Game-Theoretic Analysis on CBDC Adoption

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Abstract. As an important blockchain application, CBDC (Central Bank Digital Currency) has received significant worldwide attention as it can restructure financial market, affect national currency policies, and introduce new regulation policies and mechanisms. It is widely predicted that CBDC will introduce numerous digital currency competitions in various aspects of the global financial market, and winners will lead the next wave of digital currency market. This paper applies the game theory to study the competitions between different countries, in particular to analyze whether they should adopt the CBDC program. We propose two game-theoretic models for CBDC adoption, both analyzing whether to adopt the CBDC program via the Nash equilibrium. Both game-theoretic models draw the same conclusion that each country should adopt the CBDC program regardless of the choices of other counties. In other words, current currency leaders should adopt CBDC because it may lose the premier status, and other countries should adopt CBDC otherwise they risk of getting even further behind in the digital economy. According to our game-theoretic models, the current market leader who has 90% of market shares may lose about 19.2% shares if it is not the first mover.

Keywords: Central Bank Digital Currency · Game theory · Blockchain · Currency competition

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1 Introduction

CBDC (Central Bank Digital Currency) has received significant attention recently, and it is an important blockchain application [4,9,17–19]. Many central banks including US Federal Reserve, ECB (European Central Bank), PBOC (People's Bank of China), Bank of England have all announced their CBDC projects. Numerous financial institutions such as World Bank, IMF (International Monetary Fund), BIS (Bank for International Settlements) have initiated their own CBDC projects. In 2017, IMF recommended that each country develop her own CBDC program to compete with the cryptocurrencies.

Bank of England (BoE) is the first central bank to propose her own CBDC program, and since 2014 has published numerous research reports such as RTGS (Real-Time Gross Settlement) blueprints and conducted many experiments. One of earliest conclusions of their studies is that there may be a competition between commercial banks and central banks for deposits because now central banks offer CBDC, and customers may prefer to save their money as CBDC as it is without any credit risks, while money in commercial banks still carries risks. This is one of many competitions that may happen when CBDC is introduced.

Since 2015, BoE has suggested that CBDC will have a profound impact to the financial world, affect national currency policies, and change the way financial transactions are made. Indeed, the importance of CBDC cannot be underestimated. In 2017, Bordo and Levin predicted that if a country does not develop its own CBDC program, the country will incur financial risks in future [5][1].

In November 2019, Rogoff of Harvard University said currently there is a new currency war, but this is not a conventional currency war, but a digital version [15]. He also mentioned that the new war involves of both regulated financial market and underground market, where cryptocurrencies such as Bitcoins are often used. He also mentioned that technology is the key driver for these changes.

In addition to the central bank-commercial bank competition for deposits, IMF have suggested stablecoins issued in the private sector can have a profound impact to the financial world. Stablecoins are those digital currencies backed by fiat currencies or other assets such as bonds, but they have stable price, and can be used do cross-border transactions. The IMF July 2019 report [1] claims if a stablecoin is supported by a central bank, it behaves like a CBDC. This new digital currency is called synthetic CBDC (short as sCBDC hereafter), rather than CBDC, but like CBDC the reserve money is stored in a central bank so that sCBDC does not have any credit risks. But in this manner, the IMF report says that there will be competitions between those sCBDC with fiat currency as people may prefer using those stablecoins rather than their fiat currency. This

[1] "Given the rapid pace of payment technology innovation and the proliferation of virtual currencies such as bitcoin and Ethereum, it may not be wise for the central bank to adopt a negative attitude in dealing with CBDC. If the central bank does not produce any form of digital currency, there is a risk of losing monetary control, and the possibility of a serious economic recession is greater. Because of this, central banks act quickly when considering adopting CBDC.".

will also create another competition between commercial banks and stablecoin entities, both seeking for deposits.

In August 2019, former BoE governor Mark Carney said that a synthetic hegemony digital currency may replace US dollar as the world's reserve currency. This is another competition where an sCBDC may compete with US dollars or any other fiat currency to be the world's reserve currency.

