Satellite launch contract design based on blockchain-embedded fintech

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Abstract

The commercial launch industry is booming but abounds enormous-loss risks, which is similar to the disruption risk in the supply chain. Traditionally, launch insurance is the commonly used financial tool to hedge such risks. Nowadays, with the development of blockchain technology, it also is implemented to decrease launch risks from a technical perspective. However, the cost of both launch insurance and blockchain technology stop lots of satellite owners who think they are not cost-effective. In this paper, we apply a game-theoretic approach to study the fintech launch contract supported by blockchain for solving the trade-off between high risk and high cost. More precisely, we consider a Stackelberg strategy in a space launch supply chain and build math models to examine the cases with launch insurance (Model I) and with blockchain-embedded launch (BEL) insurance (Model B). From a theoretical perspective, we investigate the optimal launch price and the optimal effort (for improving launch success probability) expressions. We find that as SO's resilience increases, both SO and VM benefits increase. Besides, the BEL platform based on improving data flow will strengthen the outcome. However, there is no revenue improvement of the VM whether he uses the BEL or not when SO's anti-risk ability is low. In addition, we also find that once the blockchain technology is adopted, contract prices always go down, VM exerts more effort, and the premium rate always is lower as the launch missions become more efficient and believable. Moreover, no matter the SO risk resistance, the cost-advantage BEL platform is beneficial to all participants. Finally, coupling with these findings, we further discuss the managerial implications for the commercial space launch market.

Keywords: Satellite launch, insurance, blockchain, commercial launch supply chain

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1. Introduction

1.1. Background

Due to Earth's insatiable need for information and communication, the artificial satellite industry is booming. The ability of satellites to collect signals and data extensively, even from places hard to reach, allows for a variety of functions such as providing satellite telecommunication, satisfying weather and climate monitoring, supporting satellite television (BskyB, Direct TV, SkyTV and Dish), meeting Global Positioning System (GPS) needs, and serving for military and scientific. Since the 1980s, with the privatization of telecommunication organizations as well as the development of space laws and regulatory regimes, commercial space has begun to sprout (OECD, 2014). Furthermore, SpaceX Falcon 9 delivering the SES-8 satellite into orbit marks on Dec.3th, 2013, marks the rise of the private space launch market (Tariq, 2013). Space is no longer confined to government and military agencies like NASA and its contractors but expanding rapidly via private commercial companies like SpaceX, Blue Origin, Cloud Constellation Corporation, and more. According to Report (2021), the space economy grew 176% during the last 15 years, reaching 447 billion dollars in 2020. It is worth noting that 80% of the total income is contributed by the commercial space. In addition, there are more than 1,100 SmallSats launched in 2020, which is twice in average size over the same period. Thus the space launch market gradually plays a pivotal part in modern societies and economic growth. In parallel, the vigorous development of the space economy also points that the needs of operation management implanting in the space launch market are increasing (Kucukcay, 2018).

While the successful SpaceX mission has created new enthusiasm for commercial satellite launching, there are still many risks that should not be ignored in satellite launch services, such as the responsibility of the vehicle, the indicators of the satellite, the condition of the launch activity so on. In addition, many private investors are hesitant about investing in space businesses because of the costly infrastructure and extended timelines. From the perspective of private companies, once the launch fails, the loss for both satellite owner and launch servicer is enormous. While governmental and military satellites are usually self-insured, commercial satellite owners often require insurance to be in place.

In order to hedge launch risks, space insurance emerged. Insurance companies like Global Aerospace have been providing insurance for space initiatives since the first commercial satellites and launch vehicles required financial support to cover their risk. New concepts and technologies such as prominent constellations of satellites have distinctive risk profiles requiring unique coverages. According to the satellite launch project process, space insurance is roughly divided into four types of coverage which reflect the various phases of most satellite projects - pre-launch insurance [1], launch insurance [2], in-orbit insurance [3], and launch plus life insurance [4]. The launch insurance is usually the most widely focused (Suchodolski, 2018) because the launch is the riskiest part of any space activity, and the damage is often catastrophic. (Gould & Linden, 2000; Kunstadter, 2020).

In addition to compensating for risk financially, reducing the launch failure rate on the technical side is also an available way for commercial space companies. While commercialized space projects have braved all the challenges, they are still involved in conventional economic models that may hamper their growth and success. Luckily, blockchain technology supports building smart contracts and tracking data, considered a disruptive technology that facilitates data flow. In the real world, companies are emerging to implementing blockchain technology specifically for space launches, such as SpaceChain, IBM and Cloud Constellation Corporation. The blockchain is used to deal with the above complexities such as contracts, order tracking, parts assembly, shipments, design and test documents, test results data,

[1]Pre-launch insurance covers damage to a satellite or launch vehicle during the construction, transportation, and processing phases prior to launch.

[2]Launch insurance covers losses of a satellite occurring during the launch phase of a project. It insures against complete launch failures as well as the failure of a launch vehicle to place a satellite in the proper orbit.

[3]In-orbit policies insure satellites for in-orbit technical problems and damages once a satellite has been placed by a launch vehicle in its proper orbit.

[4]Third-party liability and government property insurances protect launch service providers and their customers in the event of public injury or government property damage, respectively, caused by launch or mission failure.

near real-time data, workflows for approvals, auditing, launch, and control, which make the project more visible, responsive and mitigate costly interruptions during the launch, in other words, it increases the probability of successful launch (Zheng et al., 2021). Here are the main features in details of blockchain about supporting space launch:

(1) Reliability: The verified data on the blockchain launch platform is reliable, which cannot be changed based on decentralizing electronic record-keeping.

(2) Efficiency: Blockchain supports the smart contract to build an efficient network between the participants who get a node to share, add and update information.

Despite the ideas given above being excellent, both space insurance and blockchain technology are high-cost, which make lots of private space companies hesitate to adopt them. Considering the trade-off between handling risk and considerable cost, we examine the contract price problem. From the perspective of operation management, we refer to the participants as supply chain members and simplify the question as a two-echelon supply chain consisting of a satellite owner and vehicle manufacturer who provide the launch service. We examine how the insurance contract and blockchain technology to help improve the supply chain value and how it affects the contract price in the supply chain. We consider two modes: 1) the satellite owner contract with the vehicle manufacturer under insurance; 2) the satellite owner contracts with the vehicle manufacturer under blockchain-embedded insurance.

1.2. Research questions and key findings

Motivated by the application of fintech and the importance of space launching operation management in the real world, we theoretically study the research questions listed below:

RQ1. How to analytically build the mathematical models under traditional launch insurance and blockchain-embedded launch insurance, respectively? How to price the launch service contract for the satellite owner? Furthermore, how to make the optimal decision for the vehicle manufacturer?

RQ2. When will the blockchain launch platform be feasible and how does it affect the optimal decisions?

RQ3. What are the blockchain values for the satellite owner and the vehicle manufacturer, respectively? When will the presence of the blockchain launch platform achieve a win-win in which both the satellite owner, and the vehicle manufacturer are beneficial?

To address the above research questions, we conduct a game-theoretic analytical study by building math models. By arithmetic derivation and analysis, we obtain the following results: (1) When the anti-risk ability of the satellite owner is enhanced, the profits of both the satellite owner and the vehicle manufacturer will increase. Significantly, the implementation of the blockchain launch platform will make this effect more pronounced. Moreover, the adoption of blockchain will decrease the threshold of the satellite owner to set the optimal price. (2) Particularly, the optimal effort the vehicle manufacturer exert will increase and the contract price as well as the premium rate will decrease with the support of blockchain. (3) Via analyzing the value of blockchain, we note that the blockchain launch platform will always benefit the satellite owner no matter how weak her risk resistance is. However, it is profitable for the vehicle manufacturer to implement cost-advantage blockchain technology only when the satellite owner has a strong capacity for risk.

2. Literature review

Our paper is closely related to three research streams: supply chain insurance, space supply chain management and blockchain. We review them as follows.

