Blockchain Adoption Time of Shipowners: A Game Theoretic Analysis

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Abstract – **With continuous overcapacity in vessel tonnage and slower growth of global trade, shipowners are facing fierce competition and are pushed to look for innovative ways to improve their performance and reduce costs. Blockchain is one of the emerging technologies that has the potential to help shipowners to achieve these goals. This study aims to analyse if and when shipowners would adopt blockchain when facing a request from a big shipper. A game theory model is developed to analyse the optimal adoption time of shipowners. The analytical solutions of the optimal adoption time of each shipowner are obtained in different situations. The numerical analysis reveals that the higher shipping quantity carried by the shipowners, the earlier they would join the blockchain network. Shipowners with very small shipping quantities would be unlikely to adopt blockchain until more than a decade later. It is suggested that blockchain initiators should start with large shipowners when promoting blockchain.**

Keywords - **Adoption time, blockchain, game theory, maritime, shipping**

I. INTRODUCTION

Ocean shipping has experienced overcapacity in vessel tonnage for years. Shipowners are under fierce competition. They are proactively looking for ways to streamline their operational process as process innovation is important for improving their competitive advantage [1]. Blockchain has great potential to assist shipowners in achieving higher competitive advantage through streamlined process, enhanced efficiency and reduced costs.

Even though shipowners are actively exploring the potential of blockchain in the industry, their major customers, i.e. big shippers seem to be faster in deploying this technology as seen from the case of BHP, Shell, ABInBev [2]–[4]. These shippers even exert their influences on shipowners in blockchain adoption. For example, BHP requested its shipping vendors to adopt blockchain as part of its supply chain [2]. With the growing trend that big shippers request shipowners to adopt blockchain, it would be interesting to know how shipowners would respond to the request, i.e. whether they will adopt or not and when.

Despite its popularity and growing importance to the maritime industry, there are limited studies on the adoption of blockchain in the maritime sector and previous studies mainly focus on areas like drivers, barriers, intention to use and possible application areas [5]–[9]. Although the benefits of blockchain the maritime industry have been quite established from these studies, it may not be favourable to all maritime stakeholders. It is necessary to investigate whether and when to adopt blockchain for maritime stakeholders, which have not been discussed in previous literature. Considering the literature gap and the current trend of blockchain adoption in maritime supply chains, this paper aims to analyse the adoption decisions of shipowners in terms of whether and when to adopt blockchain when facing a big shipper's request.

The paper is organised in the following way: The second section presents a game-theoretic model to analyse the optimal adoption time of shipowners, followed by numerical applications and result analysis. In the last section, conclusions are drawn accordingly.

II. MODEL SETUP

This model analyses an ocean shipping market with a very large shipper and multiple shipowners. The shipper plans to deploy blockchain to digitize its current supply chain documentation systems and wants its shipowners to join the system.

q_i^0 represents the original shipping quantity of shipowner i at time 0 when the shipper's blockchain initiative is announced. The shipper also announces a penalty policy with a penalty ratio (β) and a cutoff time (T_c). Shipowners will be divided into two groups based on their adoption time (T_i): leaders and followers. Leaders are those shipowners which participate in shipper's blockchain system no later than the cutoff time and followers are those which participate in the system later than the cutoff time. Under the penalty policy, the shipper would reduce followers' business quantity by a ratio of β, and the total reduced amount will be transferred to leaders proportionally based on the leaders' original shipping quantity, i.e. q_i^0 for $\forall i \in \{\text{leaders}\}$. The total quantity deducted from all followers equals the total amount increased to all leaders. Once all shipowners are in the network, the shipper would restore the business quantity of all shipowners to the original ones.

A. Model Assumption

A few assumptions are made in the model as below:

1) The total shipping quantity of the shipper remains constant every year.

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2) The cost of blockchain adoption includes the setup cost (C_0) and annual membership fee (C_a). The costs decline with time at a rate of λ.

3) The efficiency gains from blockchain adoption to shipowners $g_i(\cdot)$ are proportional to the shipping quantity of shipowners and the interest rate is γ.