In June 2020, US Federal Reserve published a research paper [7] supporting the claim of deposit competition between central banks and commercial banks. If this is the case, the financial market will indeed be fundamentally changed due to introduction of CBDC or sCBDC.

Furthermore, stablecoins or sCBDC may compete with each other in the market place, for example, a large stablecoin will have strong competitive edge over other stablecoins. For example, in May 2020, ECB issued a report predicting that Facebook's Libra may have over 3 trillion Euros in deposit and it may become the largest fund in Europe. The ECB made this prediction based on the fact that Facebook is widely used in the world, many Facebook users will become Libra users.

Thus, many competitions are created due to CBDC or sCBDC:

– Between central banks and commercial banks for deposits;
– Between stablecoin entities and commercial banks for deposits;
– Between stablecoins and fiat currencies;
– Between stablecoins and stalecoins; and
– Between different CBDCs or sCBDCs.

This paper is our first attempt in a series to theoretically study various competitions introduced by CBDC or sCBDC from the viewpoint of game theory [8]. As done in the game-theoretic analysis on software crowdsourcing [10,11,13], this paper applies the game theory to investigate whether a specific country will attempt to develop its own CBDC program. Developing a CBDC program is a challenge task because this will affect national monetary policies, regulator policies, technology solutions, security issues as well as consumer protection issues. Some countries may not have the technology know-how to develop her own technologies, and for this reason Facebook Libra 2.0 offers to assist any country to establish her own CBDC programs.

This paper makes the following contributions: game-theoretic models are applied to analyze whether a country should adopt the CBDC program with respect to beneifts and cost; and according to these models, each country will eventually commit to her own CBDC program regardless, confirming the IMF recommendation made in 2017. In particular, the detailed game-theoretic model provides explicitly, for a simplified market of two countries of 90% and 10% market shares respectively, the changes of market shares for all the four possible cases of whether they adopt CBDC or not (see Table 3 for the details). It is interesting to see that in such settings, if the current market leader does not adopt CBDC, it risks 19.2% of the economic market share. This confirms the conjecture made by Bordo and Levin in 2017 that the CBDC has a serious impact on national economy system and global market leadership.

This paper is organized as follows: Sect. 2 reviews the existing work related to CBDC; Sect. 3 and Sect. 4 present our simple and detailed game-theoretic models for CBDC adoption respectively; Sect. 5 reports our implementation and preliminary experimental results with the detailed game-theoretic model; Sect. 6 concludes this paper with remarks and future work.

2 Related Work

IMF Report

IMF issued a report "The Rise of Digital Money" in July 2019 [1], and one of the main theses is that people will choose different forms of money due to convenience. The report proposes two key concepts: 1) sCBDC where reserve money will be placed in central banks so that stablecoins will be risk free; 2) proposes three stages of financial market restructuring: coexistence, complementarity, and substitution. The June 2020 Federal Reserve Report [7] further confirms that the 3rd stage, i.e., substitution, is a likely event as central banks will have monopoly of deposits. In this case, financial market structure is fundamentally changed.

Digital Currency Areas

Brunnermeier, James and Landau of Princeton University proposed this Digital Currency Areas (DCA) theory in 2019 [6]. Some of their key findings include: 1) Platforms become the center of financial market: traditionally the centers are banks, but once Internet-based platforms become the financial center, financial markets are significantly restructured. Furthermore, those who manage those platforms will have significant economic advantages; 2) Digital dollarization, i.e., digital currencies will compete with fiat currencies; 3) Digital fragmentation: different parts of the world will run different digital currencies due to stiff competitions among different digital currencies; 4) Role of digital money: digital currencies and fiat currencies have overlapping but different emphasis as digital currencies are mainly used in transactions including cross-border transactions. This theory has received significant attention as BoE, ECB, and Federal Reserve have quoted and discussed this theory publicly.