2.1. Supply chain insurance

Our paper is closely related to the topic of insurance adopted to manage disruptive risk, which is a stream of supply chain finance. For a comprehensive overview, we refer readers to read Wang et al. (2021a), Chakuu et al. (2019), Xu et al. (2018), Gelsomino et al. (2016), Zhao & Huchzermeier (2015), and Gomm (2010). As a financial derivative instrument of risk aversion, insurance contracts can be seen as hedging at the expense of current profits and improving the risk tolerance by compensating the economic losses of enterprises when the supply chain disrupt caused by internal (e.g., the quality of products, the interruption of funds, and the disruption of logistic) or external (e.g., the change of weather, the pandemic of COVID-19, and the change of market) risks (Sodhi et al., 2012; Heckmann et al., 2015).

According to the type of risks, the literature of supply chain insurance contracts can be reducible to two categories. (1) One is to hedge internal risks by combining insurance contracts with supply chain contracts. As insurance contracts could coordinate the supply chain (Lin et al., 2010), researchers compared it with the revenue sharing contract according to different agents' risk aversion based on the newsvendor model. Besides, Wang et al. (2021b) also discussed which contract is better for the supply chain partners between the advanced payment contract, penalty contract, and time insurance contract in the express delivery supply chain.

(2) Another is to study the trade-off between high commercial insurance and the substantial economic losses caused by external risks. The typical market risk of demand uncertainty is a thorny question that the newsvendor model faces thus Lodree Jr & Taskin (2008) design an insurance policy framework to quantify the risks and benefits, which give decision-makers a practical approach to prepare for supply chain disruptions. Moreover, Yu et al. (2021) considered the interrupt probability of the supply chain and illustrate the value of business interruption insurance which increases the profit of each participant. Brusset & Bertrand (2018) constructed a weather index through case studies that transfer entrepreneurial risk to other risk-takers through insurance or options contracts. Similar to these researches, our paper also adopts the insurance contract to hedge the interrupt risk while the focal point is in the space launch supply chain, which is remarkable for technical complexity, high quality & reliability requirements, and colossal failure losses.

2.2. Space supply chain management

At present, supply chain management in space era is initiated by research institutes, universities and researchers. Such as China Aerospace Industry Corporation, European Space Agency and Indian Space Research Organisation conducted a series of research on space supply chain management (Kucukcay, 2018). Moreover one of the famous works is the Interplanetary Supply Chain Management and Logistics Architectures project from MIT, which develops an integrated supply chain management framework for space logistics.

According to the types of existing studies in this topic, they can be reducible to two categories:

(1) One kind of research focuses on optimizing the operating system to improve the efficiency from mathematical models and simulation. Galluzzi et al. (2006) regarded supply chain management as a critical piece of framework in the aerospace industry, and they elaborated the pattern operation in this area. Taylor et al. (2006) also designed and evaluated the operating system in the space supply chain, but they primarily engaged in optimizing delivery operation, which sustains the exploration initiative. Moreover, Gralla et al. (2006) gave a comprehensive model and simulation of the supply chain management implemented in the aerospace industry, which is low-volume and schedule-driven compared to the high-volume and market demand-driven SCM in the commercial sector.

(2) Another type of study starred in analyzing the business problem in supply chain management. The research on this topic is relatively few. Wooten & Tang (2018) examined the space industry's operation management, which involves manufacturing operations, supply chain management, and sustainable operations. Besides, they also outlined the challenges and essential questions related to stakeholders. Raghunath & Kang (2021) discussed the challenges that commercial space operation faces from a business perspective. Furthermore, Guo et al. (2021) comprehensively analyzed the global aerospace industry's current situation and future development from the upstream supply chain, midstream production chain, and downstream application chain. In addition, Donelli et al. (2021) considered the profitability and efficiency during the aircraft manufacturing and supply chain. The paper proposed a model-based approach to optimal the multiple-choice. Furthermore, Dewicki et al. also based on operational management analyze the business model in commercial space.

As review literature, most papers target SCM in space give the mathematical model from optimizing logistics, even the system flow. While our paper builds models from the business angle, we concentrate on the game theory between participants during the launch activity.

2.3. Blockchain technology support supply chain management

As a “trust ledger”, blockchain has overwhelming advantage of data storage such as openness, transparency, tampering, and traceability, which make it possible to manipulate higher quality data (Choi, 2019), improving the supply chain efficiency and so on (Chod et al., 2020). According to its characters, Queiroz et al. (2019); Wang et al. (2019); Babich & Hilary (2020); Li et al. (2022) gave the review of this topic.

Besides, more and more scholars have begun to study the application of blockchain in the supply chain. (1) Inside the supply chain, (i) in upriver, blockchain technology facilitates the flow of raw materials from the suppliers (Naydenova, 2017; Nash, 2016); (ii) in the midstream, it promotes the exchange of manufacture information and design smart contracts between participants in the supply chain upstream and downstream and achieve coordination eventually (Moise & Chopping, 2018; Hilary, 2022; Chod et al., 2020; Korpela et al., 2017; Wang et al., 2021c). (2) Outside the supply chain, (i) face the third party, it provides an innovative way for the capital constraint companies to finance (Choi, 2020; Choi & Ouyang, 2021); (ii) face the market, it helps products to fight counterfeits, earn trust of customers and win company reputation in the market (Pun et al., 2021; Shen et al., 2021; Fan et al., 2020).

Regarding our topic, this article mainly refers to articles on the application of blockchain in the space supply chain. Adhikari & Davis (2020) gave a clearly analysis on the implementation of blockchain in the area of space cybersecurity framework against global positioning system spoofing. Zheng et al. (2021) studied a three-tier space supply chain under the decision-making problem and investigated how blockchain technology optimizes decisions based on information sharing. Moreover, Hyland-Wood et al. (2020) examined three potential blockchain properties applied in space: real-time communication during the interplanetary space operating and operations realm of the solar system. However, different from them, this article's focal point is on launching a service supply chain supported by fintech (blockchain-embedded insurance) to facilitate launching risks and contract pricing.

2.4. Summary

Supply chain insurance and blockchain technology adoption are essential topics in space launch operation management. Motivated by real-world blockchain application such as IBM and Cloud Constellation Corporation are working together to build a blockchain-based platform in the space launch supply chain, this paper theoretically investigates the blockchain-embedded insurance model operations. The insights not only contribute to the literature in operation management but also advance the industrial knowledge regarding blockchain launch platforms.

The following parts in this paper are organized as: Section 3 establishes the main models and investigates corresponding optimal decisions, one for insurance model (model I) and the other for blockchain-embedded insurance model (Model B). Section 4 further demonstrates the effect on optimal decisions and value for participants brought by the blockchain-embedded launch platform. Section 5 concludes this study and gives analytical insights.

3. Main Models

Consider a make-to-order supply chain consisting of one vehicle manufacturer (VM, he), one satellite owner (SO, she) and an insurance company (IC, it). As shown in Figure 1, to launch the satellite successfully, the SO usually conducts a series analyses to choose the vehicle and design the launch service contract with price p and prepay ratio α. Once the satellite is on-track, the SO will pay VM last part $(1-\alpha)p$. Without loss generality, the SO has already signed contracts future servicing missions at income F before launching (SpaceFund, 2022), which rely on satellite service to function. So the satellite income also is one factor that SO needs to consider while designing the launch contract, which is an indicator of her risk resistance (Li, 2010).

As common in launch activity, our models capture two typical features in the space supply chain. First, the launch activity is risky, which means there is a probability for the satellite operating in its final orbital position. The VM can improve the probability of mission success (aka reliability) by exerting costly efforts (e.g., improving technologies, equipment or processes) (Bailey, 2020; Kunstadter, 2020). Following Tang et al. (2018), we scale the base launch success probability to 0. To increase the probability from 0 to e, where $e \in (0, 1)$, the VM needs to exert effort associated with a disutility (cost of effort) ke^2 with $k > 0$. The setting of such a disutility is common in many models.

