The Impact of Covid-19 on Blockchain Adoption Time of Shipowners

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Abstract - **The outbreak of Covid-19 has accelerated the need for digitalisation in maritime supply chains. Blockchain is a promising digital technology for post-Covid-19 recovery because of its immutability, transparency, traceability and security. This paper aims to analyse the impact of Covid-19 on blockchain adoption time among shipowners. A game theoretical model is built to solve the problem. In numerical applications, the impact of Covid-19 is observed by comparing the results to those without Covid-19. It is found that Covid-19 has a positive effect on accelerating blockchain adoption for a few small shipowners. This indicates that Covid-19 provides a good business opportunity for blockchain developers to market their products.**

Keywords - **Adoption time, blockchain, Covid-19 pandemic, game theory, maritime, shipping**

I. INTRODUCTION

The maritime supply chain is under digital transformation to revolutionise its processes. Various technologies are increasingly deployed by maritime stakeholders, such as sensors, RFID, big data analytics and blockchain [1], [2]. However, the diffusion of digitalisation varies across maritime organisations. For example, among the 174 members of International Maritime Organization (IMO), only 49 countries have digital port community systems by June 2020 [3]. The outbreak of Covid-19 has urged stakeholders to expedite the use of digital technologies in maritime supply chains to reduce human interaction, sustain operations and enhance efficiency.

Blockchain is considered a promising technology to solve the problems amplified by Covid-19, due to its features of immutability, transparency, security and traceability. Quite a few blockchain initiatives from maritime organisations are observed after the outbreak of Covid-19, such as COSCO shipping, Shanghai International Port Group and the International Maritime Employer's Council and the International Transport Worker's Federation [4]–[7]. As mentioned by [8], it is an emerging trend in the maritime industry that big customers such as BHP adopt blockchain at an increasing speed and they require their vendors like shipowners to join their blockchain system. The optimal adoption time of shipowners under this situation has been discussed by [8]. However, in view of Covid-19, a new important question arise - how the pandemic would affect shipowners' decisions on blockchain adoption time under this situation.

Due to the Covid-19 pandemic, different organisations are affected at various levels, either positively or negatively. Some of them may not even afford to adopt a new technology like blockchain in the short term despite the understanding that the technology helps them. It remains unclear how those organisations would respond to the Covid-19 in terms of whether and when to adopt a new technology.

In the existing literature, the impact of Covid-19 on the maritime industry is mainly discussed from the aspects of freight rate, vessel calls, cargo volume and crew change [9]–[11]. Although automated and digital technologies are recommended by [9]–[11] to improve resilience to the pandemic crisis, they do not focus on technology adoption itself. Very few studies discuss the impact of Covid-19 on technology adoption, particularly on technology adoption time.

In order to narrow the research gap, this paper analyses the impact of Covid-19 on shipowners' adoption time when facing a blockchain adoption request from a big shipper, which is an emerging trend in the industry. It extends the work of [8] by including pandemic-related settings to capture the potential changes in shipowners' business performance due to Covid-19.

The remaining of the paper is organised in the following way. Section II presents the model setup. Section III conducts a numerical application and provides result analysis. At last, conclusions are drawn in section IV.

II. MODEL SETUP

The model considers a two-layer maritime shipping market with a very large shipper and multiple shipowners. Since the outbreak of Covid-19, the shipper would like to adopt a blockchain-based system to digitalise the documentation process of its current supply chain and require its shipowners to participate in the system.

A. The Model

Before we describe the model in detail, a few assumptions are made. Firstly, the annual shipping quantity of the shipper remains the same unless a disruption happens. The affected shipping quantity remains the same during the disruption impact period. Secondly, the cost of blockchain adoption consists of two parts, namely an initial setup cost (C_0) and annual membership fee (C_a). Thirdly, the costs and gains relating blockchain adoption are discounted at a rate of λ, which is different from interest rate γ. Fourthly, the special benefits to a shipowner due to blockchain adoption is denoted as $g_i(q_i^t)$. It is proportionally to shipping quantities handled $g_i(q_i^t)=kq_i^t$, where k is the coefficient of blockchain benefits to shipowners. Lastly, the shipper is assumed to have a very strong market position so that it has the bargaining power to impose penalty policies on shipowners.