Federal Reserve Report

In June 2020, the Philadelphia Federal Reserve released a research report "Central Bank Digital Currency: Central Banking for all?" [7]. This report uses a game theory model, confirming the theory by BoE that there will be competition between central banks and commercial banks for deposits. It also points out that the current two-tiered system with a central bank and commercial banks came after the World War II, before, central banks can play the role of lending (currently done by commercial banks). Thus, it is not inconceivable that commercial banks provide different services. In other words, the current banking structure can be changed if necessary due to CBDC.

The models used include consumers, banks and central banks according to various scenarios. Yet, over time, people will choose to deposit their money into their central bank as the money will be risk free as money in commercial banks carries some risks. In this case, central banks have monopoly of deposit, and commercial banks need to provide different services.

Libra Stablecoin

On June 18th 2019, Libra Association released the whitepaper [2], and created a great of discussions in the world, especially among central banks and commercial banks. On April 16th, 2020, the Association released Libra 2.0 whitepaper [3] (hereinafter referred to as "Libra 2.0"). According to the whitepaper of Libra 2.0, if a country or region is worried that its own fiat currency can be replaced by Libra, Libra will cooperate with the central bank to establish the CBDC for the country. Libra 2.0 will no longer pursue public blockchain route, instead it will follow FATF regulations, such as Travel Rules. Libra 2.0 will also incorporate embedded supervision mechanisms to monitor transactions in real.

3 Simple Game-Theoretic Model

For a specific country, it has two choices to adopt CBDC, or not. To start it simple, we assume there are only two countries–C_1 and C_2, and they compete in the financial market.

Suppose that E_1 is the benefit country C_1 gained for a successful domestic CBDC project, and H_1 is the damage to country C_2 incurred of a successful foreign CBDC project in country C_1. They are of the similar meanings for E_2 and H_2.

The benefits gained for a successful domestic CBDC project include improving its international financial position, gaining the reserve currency status, providing the same services and sharing platform to countries that cannot develop their own CBDC as well as managing the digital currency platform. According to the DCA theory, the entity or the country that owns the platform will have significant advantage over others who do not. There are other benefits as well.

The damage incurred of a successful foreign CBDC project include deterioration of international monetary position, and possibility of a major financial crisis, lose of ability to manage national currency policies.

In digital economy, the first mover will have significant advantages over followers according to the Davidow law. This law says that the first product of a class to reach a market automatically gets a 50% market share. If CBDC economic model follows the Davidow law, this means those entities that move first will dominate the market, and this will apply to CBDC issued by central banks, or CBDC by private parties. In this case, if country (or entity) C_1 develops her CBDC program, while country (or entity) C_2 does not, C_1 will gain significant advantages over C_2 by owing more than 50% of market share. According the DCA theory, C_1 will have significant economic benefit over C_2.

Assume that α_i is the success rate for country C_i to develop CBDC program for $i = 1, 2$. For example, if C_1 has superior technology, then α_1 will be close to 1. The game model between these two countries are expressed in the following Table 1.

Table 1. Simple game-theoretic model for CBDC adoption of two countries C_1 and C_2

C_1	C_2	
	Develop CBDC	Do not develop CBDC
Develop CBDC	$(E_1\alpha_1 - H_2\alpha_2, E_2\alpha_2 - H_1\alpha_1)$	$(E_1\alpha_1, -H_1\alpha_1)$
Do not develop CBDC	$(-H_2\alpha_2, E_2\alpha_1)$	$(0, 0)$

In the case that country C_2 decides to develop CBDC program: if C_1 decides to develop, it will get the payoff of $E_1\alpha_1 - H_2\alpha_2$; if C_1 decides not, it will get $-H_2\alpha_2$. Obviously $E_1\alpha_1 - H_2\alpha_2$ is larger than $-H_2\alpha_2$, and thus C_1 should develop her own CBDC program.

If C_2 decides not to develop her CBDC program, then C_1 should still choose to develop CBDC, because the benefit of choosing is $E_1\alpha_1$, while the benefit of not developing CBDC is 0, obviously $E_1\alpha_1$ is larger. Thus, no matter how C_2 chooses, C_1 should develop her own CBDC program.