Notedly, a launch failure is costly to all involved parties. For the SO, she will lost her satellite and the income. For the VM, what he will face is not only the current contract loss but also the damage of his reputation. To reflect the VM's additional loss, a penalty denoted by θ is adopted into the profit function. Considering the launch risk, it is natural that SO attempts to buy launch insurance before launching. IC designs the launch insurance according to the analyses of conducting serious technological analyses of satellite and the VM. The claim usually covers the whole loss, including the cost of satellite, the prepay price, and the future income that the SO will earn.

We summarize the notation used throughout the paper in Table 1.

Table 1: Notation

Variable	Remark
p	The launching service price
e	The "rate of successful launch ," which is the same as "the level of effort the VM exerting" in this paper
c_i	The cost of VM ($i = V$) or SO ($i = S$)
r	The premium rate
F	The income of satellite obtain before launching
α	The upfront payment ratio
θ	The penalty of VM
k	The effort cost factor
π_i	The cost of vehicle ($i = V$) or satellite ($i = S$)

[a] Subscripts S and V are the indices of SO and VM, respectively.

[b] p: decision variable; F: exogenous variable.

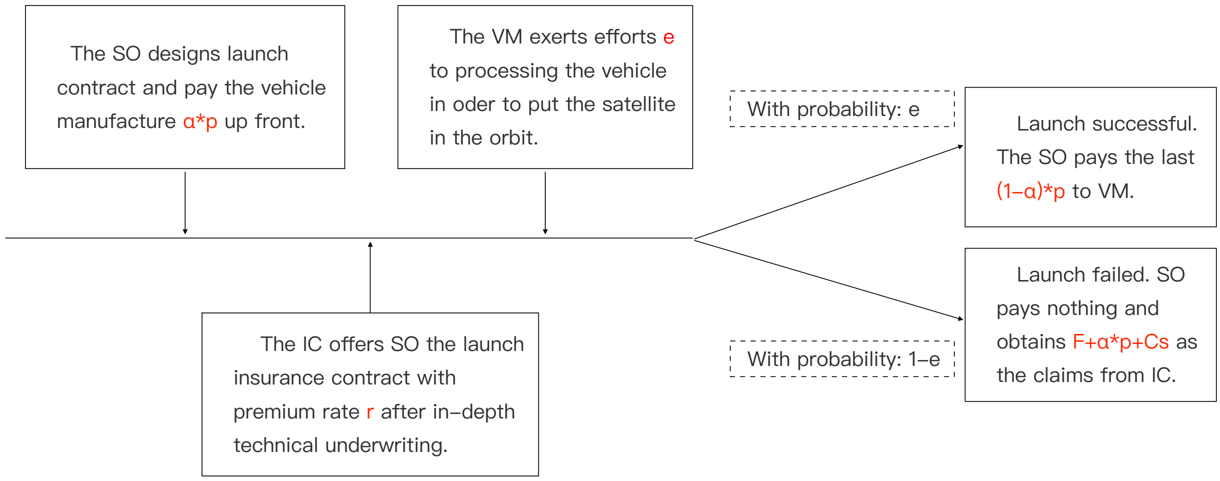


Figure 1: Sequence of events. SO :the satellite owner; VM: the vehicle manufacture; IC: the insurance company.

3.1. Traditional launch supply chain (Model I)

Acting as the Stackelberg leader, the SO sets the contract terms and the VM, as the follower, decides whether to accept the contract. Without loss of generality, we focus on the following contract: the SO pays the VM a certain α [5] of launch price p upfront when launch services are procured. (Usually, the upfront payment ratio α is less than 80% (Andrews & Bonnema, 2011; Barschke, 2020).) Furthermore, when the launch is successful, the VM then receives the balance of the payment $(1-\alpha) * p$ for services or 0 otherwise. Concerning risk, the SO buys the launch insurance with the premium rate r to compensate the loss if the launch failed. Figure 1 shows the sequence of events corresponding to the game model. Therefore, the SO's payoff π_S can be measured as follows:

$$\max_p \mathbb{E}[\pi_S(p,e,r)] = eF - [\alpha + e(1-\alpha)]p - r(c_S + F + \alpha p) + (1-e)(c_S + F + \alpha p) - c_S, \qquad (1)$$
$$s.t.\ F \geq c_S + p$$

As shown, π_S consists of five parts: (1) the income she can obtain once the satellite works in orbit (eF); (2) the expect launch service price ($[\alpha + e(1-\alpha)]p$); (3) the premium for the

[5]The standard payment structure likes that in detail: 1) 10% down to reserve. 2) 40% at start of VM manufacture. 3) 20% when payload arrives at launch pad or 2 months prior to launch. 4) 20% remaining once launch occurs.

launch insurance ($r(c_S + F + \alpha p)$); (4) the compensate she will get once the launch failed ($(1 - e)(c_S + F + \alpha p)$). (5) the cost of building the satellite (c_S). Without loss of generality, the satellite income covers its building and launch cost; i.e., the SO sets a contract only when $F \geq c_S + p$.

As depicted in Figure 1, the VM accepts a contract with price p and receives the prepayment $\alpha * p$ from the SO, then he manufactures the rocket which cost c_v. If the vehicle launch successfully, he receives the last $(1 - \alpha) * p$ from the SO. If launching is not successful, the VM not only receives no payment but also suffers penalty which monetized as θ . Therefore, the VM's objective is to maximize his expected payoff π_V as follows:

$$\begin{aligned} &\max_e \mathbb{E}[\pi_V(p, e)] = [\alpha + e(1 - \alpha)]p - (1 - e)\theta - (ke^2 + c_V), \\ &s.t.\ \pi_V \geq 0 \end{aligned} \tag{2}$$

As shown, π_V consists of three parts: (1) the prepaid income and expected gain upon successful launch $[\alpha + e(1 - \alpha)]p$, (2) the expected loss of failure penalty in the event of launch failure $(1-e)\theta$, and (3) the cost of effort and vehicle ke^2+c_V. The non-negative profit constraint ensures the profitability of launch successfully; otherwise, the VM will reject such a contract.

3.1.1. The benchmark

Before we analyze the Stackelberg game as depicted in Figure 1, we first establish the first-best solution by analyzing a centralized controlled supply chain as a whole. Hence, the total profit is expressed as follows:

$$\pi_C = eF - (1 - e)\theta - c_V - c_S - ke^2 \tag{3}$$

Lemma 3.1. In a centralized chain, the SO contracts with the VM if and only if $\frac{F+\theta}{4k} \geq c_S + c_V + \theta$. The resulting launch success probability is $\frac{F+\theta}{2k}$, and the corresponding chain payoff is $\frac{(F+\theta)^2}{4k} - c_S - c_V - \theta$.

Following from the Lemma 3.1, we assume that $k \geq \frac{F+\theta}{4k}$ and $\frac{(F+\theta)^2}{4k} \geq c_S + c_V + \theta$ throughout this paper to avoid trivial cases.

3.1.2. The VM's effort

We now solve the Stackelberg game as depicted in Figure 1 using backward induction. First, given any launch price p, by considering the first-order condition of Equation (2), the VM's best response is given as:

$$e(p) = \frac{(1-\alpha)p+\theta}{2k}. \tag{4}$$

By substituting 4 into the VM's payoff π_V given in Equation (2), it can be obtained that:

$$\pi_V = \frac{[(1-\alpha)p+\theta]^2}{4k} + 2p - c_V - \theta \tag{5}$$

Hence, the VM's participation constraint, i.e., $\pi_V \geq 0$, the VM's acceptance (VA) constraint can be written as:

$$p \geq p^{VA} \equiv \frac{2A - 2\alpha k - (1-\alpha)\theta}{(1-\alpha)^2}, \tag{6}$$

where $A = \sqrt{k[(1-\alpha)^2 c_V + \alpha^2 k + (1-\alpha)\theta]}$.

