^{EM*}	The optimal service price (under Model EM)
$\ddot{k}^{EM}$	The feasibility risk-averse coefficient threshold (under Model EM)
$\bar{\Pi}_{PF}^{EM*}$	The expected profit function of the ride-hailing platform (under Model EM)
$EVBT_{PF}^{EM}$	The expected value of BT for the ride-hailing platform under Model EM

References[6]

[1] A. Mardani, M.K. Saraji, A.R. Mishra, P. Rani, "A novel extended approach under hesitant fuzzy sets to design a framework for assessing the key challenges of digital health interventions adoption during the COVID-19 outbreak," *Applied Soft Computing*, vol. 96, pp. 106613, 2021.

[2] H.L. Chan, Y.K. Kwok, S.M. Wong, "Marketing and operational strategies during the COVID-19 pandemic: a case study of a Hong Kong footwear enterprise," *Journal of Fashion Marketing and Management: An International Journal*, published online (DOI: 10.1108/JFMM-10-2021-0270).

[3] J. Piñeiro-Chousa, M.Á. López-Cabarcos, D. Ribeiro-Soriano, "The influence of financial features and country characteristics on B2B ICOs' website traffic," *International Journal of Information Management*, vol. 59, pp. 102332, 2021.

[4] T.M. Choi, "Financing product development projects in the blockchain era: Initial coin offerings versus traditional bank loans," *IEEE Transactions on Engineering Management*, vol. 69, no. 6, pp. 3184-3196, 2022.

[5] P. Dutta, T.M. Choi, S. Somani, R. Butala, "Blockchain technology in supply chain operations: Applications, challenges and research opportunities," *Transportation Research Part E: Logistics and Transportation Review*, vol. 142, pp. 102067, 2020.

[6] T.M. Choi, S. Kumar, X. Yue, H.L. Chan, "Disruptive technologies and operations management in the Industry 4.0 era and beyond," *Production and Operations Management*, vol. 31, no.1 , pp. 9-31, 2022.

[7] S. Tiwari, P. Sharma, T.M. Choi, A. Lim, "Blockchain and third-party logistics for global supply chain operations: Stakeholders' perspectives and decision roadmap," *Transportation Research Part E: Logistics and Transportation Review*, vol. 170, pp. 103012, 2023.

[6] All URLs were last accessed on 14 December, 2022.

[8] T.M. Choi, “Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 128, pp. 17-29, 2019.

[9] X. Shi, S. Yao, S. Luo, “Innovative platform operations with the use of technologies in the blockchain era,” *International Journal of Production Research*, published online (DOI: 10.1080/00207543.2021.1953182).

[10] X. Xu, L. Yan, T.M. Choi, T.C.E. Cheng, “When is it wise to use blockchain for platform operations with remanufacturing?” *European Journal of Operational Research*, published online (DOI: 10.1016/j.ejor.2023.01.063).

[11] T.M. Choi, S. Luo, “Data quality challenges for sustainable fashion supply chain operations in emerging markets: Roles of blockchain, government sponsors and environment taxes,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 131, pp. 139-152, 2019.

[12] T.M. Choi, X. Shi, “On-demand-ride-hailing-service platforms with hired drivers during coronavirus (COVID-19) outbreak: Can blockchain help?” *IEEE Transactions on Engineering Management*, published online (DOI: 10.1109/TEM.2021.3131044).

[13] S. Bag, S. Gupta, T.M. Choi, A. Kumar, “Roles of innovation leadership on using big data analytics to establish resilient healthcare supply chains to combat the COVID-19 pandemic: A multimethodological study,” *IEEE Transactions on Engineering Management*, published online (DOI: 10.1109/TEM.2021.3101590).

[14] J.B. Sheu, T.M. Choi, “Can we work more safely and healthily with robot partners? A human-friendly robot-human coordinated order fulfilment scheme,” *Production and Operations Management*, published online (DOI:10.1111/poms.13899).

[15] L. Yang, J. Zhang, X. Shi, “Can blockchain help food supply chains with platform operations during the COVID-19 outbreak?” *Electronic Commerce Research and Applications*, vol.49, pp. 101093, 2021.

[16] S.H. Yoo, T.Y. Choi, J.B. Sheu, “Electric vehicles and product–service platforms: Now and in future,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 149, pp. 102300, 2021.

[2] Chan, H.L., Kwok, Y.K., & Wong, S.M. (2022). Marketing and operational strategies during the COVID-19 pandemic: a case study of a Hong Kong footwear enterprise. *Journal of Fashion Marketing and Management: An International Journal*, published online.