When the shipper announces its blockchain initiative, it also introduces a penalty policy with two concepts of penalty ratio (β) and cutoff time (T_c). Shipowners who join the shipper's blockchain system within the cutoff time are defined as leaders. Otherwise, they are followers. The original shipping quantity between the shipper and shipowner i before the outbreak of Covid-19 is denoted as q_i^0. The penalty policy works in the way that followers' shipping quantities will be reduced by the shipper at a ratio of β. The reduced quantities from followers will be re-allocated to leaders proportionally (α) based on leader's original shipping quantities with the shipper. The total reduced quantities of followers are equal to the total increased quantities of leaders, i.e., $\beta \sum_{i\in\{followers\}} q_i^0 = \alpha \sum_{i\in\{leaders\}} q_i^0$. The shipping quantities will be returned to the original ones once all shipowners join the blockchain system.

Due to Covid-19, shipowners experience changes in shipping quantities and profit margin. At the same time, it is uncertain how long the impact will last. T_p denotes the impact duration of Covid-19 pandemic. η denotes the percentage change in shipping quantities between the shipper and shipowners, so the new shipping quantity of shipowner i during the pandemic period is $(1+\eta)q_i^t$ for $t\in[0,T_p]$. δ denotes a scaling parameter reflecting the changes in shipowners' normal business profit margin. The new business profit of shipowner i during the pandemic period is hence $\delta\pi_i(q_i^t)$ for $t\in[0,T_p]$, where $\pi_i(q_i^t)=mq_i^t$ represents the normal business profit of shipowner i at time t before Covid-19 and m is the shipowner i's profit margin per shipping quantity.

B. Payoff Function

T_i denotes the adoption time of shipowner i. Π_i denote the payoff function of shipowner i, which will be different if the shipowner is a leader Π_i^l and a follower Π_i^f.

$$\Pi_i(T_1,\cdots,T_i,\cdots,T_n)=\begin{cases}\Pi_i^l(T_1,\cdots,T_i,\cdots,T_n), \text{ if } T_i\le T_c,\\ \Pi_i^f(T_1,\cdots,T_i,\cdots,T_n), \text{ if } T_i> T_c.\end{cases} \quad (1)$$

Depending on the relative value among T_i, T_p and T_c, the payoff function of shipowner i as a leader can be obtained by (2), (3) and (4), where $T^{max}=\max(T_1,\dots,T_i,\dots,T_n)$:

i) If $T_p<T_c$ and $T_i\le T_p$,

$$\begin{aligned}\Pi_i^l(T_1,\cdots,T_i,\cdots,T_n)&=\int_0^{T_i}\delta\pi_i(q_i^0+\eta q_i^0)e^{-\gamma t}dt\\&+\int_{T_i}^{T_p}[\delta\pi_i(q_i^0+\eta q_i^0)+g_i(q_i^0+\eta q_i^0)]e^{-\gamma t}dt\\&+\int_{T_p}^{T_c}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt\\&+\int_{T_c}^{T^{\max}}[\pi_i(q_i^0+\alpha q_i^0)+g_i(q_i^0+\alpha q_i^0)]e^{-\gamma t}dt\\&+\int_{T^{\max}}^{\infty}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt\\&-C_0e^{-\lambda T_i}-\int_{T_i}^{\infty}C_a e^{-\lambda t}dt,\end{aligned} \quad (2)$$

ii) If $T_p<T_c$ and $T_i>T_p$,

$$\begin{aligned}\Pi_i^l(T_1,\cdots,T_i,\cdots,T_n)&=\int_0^{T_p}\delta\pi_i(q_i^0+\eta q_i^0)e^{-\gamma t}dt\\&+\int_{T_p}^{T_i}\pi_i(q_i^0)e^{-\gamma t}dt\\&+\int_{T_i}^{T_c}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt\\&+\int_{T_c}^{T^{\max}}[\pi_i(q_i^0+\alpha q_i^0)+g_i(q_i^0+\alpha q_i^0)]e^{-\gamma t}dt\\&+\int_{T^{\max}}^{\infty}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt\\&-C_0e^{-\lambda T_i}-\int_{T_i}^{\infty}C_a e^{-\lambda t}dt,\end{aligned} \quad (3)$$

iii) If $T_p\ge T_c$,

$$\begin{aligned}\Pi_i^l(T_1,\cdots,T_i,\cdots,T_n)&=\int_0^{T_i}\delta\pi_i(q_i^0+\eta q_i^0)e^{-\gamma t}dt\\&+\int_{T_i}^{T_c}[\delta\pi_i(q_i^0+\eta q_i^0)+g_i(q_i^0+\eta q_i^0)]e^{-\gamma t}dt\\&+\int_{T_c}^{T_p}[\delta\pi_i((1+\alpha)(q_i^0+\eta q_i^0))\\&+g_i((1+\alpha)(q_i^0+\eta q_i^0))]e^{-\gamma t}dt\\&+\int_{T_p}^{T^{\max}}[\pi_i(q_i^0+\alpha q_i^0)+g_i(q_i^0+\alpha q_i^0)]e^{-\gamma t}dt\\&+\int_{T^{\max}}^{\infty}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt\\&-C_0e^{-\lambda T_i}-\int_{T_i}^{\infty}C_a e^{-\lambda t}dt.\end{aligned} \quad (4)$$