Similarly, regardless whatever C_1 chooses, ultimately country C_2 needs to develop her own CBDC program. In this way both countries will develop CBDC programs as a Nash equilibrium for this model.

However, C_1 and C_2 will have different benefit E_1, E_2 and damage H_2, H_1. If C_1 is powerful economically, but does not develop her CBDC program, the damage that may be incurred will be significant because potentially it loses her premier status. However, if C_1 develops CBDC, but country C_2 does not, C_2 will be lagging further behind.

The success probability α_i is a function of time and increases with time as more research results will be available over time, and each country eventually will be able to develop her own CBDC program. An advanced country may reach 1 before other countries, and achieve Davidow advantages. But eventually, both α_1 and α_2 will be close to 1, and this means that every country will be able to develop her own CBDC program. Yet the first mover will own market shares.

4 Detailed Game-Theoretic Model

Next we aim at establishing a detailed game-theoretic model to analyze the benefits or losses of a country or an entity in the choice of adopting CBDC. The benefits or losses are represented merely by the change of the market shares, and this is because the cost for the economy's transformation to the existence of CBDC is negligible compared with the change of market shares.

4.1 Game-Theoretic Settings of the Model

As in Sect. 3, let us focus on the simplest game of 2 players C_1 and C_2 with current market shares of M_1 and M_2, where $M_1 + M_2 = 1$. Let $S_1 = S_2 = \{Y, N\}$ be the set of pure strategies for C_1 and C_2, where Y and N stand for adopting and not adopting CBDC respectively. Then for $i = 1$ and 2, the payoff function p_i for C_i is a mapping from $S_1 \times S_2$ to $[-1, 1]$, and $p_i(\boldsymbol{s})$ represents C_i's payoff given a profile $\boldsymbol{s} = (s_1, s_2)$ of pure strategies $s_1 \in S_1$ and $s_2 \in S_2$.

For $i = 1$ and 2, a *mixed strategy* σ_i of C_i is a probability distribution over the pure strategies in S_i, where $\sigma_i(s)$ is the probability for C_i to choose a pure strategy $s \in S_i$. Denote the space of mixed strategies of C_i by Σ_i. We can define the payoff $\tilde{p}_i(\boldsymbol{\sigma})$ of C_i for a mixed strategy profile $\boldsymbol{\sigma} = (\sigma_1, \sigma_2) \in \Sigma_1 \times \Sigma_2$ as

$$\tilde{p}_i(\boldsymbol{\sigma}) = \sum_{(s_1, s_2) \in S_1 \times S_2} \sigma_1(s_1)\sigma_2(s_2)p_i(s_1, s_2),$$

which is essentially the expected payoff of C_i for the probability distribution $\boldsymbol{\sigma}$.

A mixed strategy profile $\boldsymbol{\sigma}^* = (\sigma_1^*, \sigma_2^*) \in \Sigma_1 \times \Sigma_2$ is called a *Nash equilibrium* of the game if $\tilde{p}_1(\sigma_1^*, \sigma_2^*) \geq \tilde{p}_1(s_1, \sigma_2^*)$ and $\tilde{p}_2(\sigma_1^*, \sigma_2^*) \geq \tilde{p}_2(\sigma_1^*, s_2)$ for any pure strategy $s_1 \in S_1$ and $s_2 \in S_2$. A Nash equilibrium is a state such that each player in the game maximizes his expected payoff under the condition that the mixed strategies of the other players are fixed, and thus anyone attempting to change his mixed strategy from the Nash equilibrium will face a reduced payoff. For a finite non-cooperative game, at least one Nash equilibrium exists [14].

In this model we will compute the Nash equilibrium of the game to reveal the probability of a certain player to adopt CBDC. To do this, we need explicit expressions for the payoff functions.

4.2 Construction of Payoff Functions

We consider a dynamic game in the time t. The players of the game C_1 and C_2, together with their pure strategies $\{Y, N\}$, keep unchanged regardless of the time t. But their payoff functions p_1 and p_2 indeed change with t, as explained as follows. To simplify our model, the time is discretized to take only non-negative integers. It may help to assume a unit interval $[t_0, t_0 + 1]$ of time to be 3 months in the real world.