[17] A. Anand, S. Dutta, P. Mukherjee, “Platform exploitation in the sharing economy,” *Operations Research Letters*, vol. 51, no. 1, pp. 47-53, 2023.

[18] G.P. Cachon, K.M. Daniels, R. Lobel, “The role of surge pricing on a service platform with self-scheduling capacity,” *Manufacturing and Service Operations Management*, vol. 19, no. 3, pp. 368-384, 2017.

[19] J. Bai, K.C. So, C.S. Tang, X. Chen, H. Wang, “Coordinating supply and demand on an on-demand service platform with impatient customers,” *Manufacturing and Service Operations Management*, vol. 21, no. 3, pp. 479-711, 2018.

[20] T.F. Stafford, “Platform-dependent computer security complacency: The unrecognized insider threat,” *IEEE Transactions on Engineering Management*, vol. 69, no. 6, pp. 3814-3825.

[21] Z. Du, Z.P. Fan, G.X. Gao, “Choice of O2O food delivery mode: Self-built platform or third-party platform? Self-delivery or third-party delivery?” *IEEE Transactions on Engineering Management*, published online (DOI: 10.1109/TEM.2021.3069457).

[22] L. Hu, X. Sun, H. Yu, S.H. Chung, “Seize the opportunity of targeted marketing under the platform membership mechanism,” *IEEE Transactions on Engineering Management*, published online (DOI: 10.1109/TEM.2022.3169392).

[23] E.J. He, S. Savin, J. Goh, C.P. Teo, “Off-platform threats in on-demand services,” *Manufacturing and Service Operations Management*, published online (DOI: 10.1287/msom.2022.1179).

[24] L. Li, G. Li, “Integrating logistics service or not? The role of platform entry strategy in an online marketplace,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 170, pp. 102991, 2023.

[25] T. Siqin, T.M. Choi, S.H. Chung, X. Wen, “Platform operations in the Industry 4.0 era: Recent advances and the 3As framework,” *IEEE Transactions on Engineering Management*, published online (DOI: 10.1109/TEM.2021.3138745).

[26] X. Shi, S. Yao, S. Luo, “Innovative platform operations with the use of technologies in the blockchain era,” *International Journal of Production Research,* published online. (DOI: 10.1080/00207543.2021.1953182).

[27] X. Wang, F. He, H. Yang, H.O. Gao, “Pricing strategies for a taxi-hailing platform,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 93, pp. 212-231, 2016.

[28] J.J. Yu, C.S. Tang, Z.J.M. Shen, X.M. Chen, “A balancing act of regulating on-demand ride services,” *Management Science,* vol. 66, no. 7, pp. 2975-2992, 2020.

[29] Y. Liu, F. Wu, C. Lyu, S. Li, J. Ye, X. Qu, “Deep dispatching: A deep reinforcement learning approach for vehicle dispatching on online ride-hailing platform,” *Transportation Research Part E: Logistics and Transportation Review*, vol. 161, pp. 102694, 2022.

[30] M. Tripathy, J. Bai, H.S. Heese, “Driver collusion in ride-hailing platforms,” *Decision Sciences*, published online (DOI: 10.1111/deci.12561).

[31] Y. Liu, Q. Gao, P.L.P. Rau, “Chinese passengers' security perceptions of ride-hailing services: An integrated approach combining general and situational perspectives,” *Travel Behaviour and Society,* vol. 26, pp. 250-269, 2022.

[32] T. Monahan, C.G. Lamb, “Transit's downward spiral: Assessing the social-justice implications of ride-hailing platforms and COVID-19 for public transportation in the US,” *Cities,* vol. 120, pp. 103438, 2022.

[33] Y. Yang, S. Hu, D. Liao, X. Huang, "What affects safety perception of female ride-hailing passengers? An empirical study in China context," *Journal of Advanced Transportation*, published online (DOI: 10.1155/2022/3316535).

[34] M. Du, Q. Chen, J. Xiao, H. Yang, X. Ma, "Supply chain finance innovation using blockchain," *IEEE Transactions on Engineering Management*, vol. 67, no. 4, pp. 1045-1058, 2020.

[35] K. Nelaturu, J. Adler, M. Merlini, R. Berryhill, N. Veira, Z. Poulos, A. Veneris, "On public crowdsource-based mechanisms for a decentralized blockchain oracle," *IEEE Transactions on Engineering Management*, vol. 67, no. 4, pp. 1444-1458, 2020.

[36] L. Koh, A. Dolgui, J. Sarkis, "Blockchain in transport and logistics-paradigms and transitions," *International Journal of Production Research*, vol. 58, no. 7, 2054-2062, 2020.