3.1.3. The IC's premium rate

Observing the contract price p selected by the SO, the insurance company can anticipate the VM's effort $e(p)$ as given in (4). Operating in a competitive market, the insurer sets its rate r to break-even in expectation. In other words, under the rate r that it offers, the insurance company's expected payoff, $r(c_S + F + \alpha p)$, equals the amount of coverage, $(1-e)(c_S + F + \alpha p)$. Substituting e given in (7), the insurer's break even condition is $p \geq p^{IA} \equiv \frac{2k(1-r)-\theta}{(1-\alpha)}$, which we refer to it as the insurance company's accepting-to-underwrite constraint. When the constraint is satisfied, the equilibrium interest rate for any given p becomes

$$r(p) = 1 - \frac{(1-\alpha)p+\theta}{2k}. \tag{7}$$

3.1.4. The SO's optimal price

Anticipating the VM's best response e given in (4) and the condition (6), the SO's payoff given in Equation (1) can be rewritten as:

$$
\begin{aligned}
\max_{p} \mathbb{E}[\pi_S(p)] = &\frac{[F-(1-\alpha)p]*[(1-\alpha)p+\theta]}{2k} - \alpha p - c_S, \\
s.t.\ & F \geq c_S + p, \\
& p \geq p^{VA}, \\
& p \geq p^{IA}.
\end{aligned} \tag{8}
$$

According to SO's payoff, we can get the best price for her is $p^S = \frac{(1-\alpha)(F-\theta)-2\alpha k}{2(1-\alpha)^2}$. Consider the constraints, the SO aims to select the optimal contract price $p^* = \max(p^S, p^{VA})$ that maximizes her payoff, given in Equation (8). The optimal contract and corresponding equilibrium outcome can be summarized in Proposition 3.1 and illustrated in Figure 2.

Proposition 3.1. (i) When (F,α) satisfied $F \geq \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^S \geq p^{VA}$, Region I in Figure 2), the SO offers launch price $p^* = p^S = \frac{(1-\alpha)(F-\theta)-2\alpha k}{2(1-\alpha)^2}$, the IC determines the premium rate $r = 1 - \frac{1}{4}(\frac{F+\theta}{k} - \frac{2\alpha}{1-\alpha})$. The equilibrium launch success probability is $e^* = \frac{1}{4}(\frac{F+\theta}{k} - \frac{2\alpha}{1-\alpha})$. The payoffs of SO and VM are $\pi_S = \frac{(F+\theta)^2(1-\alpha)^2+4k\alpha[\alpha k+(\theta-F)(1-\alpha)]}{8k(1-\alpha)^2} - c_S$, $\pi_V = \frac{(F+\theta)^2(1-\alpha)^2+4k[3\alpha^2 k+\theta(1-\alpha)(4-\alpha)-\alpha F(1-\alpha)]}{16k(1-\alpha)^2} - c_V$, respectively. Thus the whole supply chain payoff is $\pi_C = \frac{3(F+\theta)^2(1-\alpha)^2-4\alpha^2k^2+4k(1-\alpha)(3\alpha\theta-\alpha F-4\theta)}{16k(1-\alpha)^2} - c_S - c_V$.

(ii) When (F,α) satisfied $F < \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^S < p^{VA}$ Region II in figure Figure 2), the SO offers launch price $p^* = p^{VA} = \frac{2A-2\alpha k-(1-\alpha)\theta}{(1-\alpha)^2}$, the IC determines the premium rate $r = \frac{k-A}{(1-\alpha)k}$. The equilibrium launch success probability is $e^* = \frac{A-\alpha k}{(1-\alpha)k}$. The payoffs of SO and VM are $\pi_S = \frac{A*[(1-\alpha)(F+\theta)+2\alpha k]-(1-\alpha)(\alpha F+2\theta)k-2\alpha^2k^2}{(1-\alpha)^2 k}$, $\pi_V = 0$, respectively, where $A = \sqrt{k[(1-\alpha)^2 c_V + \alpha^2 k + (1-\alpha)\theta]}$. And the whole supply chain payoff is $\pi_C = \frac{A*[(1-\alpha)(F+\theta)+2\alpha k]-(1-\alpha)(\alpha F+2\theta)k-2\alpha^2k^2}{(1-\alpha)^2 k}$ which is equal to SO's profit.

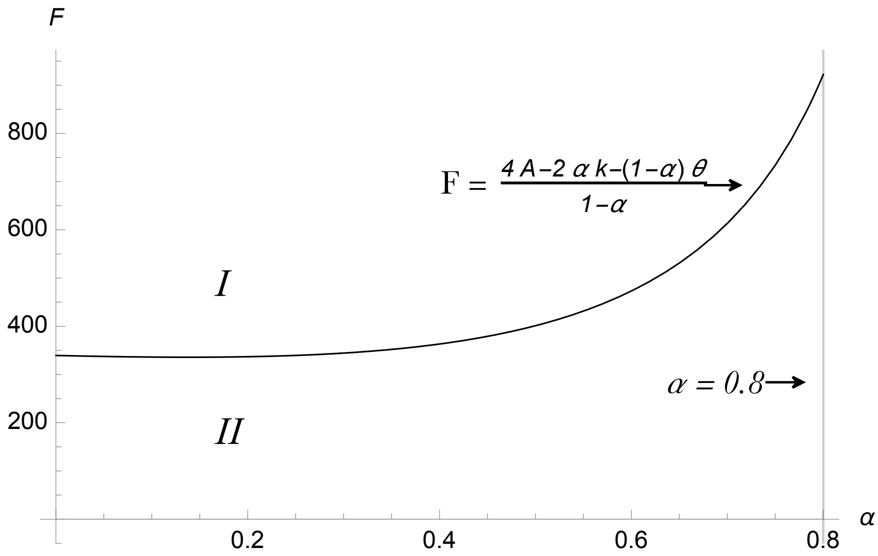
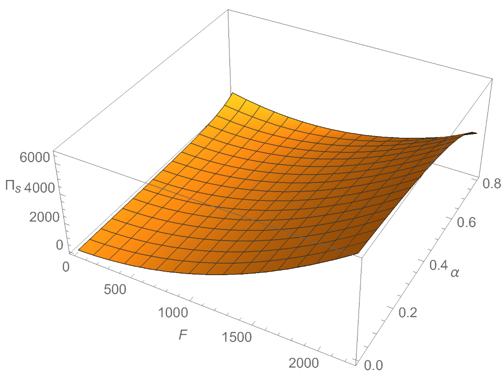
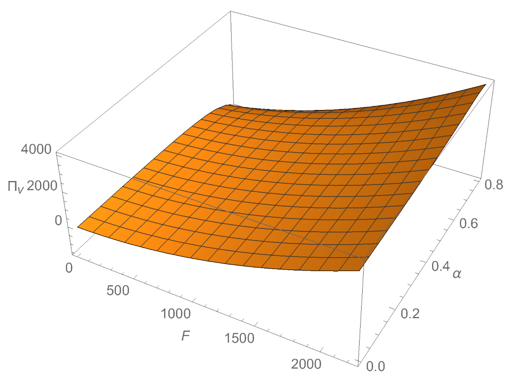


Figure 2: Regions illustrated by satellite income F and prepayment ratio α, when $k = 100, c_V = 30, c_S = 20, \theta = 80$. Region I means $F \geq \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^S \geq p^{VA}$), implies the SO's risk resistance is relatively strong; region II means $F < \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^S < p^{VA}$), implies the SO's risk resistance is relatively weak.



(a) Profit of SO in model I



(b) Profit of VM in model I

Figure 3: Profits of SO and VM in model I, under satellite income F and prepayment ratio α, when $k = 100, c_V = 30, c_S = 20, \theta = 80$.