For each player C_i in our game, there is a probability of success $Prob_i(t)$ if he chooses to adopt CBDC. This probability has an initial value $Prob_i(0) = P_i$ and it increases with time (to mimic the increasing storage of underlying related knowledge and technologies to adopt CBDC). We assume that the increase rate is a constant c in time for both C_1 and C_2, and thus we know that the probability of success for C_i is $Prob_i(t) = \min\{ct + P_i, 1\}$ for $i = 1, 2$. Once a player C_i chooses to adopt CBDC at a certain time $\bar{t}$, there is a preparatory duration of d units of time, and this means that C_i will succeed at the time $\bar{t} + d$ with a probability of $Prob_i(\bar{t})$.

Next we discuss the payoff of each player with respect to the four possible combinations of pure strategies. Basically the payoff of C_1 in this game is to gain the market share of C_2 if C_1 chooses to adopt CBDC and succeeds while C_2 fails or chooses not to adopt it, and vice versa. Suppose that at a certain time $\bar{t}$, C_1 finishes its preparatory duration and succeeds in adopting CBDC, then C_1 will take a percentage of C_2's market share at $\bar{t}$ in the next time interval $(\bar{t}, \bar{t} + 1)$.

Denote by $M_1(t)$ and $M_2(t)$ the market shares of C_1 and C_2 with respect to t, and let r $(0 < r < 1)$ be the percentage of gaining (or losing) the market share in one unit time interval. Then in the above scenario,

$$M_1(\bar{t}+1) = M_1(\bar{t}) + rM_2(\bar{t}), \qquad M_2(\bar{t}+1) = (1-r)M_2(\bar{t}).$$

And the payoff of C_1 in the interval $(\bar{t}, \bar{t}+1)$ is $rM_2(\bar{t})$, while that for C_2 is $-rM_2(\bar{t})$.

Combination I, (N, N) at $\bar{t}$: in this case the payoffs are $p_1(N,N)(\bar{t}) = p_2(N,N)(\bar{t}) = 0$.

Combination II, (Y, Y) at $\bar{t}$: in this case both C_1 and C_2 choose to adopt CBDC, and then their payoffs depend on which succeeds first. Since the function of success probability is $Prob_i(t) = \min\{ct + P_i, 1\}$ which linearly grows to 1, we know that the maximum possible length of time in which there exists one and only one player who succeeds in adopting CBDC is $[\bar{t}+d, T]$, where

$$T := \bar{t} + d + \max\left\{\lceil\frac{1-Prob_1(\bar{t})}{c}\rceil, \lceil\frac{1-Prob_2(\bar{t})}{c}\rceil\right\}.$$

For each integer $t \in [\bar{t}+d, T]$, we can explicitly compute the probability $\tilde{Prob_i}(t)$ for C_i to succeed in adopting CBDC at t for the first time (which implies that C_i fails in the interval $[\bar{t}+d, t-1]$). See Table 2 for an illustrative example of the computed success probabilities.

With $\tilde{Prob_1}(t)$ and $\tilde{Prob_2}(t)$ for $t \in [\bar{t}+d, T]$, we can enumerate each possible combination of the two first success time $T_1, T_2 \in [\bar{t}+d, T]$ of C_1 and C_2 respectively, together with the possibility P_{T_1,T_2} for this combination to happen. In this way, we can compute the expected payoff of C_1, for example (that for C_2 is just the opposite):

$$p_1(Y,Y)(\bar{t}) = \sum_{T_1,T_2\in[\bar{t}+d,T]} P_{T_1,T_2} \cdot \begin{pmatrix} M_2(\bar{t})r \cdot \sum_{j\in[0,T_2-T_1]}(1-r)^j & \text{when } T_2 > T_1 \\ -M_1(\bar{t})r \cdot \sum_{j\in[0,T_1-T_2]}(1-r)^j & \text{otherwise.} \end{pmatrix}.$$