4) The shipper has a strong bargaining power so that it is possible for the shipper to impose penalties on shipowners who do not join the blockchain system before the cutoff time.

B. Payoff Function

Let $\pi_i(q_i^t)$ stand for the profit of shipowner i at time t without blockchain implementation. If shipowner i is a leader, its payoff functions with blockchain adoption being a leader and being a follower are given by (1) and (2) respectively, where $T^{max} = \max(T_1,\ldots,T_i,\ldots,T_n)$.

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

$$\begin{aligned}
&\Pi_i(T_1,\cdots,T_i,\cdots,T_n) = \Pi_i^f(T_1,\cdots,T_i,\cdots,T_n)\\
&= \int_0^{T_c} \pi_i(q_i^0)e^{-\gamma t}dt\\
&+\int_{T_c}^{T_i} \pi_i(q_i^0 - \beta q_i^0)e^{-\gamma t}dt\\
&+\int_{T_i}^{T^{\max}} [\pi_i(q_i^0 - \beta q_i^0) + g_i(q_i^0 - \beta q_i^0)]e^{-\gamma t}dt\\
&+\int_{T^{\max}}^{\infty} [\pi_i(q_i^0) + g_i(q_i^0)]e^{-\gamma t}dt\\
&-C_0e^{-\gamma T_i} - \int_{T_i}^{\infty} C_a e^{-\gamma t}dt,
\end{aligned} \tag{2}$$

Proposition 1: *If shipowner i is a leader, then its optimal adoption time ($T_{i,l}^*$) is*:

$$T_{i,l}^* = \begin{cases} \min(\frac{1}{\lambda-\gamma}\ln(\frac{\lambda C_0 + C_a}{g_i(q_i^0)}), T_c), \text{ if } \lambda C_0 + C_a > g_i(q_i^0) \\ 0, \text{ if } \lambda C_0 + C_a \le g_i(q_i^0) \end{cases}.$$

The analytical solution of $T_{i,l}^*$ shows that as a leader, shipowner i would adopt blockchain immediately after shipper's announcement if $\lambda C_0 + C_a \le g_i(q_i^0)$. Otherwise, it would adopt blockchain at a time either $\frac{1}{\lambda-\gamma}\ln\frac{\lambda C_0 + C_a}{g_i\left(q_i^0\right)}$ or T_c, whichever is earlier.

Proposition 2: *If shipowner i is a follower, then its optimal adoption time ($T_{i,f}^*$) is*:

$$T_{i,f}^* = \begin{cases} \max(\frac{1}{\lambda-\gamma}\ln(\frac{\lambda C_0 + C_a}{g_i(q_i^0 - \beta q_i^0)}), T_c), \text{ if } \lambda C_0 + C_a > g_i(q_i^0 - \beta q_i^0) \\ T_c + \Delta, \text{ if } \lambda C_0 + C_a \le g_i(q_i^0 - \beta q_i^0) \end{cases},$$

where Δ is a small positive real number such that $T_{i,f}^* > T_c$.

The analytical solution of $T_{i,f}^*$ shows that as a follower, shipowner i would adopt blockchain soonest after T_c if $\lambda C_0 + C_a \le g_i(q_i^0 - \beta q_i^0)$. Otherwise, it would adopt blockchain at a time either $\frac{1}{\lambda-\gamma}\ln\frac{\lambda C_0 + C_a}{g_i\left(q_i^0 - \beta q_i^0\right)}$ or $T_c + \Delta$, whichever is later.