Proposition 3.1 shows two cases under different SO's risk tolerances denoted by F . (i) In the first case, when the risk tolerance SO is strong that F is higher than a certain level ($\frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$) which fall within the Region I in Figure 2, we obtain five results. (1) For SO, she will be willing to pay p^S for the launch service to VM, which is higher than p^{VA}. That means the risk capacity for the SO is an essential driver to pull the launching service price. (2) Thus, VM has a solid incentive to exert more effort to increase the launch success probability. So with the increasing of satellite risk tolerances or the increasing of F, the launch success probability in equilibrium also increases. (3) Noted, for IC, the increasing of SO's risk capacity also leads to a lower premium rate r. This is because the increase in launch price drives the VM to make more efforts, which positively affects the launch success probability of IC's evaluation at the launch project, and then the premium rate set by IC decreases. (4) As shown in Figure 3, both SO's and VM's profit slope upwards as F increases. It achieves a win-win situation in which SO and VM are both benefit. (5) However, in the case of solid risk tolerance, when α increases, the changes are different between SO and VM. As shown in Figure 3a, the more SO pays for VM upfront, the less her profit. However, the VM is the opposite. When the ratio is too high, SO cannot balance the VM by delaying the payment of the remaining launch fee. That is, the VM may have opportunism behavior due to sufficient advance revenue, which will lead to the failure of cooperation between the two parties.

(ii) In the other case, when SO's risk tolerance is weak, that income F drops below a certain level ($\frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$) that falls within Region II in Figure 2, we obtain four results. (1) For SO, she can not pay for a high launch price, however if she still wants to buy the launch service from that VM, the optimal price she sets should satisfy the VM's acceptance p^{VA}. (2) For VM, as the price is the underline for him, the incentive factor in increasing launch success probability is not price but the prepayment ratio α. (3) In that situation, the increase of α will lead to a higher premium rate r because the weak risk capacity cannot win trust from IC. (4) Noted, as the price only satisfied the VM's acceptance, there is no benefit for him (e.t. the payoff of VM is 0, as shown in Figure 3b). For SO, there is almost no change in payoff when the prepayment ratio increase, as shown in Figure 3a.

Moreover, compared with the benchmark in Lemma 3.1, the equilibrium launch success probability e^* in Proposition 3.1 is lower. This is because she will take less emphasis on launch success probability when she has insurance as the protection.

3.2. Blockchain-embedded launch (BEL) supply chain (Model B)

After exploring Model I, we now consider Model B in which the VM launches the satellite via a blockchain-embedded launch (BEL) platform. As depicted in Figure 4, the BEL platform is supported by blockchain technology to deal with the complexities such as contracts, order tracking, parts assembly, shipments, design and test documents, test results data, near real-time data, workflows for approvals, auditing, launch and control. That means it will improve the data flow between different participants and capture the problem in time during the process. In other words, when information is shared adequately in the whole supply chain, it will help VM to save the effort cost to reach the ideal launch success probability, which is related to the symmetric and transparent information. (such as IBM and Cloud Constellation Corporation are working together to build a range of prototype solutions from Edge Computing in Space to exploring how blockchain can optimize the logistics and supply chain for the space tech industry (Altaf, 2019).

Compared to the case under Model I, all these parties will work together on the blockchain platform and the workflow will be more efficient which will be like (i) Launch data is made accessible via application program interfaces (APIs) for each of the participants on the nodes, and all interactions such as data download are tracked. (ii) All of the above activity is logged in the form of transactions in an immutable ledger database for auditing purposes to all the authorized interested participants. Thus, the obvious advantage over Model I is that the transform data flow will decrease the effort cost, in other words, for the effort cost VM exerting to improve the launch successfully probability (denoted by $k^B e^2$ for the case under Model B), it will be lower under Model B than under Model R. We assume the blockchain platform provided by the third party which will charge SO and VM for c_{SB} and c_{VB} respectively. Figure 4 shows the whole launch success process in the avail of blockchain.

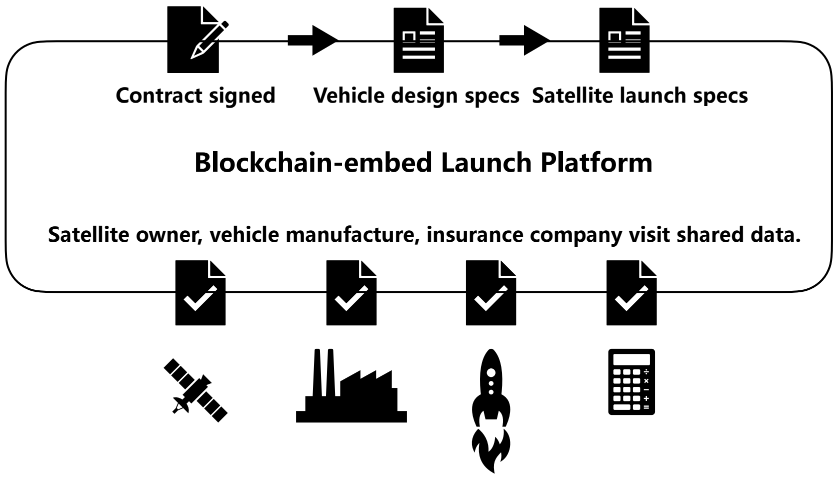


Figure 4: Satellite launch supported by blockchain platform.

Altaf (2019)

Similar to Section 3.1, as the Stackelberg leader, SO sets the contract terms and the VM, as the follower, decides whether to accept the contract. Once the cooperation is signed, each of the participants gets a node which has a copy of ledger and smart contracts. As in Section 3.1, the SO prepays the supplier part of the contract price $\alpha * p$ ahead. After launching, she will pay $(1-\alpha)*p$ upon successful delivery and pays 0 otherwise. Concerning risk, SO buy the launch insurance with premium rate r to compensate the damage if launch failed. Therefore, the SO's payoff π_S can be modeled as:

$$\max_{p^B} \mathbb{E}[\pi_S^B(p^B, e^B, r^B)] = e^B F - [\alpha + e^B(1-\alpha)]p^B - r^B(c_S + F + \alpha p^B) + (1-e^B)(c_S + F + \alpha p^B) - c_S - c_{SB},$$
$$s.t.\ F \geq c_S + c_{SB} + p^B \quad (9)$$

As shown, π_S^B consists of five parts: (1) the income she can obtain once the satellite works in orbit ($e^B F$), (2) the launch service price ($[\alpha + e^B(1-\alpha)]p^B$), (3) the premium SO pays for launch insurance($r^B(c_S + F + \alpha p^B)$), (4) the compensate she will get once the launch failed($(1-e^B)(c_S + F + \alpha p^B)$), (5) the cost of satellite and blockchain service, c_S and c_{SB}. Without loss of generality, the satellite income covers its whole cost; i.e., the SO sets a contract only when $F \geq c_S + c_{SB} + p^B$.

After receiving a contract with price p^B that is acceptable to VM, the cooperation is reached and a smart contract will be built. Then VM gets the node of checking the contract, which captures serious details to direct the conduction design, development, test and evaluation efficiently which cost $c_V + c_{VB}$. Also, he will get the prepayment $\alpha * p^B$ from the SO. If the vehicle launch successfully, he receives the last $(1-\alpha) * p^B$ from the SO. If launching is not successful, the VM receives no payment. Therefore, the VM's objective is to maximize his expected payoff π_V^B as follows:

$$\max_{e^B} \mathbb{E}[\pi_V^B(p^B, e^B)] = [\alpha + e^B(1-\alpha)]p^B - (1-e^B)\theta - k^B(e^B)^2 - c_V - c_{VB}, \qquad s.t.\ \pi_V^B \geq 0 \tag{10}$$

As shown, π_V^B consists of three parts: (1)the prepaid income and expected gain upon successful launch $[\alpha + e^B(1-\alpha)]p$, (2)the expected loss of failure penalty in the event of launch failure $(1-e^B)\theta$, (3)the whole cost $k^B(e^B)^2+c_V+c_{VB}$. The non-negative profit constraint ensures the profitability of launch; otherwise, the VM will reject such a contract.