Combination III, (Y, N) at $\bar{t}$: in this case we assume that C_2 does not realize the importance of adopting CBDC until he has lost a considerable percentage m $(0 < m < 1)$ of his market share. In other words, C_2 starts to adopt CBDC only after he loses m of his market share. Let T_1 $(\bar{t}+d \le T_1 \le \bar{t}+d+\lceil\frac{1-Prob_1(\bar{t})}{c}\rceil)$ be the time when C_1 succeeds in adopting CBDC and $T_2 = T_1 + \min\{t \in \mathbb{Z}_{\ge 0} : (1-r)^t < 1-m\}$ be the time when C_2 first loses at least m of his market share. Then the earliest time for C_2 to succeed in adopting CBDC falls in the range $\left[T_2+d, T_2+d+\lceil\frac{1-Prob_2(\bar{t})}{c}\rceil\right]$. For each $t \in \left[T_2+d, T_2+d+\lceil\frac{1-Prob_2(\bar{t})}{c}\rceil\right]$, similarly to the case above we can compute the probability and $\tilde{Prob_2}(t)$ for C_2 to succeed in adopting CBDC at t for the first time. Then the payoff of C_1 is

$$p_1(Y,N)(\bar{t}) = \sum_{t\in\left[T_2+d, T_2+d+\lceil\frac{1-Prob_2(\bar{t})}{c}\rceil\right]} \tilde{Prob_2}(t) \cdot M_2(\bar{t})r \cdot \sum_{j\in[0,t-T_1]} (1-r)^j.$$

Combination IV, (N, Y): the dual case as III above.

With the payoff functions of C_1 and C_2 known, we can compute the Nash equilibrium of the game. Let $\boldsymbol{\sigma}^* = (\sigma_1^*, \sigma_2^*) \in \Sigma_1 \times \Sigma_2$ be the Nash equilibrium of the game, then $\sigma_1^*(Y)$ (a probability) is the tendency for C_1 to choose to adopt CBDC, and $\sigma_2^*(Y)$ is that for C_2.

5 Implementation and Experiments

In this section, we first fix the values for our parameters listed in the above section to have an illustrative model, with the interval $[t, t+1]$ representing 3 months in the real world in mind.

- Market shares $M_1 = 0.9$, $M_2 = 0.1$: country C_1 takes the overwhelmingly dominant part of the market.
- Preparation duration $d = 6$: one country needs 18 months to prepare the adoption of CBDC.
- Initial success probabilities $Prob_1(0) = 0.5$ and $Prob_2(0) = 0.3$, and the increase rate r of the success rate is set to 0.05.
- The loss rate of market share (in 3 months) $r = 0.1$: this means that one country loses 10% of its market share in 3 months if the other player succeeds but it does not.
- Loss of market shares for awareness $m = 0.3$.

With the above setup, let us work out the payoff of C_1 in combination II in Sect. 4.2. In this case, both C_1 and C_2 choose to adopt CBDC at $t = 0$. Then at $t = 6$ (after 18 months, the preparation duration), the probability for C_1 to succeed is 0.5 while that for C_2 is 0.3. Furthermore, let us calculate the probability $\tilde{Prob}_i(t)$ for C_i to first succeed at time t, as in the following table.

Table 2. An example illustrating the probabilities of first success of two countries at different time

t	$\tilde{Prob}_1(t)$	$\tilde{Prob}_2(t)$
6	0.5	0.3
7	0.55×0.5	0.35×0.7
i $(8 \leq i \leq 15)$	$(0.5 + 0.05(i-6)) \times \prod_{j=0..i-7}(0.5 - 0.05j)$	$(0.3 + 0.05(i-6)) \times \prod_{j=0..i-7}(0.7 - 0.05j)$
i $(16 \leq i \leq 20)$	$\prod_{j=0..9}(0.5 - 0.05j)$	Same as above
≥ 21	Same as above	$\prod_{j=0..13}(0.7 - 0.05j)$

For example, from this table, we will be able to read that the probability for C_1 to succeed at $t = 6$ AND C_2 to succeed at $t = 7$ for the first time is $0.5 \times 0.245 = 0.1225$. In such combination the whole payoff of C_1 is $(7-6) \times 3 = 3$ months of eating C_2's market share, that is $r \times M_2 = 0.01$. Similarly, the payoff of C_2 is -0.01. Traversing all the possible combinations in the above table, we will be able to compute the expected payoffs of C_1 and C_2 for the pure strategy profile (Y, Y).