Similarly, the payoff function of shipowner i as a follower can be obtained by (5), (6) and (7) under different conditions:

i) If $T_p<T_c$,

$$\Pi_i^f(T_1,\cdots,T_i,\cdots,T_n)=\int_0^{T_p}\delta\pi_i(q_i^0+\eta q_i^0)e^{-\gamma t}dt$$
$$+\int_{T_p}^{T_c}\pi_i(q_i^0)e^{-\gamma t}dt$$
$$+\int_{T_c}^{T_i}\pi_i(q_i^0-\beta q_i^0)e^{-\gamma t}dt \tag{5}$$
$$+\int_{T_i}^{T^{\max}}[\pi_i(q_i^0-\beta q_i^0)+g_i(q_i^0-\beta q_i^0)]e^{-\gamma t}dt$$
$$+\int_{T^{\max}}^{\infty}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt$$
$$-C_0e^{-\lambda T_i}-\int_{T_i}^{\infty}C_a e^{-\lambda t}dt,$$

ii) If $T_p \ge T_c$ and $T_i \le T_p$,

$$\Pi_i^f(T_1,\cdots,T_i,\cdots,T_n)=\int_0^{T_c}\delta\pi_i(q_i^0+\eta q_i^0)e^{-\gamma t}dt$$
$$+\int_{T_c}^{T_i}\delta\pi_i((1+\eta)(q_i^0-\beta q_i^0))e^{-\gamma t}dt$$
$$+\int_{T_i}^{T_p}[\delta\pi_i((1+\eta)(q_i^0-\beta q_i^0))$$
$$+g_i((1+\eta)(q_i^0-\beta q_i^0))]e^{-\gamma t}dt \tag{6}$$
$$+\int_{T_p}^{T^{\max}}[\pi_i(q_i^0-\beta q_i^0)+g_i(q_i^0-\beta q_i^0)]e^{-\gamma t}dt$$
$$+\int_{T^{\max}}^{\infty}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt$$
$$-C_0e^{-\lambda T_i}-\int_{T_i}^{\infty}C_a e^{-\lambda t}dt,$$

iii) If $T_p \ge T_c$ and $T_i > T_p$,

$$\Pi_i^f(T_1,\cdots,T_i,\cdots,T_n)=\int_0^{T_c}\delta\pi_i(q_i^0+\eta q_i^0)e^{-\gamma t}dt$$
$$+\int_{T_c}^{T_p}\delta\pi_i((1+\eta)(q_i^0-\beta q_i^0))e^{-\gamma t}dt$$
$$+\int_{T_p}^{T_i}\pi_i(q_i^0-\beta q_i^0)e^{-\gamma t}dt \tag{7}$$
$$+\int_{T_i}^{T^{\max}}[\pi_i(q_i^0-\beta q_i^0)+g_i(q_i^0-\beta q_i^0)]e^{-\gamma t}dt$$
$$+\int_{T^{\max}}^{\infty}[\pi_i(q_i^0)+g_i(q_i^0)]e^{-\gamma t}dt$$
$$-C_0e^{-\lambda T_i}-\int_{T_i}^{\infty}C_a e^{-\lambda t}dt,$$

By the first and second order conditions, the optimal adoption time of shipowner i as a leader ($T_{i,l}^*$) and as a follower ($T_{i,f}^*$) can be obtained by $\max_{T_i\in[0,T_c]}\Pi_i^l(T_1,\cdots,T_i,\cdots,T_n)$ and $\max_{T_i\in(T_c,\infty)}\Pi_i^f(T_1,\cdots,T_i,\cdots,T_n)$, respectively. The final optimal adoption time of shipowner i , which is denoted by T_i^* can be obtained by substituting $T_{i,l}^*$ and $T_{i,f}^*$ into Π_i^l and Π_i^f , respectively. If $\Pi_i^l(T_1,\ldots,T_{i,l}^*,\ldots,T_n)>\Pi_i^f(T_1,\ldots,T_{i,f}^*,\ldots,T_n)$ is always true for all possible combinations of other shipowners' adoption time, $T_i^*=T_{i,l}^*$ is the best strategy for shipowner *i.* If $\Pi_i^l(T_1,\ldots,T_{i,l}^*,\ldots,T_n)<\Pi_i^f(T_1,\ldots,T_{i,f}^*,\ldots,T_n)$ is always true for all possible combinations of other shipowners' adoption time, $T_i^*=T_{i,f}^*$ is the best strategy for shipowner *i.* Otherwise, T_i^* switches between $T_{i,l}^*$ and $T_{i,f}^*$ when the strategies of other shipowners change. If T_i^* exists for all shipowners, the game has a Nash equilibrium $(T_1^*,\ldots,T_i^*,\ldots,T_n^*)$.