3.2.1. The VM's Effort

A similar approach as in 3.1, considering the first-order condition of VM's payoff 10 , the VM's optimal effort as follows:

$$e^B(p^B) = \frac{(1-\alpha)p^B + \theta}{2k^B}. \tag{11}$$

By substituting (11) into the VM's payoff π_V^B given in 10, it can be obtained that:

$$\pi_V^B = \frac{[(1-\alpha)p^B + \theta]^2}{4k^B} + 2p^B - \theta - c_V - c_{VB} \tag{12}$$

Hence, the VM's participation constraint, i.e., $\pi_V^B \geq 0$, the VM's acceptance (VA) constraint can be written as:

$$p^B \geq p^{VA} \equiv \frac{2B - 2\alpha k - (1-\alpha)\theta}{(1-\alpha)^2}. \tag{13}$$

where $B = \sqrt{k^B[(1-\alpha)^2 c_V + \alpha^2 k^B + (1-\alpha)\theta]}$.)

3.2.2. The Insurance Company's Premium Rate

Observing the contract price p^B selected by the SO, the IC can anticipate the VM's effort $e^B(p^B)$ as given in (11). Operating in a competitive market, the IC sets its rate r^B to break even in expectation. In other words, under the rate r^B that it offers, the IC's expected payoff, $r^B(c_S + F + \alpha p^B)$, equals the amount of coverage, $(1 - e^B)(c_S + F + \alpha p^B)$. Substituting e^B given in (11), the insurer's break-even condition can be satisfied if and only if $p^B \geq p^{IA} \equiv \frac{2k^B(1-r^B)-\theta}{(1-\alpha)}$, which we refer as the IC accepting to underwrite constraint. When the constraint is satisfied, the equilibrium interest rate for any given p^B becomes:

$$r^B(p^B) = 1 - \frac{(1-\alpha)p^B + \theta}{2k^B}. \tag{14}$$

3.2.3. The SO's Optimal Price

Anticipating the VM's best response given in (11) and the condition (13), the SO's payoff given in Equation (9) can be rewritten as:

$$\begin{aligned} \max_{p^B} max\mathbb{E}[\pi_S^B(p^B)] &= \frac{[F-(1-\alpha)p^B] * [(1-\alpha)p^B + \theta]}{2k^B} - \alpha p^B - c_S - c_{SB}, \\ s.t.\ F &\geq c_S + p^B + c_{SB}, \\ p^B &\geq p^{VA}, \\ p^B &\geq p^{IA}. \end{aligned} \tag{15}$$

According to SO's payoff, we can get the best price for her is $p^B = \frac{(1-\alpha)(F-\theta)-2\alpha k^B}{2(1-\alpha)^2}$. Consider the constraints, the SO aims to select the optimal contract price $p^{B*} = max(p^B, p^{VA})$ that maximizes her payoff, given in Equation (15). The optimal contract and corresponding equilibrium outcome can be summarized in Proposition 3.2 and illustrated in Figure 5.

Proposition 3.2. (i) When (F, α) satisfied $F \geq \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B \geq p^{VA}$), the SO offers launch price $p^{B*} = p^B = \frac{(1-\alpha)(F-\theta)-2\alpha k^B}{2(1-\alpha)^2}$, the insurance underwriter determine the premium rate $r^B = 1 - \frac{1}{4}(\frac{F+\theta}{k^B} - \frac{2\alpha}{1-\alpha})$. The equilibrium launch success probability is $e^B = \frac{1}{4}(\frac{F+\theta}{k^B} - \frac{2\alpha}{1-\alpha})$. The payoffs of SO and VM are $\pi_S^B = \frac{(F+\alpha)^2(1-\alpha)^2+4k^B\alpha[\alpha k^B+(\theta-F)(1-\alpha)]}{8k(1-\alpha)^2} - c_S - c_{SB}$, $\pi_V^B = \frac{(F+\theta)^2(1-\alpha)^2+4k^B[\alpha F(1-\alpha)-3\alpha^2 k^B-\theta(1-\alpha)(4-\alpha)]}{16k^B(1-\alpha)^2} - c_V - c_{VB}$, respectively.

(ii) When (F, α) satisfied $F < \frac{4B-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B < p^{VA}$), the SO offers launch price $p^{B*} = p^{VA} = \frac{2B-2\alpha k^B-(1-\alpha)\theta}{(1-\alpha)^2}$, the insurance underwriter determine the premium rate $r^B = \frac{k^B-B}{(1-\alpha)k^B}$. The equilibrium launch success probability is $e^B = \frac{B-\alpha k^B}{(1-\alpha)k^B}$. The payoffs of SO and VM are $\pi_S^B = \frac{B*[(1-\alpha)(F+\theta)+2\alpha k^B]-(1-\alpha)(\alpha F+2\theta)k^B-2\alpha^2(k^B)^2}{(1-\alpha)^2 k^B} - c_S - c_{SB} - 2c_V - 2c_{VB}$, $\pi_V^B = 0$, respectively, where $B = \sqrt{k^B[(1-\alpha)^2 c_V + \alpha^2 k^B + (1-\alpha)\theta]}$).

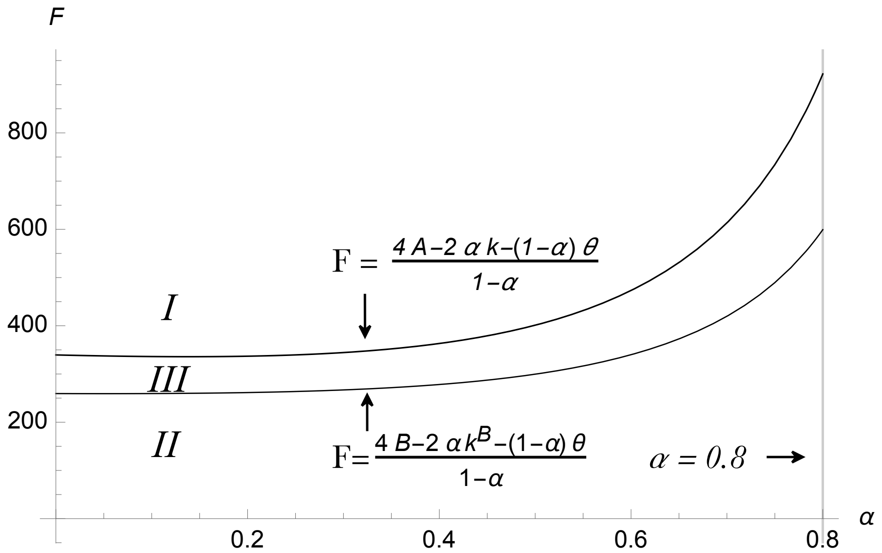
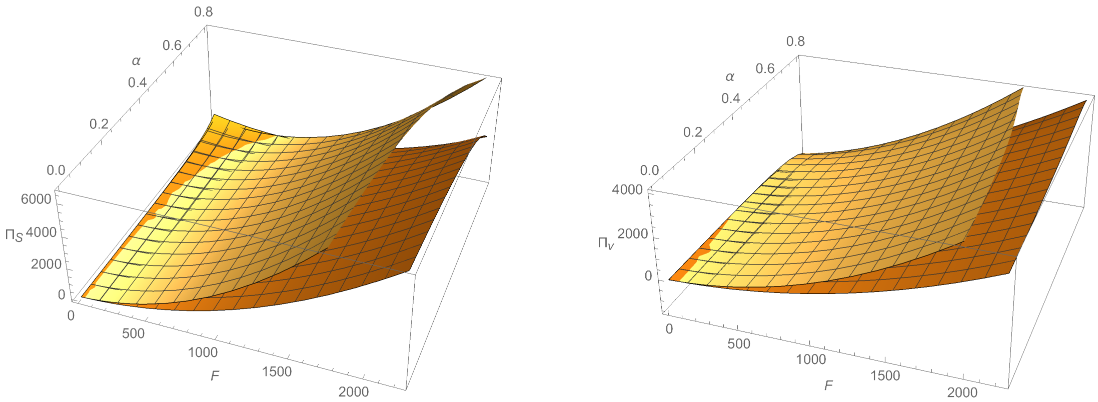


Figure 5: Relationship between satellite income F and prepayment ratio α, when $k = 100, k^B = 80, c_V = 30, c_S = 20, c_{VB} = 10, \theta = 80$. Region I plus region III means (F, α) satisfied $F \geq \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B \geq p^{VA}$), region II means $F > \frac{4B-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B < p^{VA}$).