[37] B. Müßigmann, H. Von Der Gracht, E. Hartmann, "Blockchain technology in logistics and supply chain management-A bibliometric literature review from 2016 to January 2020," *IEEE Transactions on Engineering Management*, vol. 67, no. 4, pp. 988-1007, 2020.

[38] S. Luo, T.M. Choi, "E-commerce supply chains with considerations of cyber-security: Should governments play a role?" *Production and Operations Management*, vol. 31, no. 5, pp. 2107-2126, 2022.

[39] T.M. Choi, S. Guo, N. Liu, X. Shi, "Optimal pricing in on-demand-service-platform-operations with hired agents and risk-sensitive customers in the blockchain era," *European Journal of Operational Research*, vol. 284, no. 3, pp. 1031-1042, 2020.

[40] K.K.R. Choo, S. Ozcan, A. Dehghantanha, R.M. Parizi, "Blockchain ecosystem-technological and management opportunities and challenges," *IEEE Transactions on Engineering Management*, vol. 67, no. 4, pp. 982-987, 2020.

[41] Y.J. Cai, T.M. Choi, J. Zhang, "Platform supported supply chain operations in the blockchain era: Supply contracting and moral hazards," *Decision Sciences*, vol. 52, no. 4, pp. 866-892, 2021.

[42] K. Wang, M. Liu, J. Wang, M. Wu, F. Zhao, "BBARHS: Blockchain-based anonymous ride-hailing scheme for autonomous taxi network," *Security and Communication Networks*, published online (DOI: 10.1155/2022/8296608).

[43] G. P. Cachon, T. Dizdarer, G. Tsoukalas, "Pricing control and regulation on online service platforms," *SSRN*, published online (https://dx.doi.org/10.2139/ssrn.3957209).

[44] A.K. Chakravarty, "Blending capacity on a rideshare platform: Independent and dedicated drivers," *Production and Operations Management*, vol. 30, no. 8, pp. 2522-2546, 2021.

[45] X. Sun, S.H. Chung, T.M. Choi, J.B. Sheu, H.L. Ma, "Combating lead-time uncertainty in global supply chain's shipment-assignment: Is it wise to be risk-averse?" *Transportation Research Part B: Methodological*, vol. 138, pp. 406-434, 2020.

[46] T.M. Choi, "Risk analysis in logistics systems: A research agenda during and after the COVID-19 pandemic," *Transportation Research Part E: Logistics and Transportation Review*, vol. 145, pp. 102190, 2021.

[47] T.M. Choi, S.W. Wallace, Y.L. Wang, "Risk management and coordination in service supply chains: information, logistics and outsourcing," *Journal of the Operational Research Society*, vol. 67, no. 2, pp. 159-164, 2016.

[48] N. Liu, T.M. Choi, M. Yuen, F. Ng, "Optimal Pricing, Modularity, and Return Policy Under Mass Customization," *IEEE Transactions on Systems, Man and Cybernetics – Part A*, vol. 42, no. 3, pp. 604-614, 2012.

[49] J. Li, T.M. Choi, T.C.E. Cheng, "Mean variance analysis of fast fashion supply chains with returns policy," *IEEE Transactions on Systems, Man and Cybernetics – Systems*, vol. 44, no. 4, pp. 422-434, 2014.

[50] T.M. Choi, J. Zhang, T.C.E. Cheng, "Quick response in supply chains with stochastically risk sensitive retailers," *Decision Sciences*, vol. 49, no. 5, pp. 932-957, 2018.

[51] H.L. Chan, B. Shen, Y. Cai, "Quick response strategy with cleaner technology in a supply chain: coordination and win-win situation analysis," *International Journal of Production Research*, vol. 56, no. 10, pp. 3397-3408, 2018.

[52] X. Xu, T.M. Choi, "Used-part-collection programs in manufacturing systems for products with reusable parts: Roles of risk aversion and platforms," *IEEE Transactions on Systems, Mand, and Cybernetics: Systems*, vol. 52, no.10, pp. 6038-6047, 2021.

[53] J.M.G. Martínez, R. Puertas, J.M.M. Martín, D. Ribeiro-Soriano, "Digitalization, innovation and environmental policies aimed at achieving sustainable production," *Sustainable Production and Consumption*, vol. 32, pp. 92-100, 2022.

[54] S. Yadav, T.M. Choi, A. Kumar, S. Luthra, F. Naz, "A meta-analysis of sustainable supply chain practices and performance: The moderating roles of type of economy and innovation," *International Journal of Operations and Production Management*, published online (DOI: 10.1108/IJOPM-05-2022-0328).