We have implemented an algorithm to compute the explicit payoffs for C_1 and C_2 with respect to all the 4 combinations of pure strategies. For the parameter values listed above, the computed payoffs are as shown in Table 3.

Table 3. Payoffs of C_1 and C_2 for the listed parameter values above

C_1	C_2	
	Develop CBDC	Do not develop CBDC
Develop CBDC	$(-0.020990, 0.020990)$	$(0.031578, -0.031578)$
Do not develop CBDC	$(-0.192320, 0.192320)$	(0, 0)

It is interesting that Table 3 shows, if country C_1 with the current dominant market shares (90%) does not adopt the CBDC program while the other country C_2 with 10% market shares adopts it, then C_1 will lose around 19.2% of the total market shares, which are too significant to lose for C_1. This result indeed partially confirms that the CBDC economic model follows the Davidow law, that is the first country adopting the CBCD program will take a large amount of the market shares from those who do not adopt.

Next we input the payoff functions in Table 3 into the software Gambit [12] for computing the Nash equilibria, and the Nash equilibria is $(1, 0)$ for C_1 and $(1, 0)$ for C_2, which means that both C_1 and C_2 will choose to adopt CBDC with probability 1. This accords with the analytical result we derive in Sect. 3.

6 Concluding Remarks and Future Work

CBDC and sCBDC have received significant attention by major central banks as well as bigTech such as Facebook have embraced this new technology. These will not only provide technology breakthrough but also restructure financial markets and change national currency policies. This paper has analyzed whether a given country will commit to developing her own CBDC program given the benefits for developing the CBDC and potential damages due to inactivity for not developing the program. The main conclusion is that regardless if current technology status of the country, eventually the country will commit to developing the CBDC due to competitions with other countries.

The detailed game-theoretic model indicates that, in a simplified market of two countries of 90% and 10% market shares respectively, if the current market leader does not adopt CBDC, it risks 19.2% of the economic market share. This confirms the conjecture made by Bordo and Levin in 2017 that the CBDC has a serious impact on national economy system and global market leadership. Furthermore, if one country is not the current market leader, then it has all the incentives to become the first mover of CBDC as it can gain 19.2% market shares from the current leader. According to the New Lanchester Strategy [20], if an entity achieves 41% of the market shares, it may become the new market leader.

This paper assumes that benefits associated with CBDC is real, and damages is also real, and success rates improve over time. The first two assumptions are realistic as evidenced by the impact of Facebook's Libra on central banks and commercial banks in 2019. Furthermore, blockchain or related technologies have improved significantly during the last twelve months with new theories, new architecture, new frameworks, and new regulation technologies having emerged. For example, even Libra has improved her regulation mechanism to include embedded supervision. Thus, these three assumptions are indeed realistic.

As we mentioned in the introduction, this paper is our first attempt to theoretically study various competitions introduced by CBDC from the viewpoint of game theory. The impact of different values of the parameters in our detailed game-theoretic model on the expected payoffs of the players based on our further experiments will be reported in a forthcoming paper. These further experimental results will tell, for example, how the initial success rates influence the payoffs of the players in the game, which essentially reflects the importance of the underlying technological competence of the countries with respect to CBDC adoption. The simple game-theoretic model of two players can also be extended to a multiple-player game for more sophisticated analysis, which is part of our future work. We would like to mention that some computational difficulties in such extension to a multiple-player game lie in the rapidly growing numbers of possible combinations of first success time and the increasing hardness of computing Nash equilibria when the number of players is large [16].

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