(a) Profit of SO (b) Profit of VM

Figure 6: Profits of SO and VM in model B (the light slope) and model I (the dark slope), under satellite income F and prepayment ratio α, when $k^B = 60, c_V = 30, c_S = 20, c_{VB} = 10, c_{SB} = 10, \theta = 80$.

Outcomes in Proposition 3.2 are similar to Proposition 3.1. There are two differences worth knowing. (i) First, the region I plus region III in Figure 5 is larger than in Figure 2. So the threshold for SO to set the optimal price is lower. Thus, the adoption of blockchain is helpful in decreasing the contract price. (ii) Second, as k^B is less than k, the premium rate (14) is lower than (7) in Model I. Intuitively, the blockchain technology will improve the underwriting outcome, which is known as share data, and improve the workflow. Notedly, the premium rate is only related to k^B, not to the cost of the blockchain. Therefore, as long as blockchain technology is adopted, the cost of purchasing insurance can be reduced. Other equilibrium outcomes are not neat, and we will conduct analyze in the following section ??.

Similar to Proposition 3.1, both SO's and VM's profit slope upwards as F increases, as shown in Figure 6. In other words, when SO resistance to risk becomes more robust, the SO's profit and the VM's profit all increase, achieving a win-win during the cooperation. Comparing the profits in Figure 6, both the SO's and the VM's slopes of Model B (the light) are higher than these of Model I (the dark) visually, which imply that when the risk resistance of SO is strong, both the SO and the VM will be benefit from the implement of BEL platform. However, when the anti-risk capacity of SO is weak, it can be roughly seen from Figure 6 that the benefits obtained from the adoption of BEL are lower than those obtained without the supported of blockchain. In order to figure out the conditions for implement BEL, we conduct the value study in Section 4.2.

4. Values of Implying BEL Platform

4.1. Impact on optimal decisions of BEL

After deriving the equilibrium decisions in the supply chains under Models I and B, we now explore the values of blockchain technology. By comparing the equilibrium outcomes of Proposition 3.1 and Proposition 3.2, we obtain the following results.

Proposition 4.1. The effects of adopting BEL on prices, effort, and premium rate. As $k^B < k, A < B$, then launching satellite through a BEL platform:

(i) the price of launching service is lower;

(ii) the effort VM exerting is more;

(iii) the premium rate insurance company fixed is lower.

Table 2: The summary of optimal effort, price, and premium rate in Model I and Model B. (The arrows in Model B is compared with the related results in Model I.)

s.t.	Model I		Model B	
	$F \geq \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F < \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F \geq \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$	$F < \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$
Optimal effort e^*	$\frac{1}{4}(\frac{F+\theta}{k} - \frac{2\alpha}{1-\alpha})$	$\frac{A-\alpha k}{(1-\alpha)k}$	$\frac{1}{4}(\frac{F+\theta}{k^B} - \frac{2\alpha}{1-\alpha}) \uparrow$	$\frac{B-\alpha k^B}{(1-\alpha)k^B} \uparrow$
Optimal price p^*	$\frac{(1-\alpha)(F-\theta)-2\alpha k}{2(1-\alpha)^2}$	$\frac{2A-2\alpha k-(1-\alpha)\theta}{(1-\alpha)^2}$	$\frac{(1-\alpha)(F-\theta)-2\alpha k^B}{2(1-\alpha)^2} \downarrow$	$\frac{2B-2\alpha k^B-(1-\alpha)\theta}{(1-\alpha)^2} \downarrow$
Premium rate r	$1 - \frac{1}{4}(\frac{F+\theta}{k} - \frac{2\alpha}{1-\alpha})$	$\frac{k-A}{(1-\alpha)k}$	$1 - \frac{1}{4}(\frac{F+\theta}{k^B} - \frac{2\alpha}{1-\alpha}) \downarrow$	$\frac{k^B-B}{(1-\alpha)k^B} \downarrow$

Proposition 4.1 and Table 3 give us two claims. (1) The optimal effort is higher after applying blockchain technology, which leads to a higher launch success probability directly. That also implies that blockchain technology helps to improve the work efficiency. (2) Moreover, both the contract price and premium rate are going down. It is beneficial for SO. Next, we will investigate whether BEL is profitable for both SO and VM.

4.2. Values for each participant of BEL

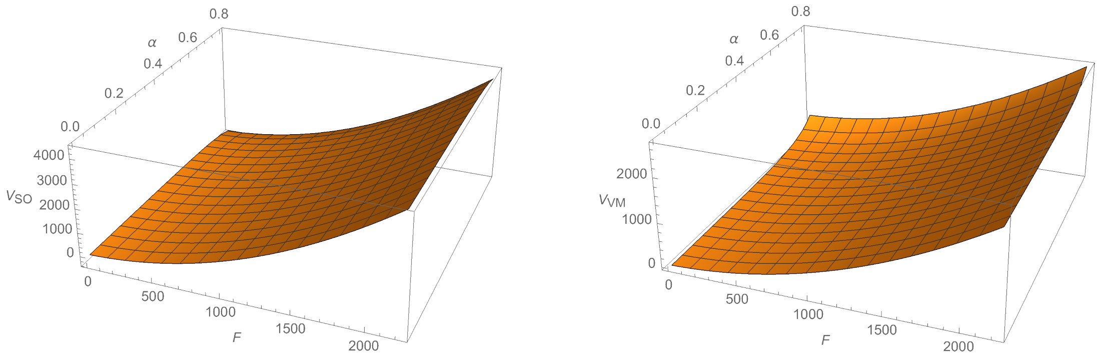
We define the following, which respectively represent the values of blockchain technology (denoted by symbol V) for the SO and the VM when Model B is adopted (compared to Model I):

$$\begin{cases} V_{SO} = \pi_S^B - \pi_S, \\ V_{VM} = \pi_V^B - \pi_V \end{cases} \tag{16}$$

Proposition 4.2. The effects of adopting BEL on profits of SO:

(i) If $c_{SB} \left(\begin{smallmatrix}<\\=\\>\end{smallmatrix}\right) \frac{(k-k^B)[(1-\alpha)^2(F+\theta)^2-4\alpha^2kk^B]}{8(1-\alpha)^2kk^B}$, then we have: $V_{SO} \left(\begin{smallmatrix}<\\=\\>\end{smallmatrix}\right) 0$, for $F \geq \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B \geq p^{VA}$);

(ii) If $c_{SB} \left(\begin{smallmatrix}<\\=\\>\end{smallmatrix}\right) \frac{2kk^B\alpha^2(k-k^B)+(1-\alpha)(F+\theta)(kD-k^BC)+2\alpha kk^B(D-C)}{(1-\alpha)kk^B} - c_S - c_{SB} - c_V - 2c_{VB}$, then we have: $V_{SO} \left(\begin{smallmatrix}<\\=\\>\end{smallmatrix}\right) 0$, for $F < \frac{4B-2\alpha k-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^{VA} > p^B$).



(a) Value of blockchain for SO

(b) Value of blockchain for VM

Figure 7: Value of blockchain for SO and VM, under satellite income F and prepayment ratio α,when $k = 100, k^B = 60, c_V = 30, c_S = 20, c_{VB} = 10, c_{SB} = 10, \theta = 80$.

Proposition 4.2 shows three neat findings. (1) It gives two thresholds of blockchain cost, which indicate that if the cost of implementing blockchain technology is high, then launching through the BEL platform is not profitable for the SO. That is because the loss of paying for blockchain cannot be offset by the benefits of improving the quality of data flow. (2) Figure 7a shows that the value that blockchain launch platforms bring to SO increases as satellites' future revenues increase. It demonstrates that more substantial SO can resist risks, the more benefit blockchain will bring to her. (3) However, when the advance payment ratio α rises, the value blockchain brings to SO will decrease. In that situation, the effect of using BEL is not as good as low prepay ratio.