III. NUMERICAL APPLICATIONS AND RESULTS

This section conducts a numerical application with a big shipper and ten shipowners with industry data. The Nash equilibrium of the numerical case in terms of shipowners' optimal blockchain adoption time is summarised in Table I. It is noted that most shipowners would adopt blockchain at the earliest possible time, i.e., $T_i^*=0$. But very small shipowners such as shipowner 9 and 10 would not adopt blockchain until 16 and 21 years later, respectively.

TABLE I
NASH EQUILIBRIUM OF THE NUMERICAL CASE WITH AND WITHOUT COVID-19

Shipowners	Shipping Quantity (TEU)	With Covid-19: T_i^* years and (L/F[1])	With Covid-19: Net Payoff (in million USD)	Without Covid-19: T_i^* years and (L/F[1])	Without Covid-19: Net Payoff (in million USD)
Shipowner 1	50000	0 (L)	357.81	0 (L)	346.23
Shipowner 2	30000	0 (L)	214.65	0 (L)	207.71
Shipowner 3	10000	0 (L)	71.49	0 (L)	69.18
Shipowner 4	380	0 (L)	2.63	0 (L)	2.55
Shipowner 5	340	0 (L)	2.35	0 (L)	2.27
Shipowner 6	310	0 (L)	2.13	0.79 (L)	2.06
Shipowner 7	290	0 (L)	1.99	1.64 (L)	1.93
Shipowner 8	250	0 (L)	1.70	2 (L)	1.65
Shipowner 9	100	16.67 (F)	0.63	15.76 (F)	0.63
Shipowner 10	70	21.19 (F)	0.44	20.28 (F)	0.44

$\beta=5\%, T_c=2, m=511, k=40, \gamma=8.1\%,\ \lambda=16\%, C_0=7500, C_a=12000,$
$\eta=-0.2, \delta=1.4, \omega=100, T_p=3$

Note: [1] L/F represents the leadership or followership of ship operators.
L: Leader; F: Follower.
Source: The results with Covid-19 are from Authors and the results without Covid-19 are adapted from [8].

For ease of analysis, Table I also presents the blockchain adoption results without Covid-19 adapted from [8]. By comparing the results with and without Covid-

19, the impact of the pandemic on blockchain adoption can be observed. Firstly, the leadership or followership does not change due to Covid-19. Those who would be a leader (follower) without Covid-19 would still be a leader (follower) with Covid-19. Secondly, the blockchain adoption time of small leaders (e.g., shipowners 6, 7 and 8) is earlier with Covid-19 than without Covid-19. The blockchain adoption time of followers is slightly delayed because of Covid-19. However, such a delay can be negligible in terms of the percentage change. Thirdly, the payoff of all leaders is increased due to Covid-19, while the payoff of followers is similar with and without the pandemic.

The results indicate that Covid-19 has a positive effect on accelerating blockchain adoption, but limited to some small shipowners. For very small shipowners, there is no significant impact of Covid-19 on them in terms of their blockchain adoption decisions. It makes sense as Covid-19 increases shipowners profits based on the market information due to increased profit margin during the pandemic. The increased profit makes earlier blockchain adoption more affordable for some small shipowners, while it cannot further improve the blockchain adoption time of big customers as their adoption time is already the earliest, i.e., $T_i^* = 0$. For very small shipowners, the additional profits brought by Covid-19 are limited by the very small shipping quantity and hence are not sufficient enough to induce them to forward their blockchain adoption time.

IV. CONCLUSION

This study analyses the impact of Covid-19 on blockchain adoption time for shipowners by extending the work of [8] with new pandemic-related settings and parameters. A numerical application with industry data is conducted to demonstrate how to apply the model. The result shows that Covid-19 has a positive effect on accelerating blockchain adoption, but limited to a range of small shipowners. It suggests Covid-19 provides a good business opportunity for blockchain developers to market their products for small shipowners, but not those very small ones.

The contributions of this study are twofold. Firstly, it makes a novel attempt to analyse the impact of Covid-19 on blockchain adoption time in an industry. Secondly, it provides practical implications to blockchain developers for expanding their market shares in maritime supply chains.

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