T_i^* represents the best strategy of shipowner i. $T_i^* = T_{i,l}^*$ if $\Pi_i^l(T_1,\ldots,T_{i,l}^*,\ldots,T_n) > \Pi_i^f(T_1,\ldots,T_{i,f}^*,\ldots,T_n)$ regardless of all other shipowners' adoption time. $T_i^* = T_{i,f}^*$ if $\Pi_i^l(T_1,\ldots,T_{i,l}^*,\ldots,T_n) < \Pi_i^f(T_1,\ldots,T_{i,f}^*,\ldots,T_n)$ regardless of all other shipowners' adoption time. If $\Pi_i(T_1^*,\ldots,T_i^*,\ldots,T_n^*) > \Pi_i(T_1^*,\ldots,T_i,\ldots,T_n^*)$ for all shipowner i, then there is a Nash equilibrium of the game, i.e. $(T_1^*,\ldots,T_i^*,\ldots,T_n^*)$.

III. NUMERICAL APPLICATIONS AND RESULTS

A numerical example is used to illustrate the application of the model. One big shipper and ten shipowners are discussed in the example. Table I lists the additional variables used in the application, apart from those mentioned in the model setup.

TABLE I
ADDITIONAL VARIABLES USED FOR THE APPLICATION CASE

Notation	Description
k	Coefficient of blockchain benefits to shipowners
f	Freight rate (USD/TEU)
c	Marginal operating cost (USD/TEU)

Table II tabulates the Nash Equilibrium of the example in terms of optimal adoption time and the corresponding net payoff. It is noted that the optimal adoption time of shipowners is negatively correlated with their shipping quantity. When the shipping quantities of shipowners are so large that $g_i(q_i^0) \geq \lambda C_0 + C_a$ (like shipowners 1-5), they would always join the blockchain system at time 0. For shipowners whose shipping quantities are relatively small with $g_i(q_i^0) < \lambda C_0 + C_a$, some of them would still choose to be leader and adopt blockchain no later than the cutoff time, like the case of shipowners 4-8. This could be attributed to the penalty ratio (β) which makes it feasible for these shipowners to be a leader as the potential losses from reduced shipping quantity is larger than the net loss from blockchain adoption ($\lambda C_0 + C_a - g_i(q_i^0)$). However, for shipowners with very small quantities such that the potential losses from reduced shipping quantity are lesser than the net loss from blockchain adoption, they would not adopt blockchain until more than 15 years later, like the case of shipowners 9 and 10.

The numerical result reveals that economies of scale encourage larger shipowners to join blockchain earlier. Therefore, blockchain initiators should start with large partners as they tend to adopt the technology earlier compared with small partners.

TABLE II
NASH EQUILIBRIUM OF THE NUMERICAL CASE

Shipowners	Shipping Quantity (TEU)	T_i^* (in year)	Leader(L)/ Follower (F)	Net Payoff (in million USD)
Shipowner 1	50000	0	Leader	346.23
Shipowner 2	30000	0	Leader	207.71
Shipowner 3	10000	0	Leader	69.18
Shipowner 4	380	0	Leader	2.55
Shipowner 5	340	0	Leader	2.27
Shipowner 6	310	0.79	Leader	2.06
Shipowner 7	290	1.64	Leader	1.93
Shipowner 8	250	2	Leader	1.65
Shipowner 9	100	15.76	Follower	0.63
Shipowner 10	70	20.28	Follower	0.44

$\beta = 5\%, T_c = 2, f = 1110, k = 40, c = 589, \Delta = 1/12, \gamma = 8.1\%,\ \lambda = 16\%,$
$C_0 = 7500, C_a = 12000$

IV. CONCLUSION

This study develops a game theory model to analyse the optimal adoption time of shipowners when facing an adoption request from a big shipper which has very strong bargaining power. The analytical solutions of the optimal adoption time for shipowners as a leader and as a follower are obtained. A numerical application is performed to illustrate the applicability of the model, and the results show that the higher shipping quantity carried by the shipowners, the earlier the shipowners would join the blockchain network. Hence it is suggested that blockchain initiators should target at large partners at first when promoting blockchain adoption.

The contributions of this study are twofold. First, it fills the literature gap with a quantitative analysis of the adoption time of blockchain from the perspective of shipowners by using a game theory model. Secondly, it introduces a method to shipowners on how to determine their optimal adoption time of blockchain when facing requests from a big shipper. The method can also be extended to analyse the adoption time for other blockchain adopters.

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