Proposition 4.3. The effects of adopting BEL on profits of the VM:

(i) If $c_{VB} \begin{pmatrix} < \\ = \\ > \end{pmatrix} \frac{(k-k^B)[(1-\alpha)^2(F+\theta)^2+12\alpha^2 kk^B]}{16(1-\alpha)^2 kk^B}$, then we have: $V_{VM} \begin{pmatrix} < \\ = \\ > \end{pmatrix} 0$, when $F \geq \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B \geq p^{VA}$);

(ii) BEL isn't profitable, that $V_{VM} \equiv 0$, when $F < \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$ (i.e. $p^B < p^{VA}$).

Proposition 4.3 shows two similar points. (1) It also gives the threshold for VM using blockchain. (2) Likewise, the increasing risk resistance of SO also leads to high blockchain value for VM, which implies that F indirectly motivates VM to implement blockchain technology.

Nevertheless, there is one difference from Proposition 4.2 that needs to notice. When the SO's risk resistance is weak, it is no use for VM to apply BEL. It lies in the launch price SO offering only matches VM's acceptance level and his payoff being zero in this situation.

5. Conclusions

5.1. Remarkble findings

Nowadays, with the prosperity of commercial launch, more and more research study the operation management in space. Motivated by real-world blockchain applications in the space launch supply chain, this paper theoretically investigates the operations of the blockchain-embedded insurance model. Firstly, we established the traditional insurance model and the blockchain-embedded insurance model. By deriving analytical results, we demonstrate the optimal decisions for each participant. We have further uncovered the effect of the blockchain on different variables. Finally, we built value models to investigate the benefit of blockchain, especially revealing the conditions under which one model outperforms the other.

As a concluding remark, we highlight the answers as follows:

(1) The adoption of blockchain will decrease the threshold of satellite owner to set the optimal price. Moreover, when the anti-risk ability of the satellite owner is enhanced, the profits of both the satellite owner and the vehicle manufacturer will increase. Significantly, the use of the blockchain launch platform will make this effect more pronounced.

(2) Particularly, the optimal effort vehicle manufacturer exerting will increase and the contract price as well as the premium rate will decrease with the support of blockchain.

(3) Via analyzing the value of blockchain, we note that the blockchain launch platform will always benefit to satellite owner no matter how weak her risk resistance is. However, it is profitable for vehicle manufacturer to implement cost-advantage blockchain technology only when the satellite owner has a strong capacity for risk.

5.2. Managerial implications

Analyzing the derived findings, we further propose the following managerial implications, which help form the action plans for satellite owners and vehicle manufacturers.

Satellite owner: We have highlighted that launch insurance is critical in improving profit for satellite owners. Moreover, the adoption of the blockchain-embedded launch platform will enhance the improvement. Nevertheless, considering the risk resistance of the satellite owner, the higher the ability, the more value she will obtain from the blockchain implementation. However, the increase in prepayment ratio will offset both the insurance and the blockchain-embedded profit. As a solution, if the satellite owner has a high anti-risk capacity, she may consider using the blockchain below a particular cost for improving data flow.

Vehicle manufacturer: The blockchain-embedded launch platform will help to motivate the manufacturer to exert more effort to improve the launch success probability based on sharing data. However, the best strategy for the manufacture is adopting blockchain technology when cooperating with high anti-risk satellite owner. In that way, they could make it a win-win.

6. Future research

For the future studies, we suggest several probable future directions. First, the risk attitude of different participants can be taken into account which will effect the optimal decisions. Second, the JIT operation management with the supported of blockchain in launch supply chain can be promising directions for future research. Last but not least, multi-tier supply chain or supply chain network will be interesting to investigate, which involve more members such as the rideshare broker in piggyback launch and rideshare or cluster launch (Barschke, 2020).

Table 3: The summary of optimal effort, price, and premium rate in Model I, Model V and Model B. (The arrows in Model B is compared with the related results in Model I.)

s.t.	Model I		Model V		Model IB		Model VB
	$F \geq \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F < \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F \geq \frac{4E-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F < \frac{4E-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F \geq \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$	$F < \frac{4B-2\alpha k^B-(1-\alpha)\theta}{1-\alpha}$	
e^*	$\frac{1}{4}(\frac{F+\theta}{k} - \frac{2\alpha}{1-\alpha})$	$\frac{A-\alpha k}{(1-\alpha)k}$	$\frac{1}{4}(\frac{F+2\theta}{k} - \frac{2\alpha}{1-\alpha})$	$\frac{E-\alpha k}{(1-\alpha)k}$	$\frac{1}{4}(\frac{F+\theta}{k^B} - \frac{2\alpha}{1-\alpha}) \uparrow$	$\frac{B-\alpha k^B}{(1-\alpha)k^B} \uparrow$	
p^*	$\frac{(1-\alpha)(F-\theta)-2\alpha k}{2(1-\alpha)^2}$	$\frac{2A-2\alpha k-(1-\alpha)\theta}{(1-\alpha)^2}$	$\frac{(1-\alpha)(F-\theta-2\beta c_S)-2\alpha k}{2(1-\alpha)^2}$	$\frac{2E-2\alpha k-(1-\alpha)(\theta+\beta c_S)}{(1-\alpha)^2}$	$\frac{(1-\alpha)(F-\theta)-2\alpha k^B}{2(1-\alpha)^2} \downarrow$	$\frac{2B-2\alpha k^B-(1-\alpha)\theta}{(1-\alpha)^2} \downarrow$	
$r*$	$1 - \frac{1}{4}(\frac{F+\theta}{k} - \frac{2\alpha}{1-\alpha})$	$\frac{k-A}{(1-\alpha)k}$	-	-	$1 - \frac{1}{4}(\frac{F+\theta}{k^B} - \frac{2\alpha}{1-\alpha}) \downarrow$	$\frac{k^B-B}{(1-\alpha)k^B} \downarrow$	

s.t.	Model I		
	$F \geq \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F < \frac{4A-2\alpha k-(1-\alpha)\theta}{1-\alpha}$	$F \geq \frac{4E-2\alpha k-(1-\alpha)\theta}{1-\alpha}$
π_S	$\frac{(F+\theta)^2(1-\alpha)^2+4k\alpha[\alpha k+(\theta-F)(1-\alpha)]}{8k(1-\alpha)^2} - c_S$	$\frac{A*[(1-\alpha)(F+\theta)+2\alpha k]-(1-\alpha)(\alpha F+2\theta)k-2\alpha^2k^2}{(1-\alpha)^2k} - c_S - 2c_V$	$\frac{(F+\theta)^2(1-\alpha)^2+4k\alpha[\alpha k+(\theta-F)(1-\alpha)]+8(1-\alpha)k\beta c_S}{8k(1-\alpha)^2} - (1$
π_V	$\frac{(F+\theta)^2(1-\alpha)^2+4k[3\alpha^2k+\theta(1-\alpha)(4-\alpha)-\alpha F(1-\alpha)]}{16k(1-\alpha)^2} - c_V$	0	$\frac{(F+\theta)^2(1-\alpha)^2+4k[3\alpha^2k+\theta(1-\alpha)(4-\alpha)-\alpha F(1-\alpha)]-16(1-\alpha)k\beta c_S}{16k(1-\alpha)^2} - c_V$
π_C	$\frac{3(F+\theta)^2(1-\alpha)^2-4\alpha^2k^2+4k(1-\alpha)(3\alpha\theta-\alpha F-4\theta)}{16k(1-\alpha)^2} - c_S - c_V$	$\frac{A*[(1-\alpha)(F+\theta)+2\alpha k]-(1-\alpha)(\alpha F+2\theta)k-2\alpha^2k^2}{(1-\alpha)^2k} - c_S - 2c_V$	$\frac{3(F+\theta)^2(1-\alpha)^2-4\alpha^2k^2+4k(1-\alpha)(3\alpha\theta-\alpha F-4\theta)}{16k(1-\alpha)^2} -$

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