Financial Innovation

RESEARCH

Open Access

An analysis of the acquisition of a monetary function by cryptocurrency using a multi-agent simulation model

Kyohei Shibano* and Gento Mogi

*Correspondence:
shibano@tmi.t.u-tokyo.ac.jp

Department of Technology Management for Innovation, School of Engineering, The University of Tokyo, Tokyo, Japan

Abstract

Many types of cryptocurrencies, which predominantly utilize blockchain technology, have emerged worldwide. Several issuers plan to circulate their original cryptocurrencies for monetary use. This study investigates whether issuers can stimulate cryptocurrencies to attain a monetary function. We use a multi-agent model, referred to as the Yasutomi model, which simulates the emergence of money. We analyze two scenarios that may result from the actions taken by the issuer. These scenarios focus on increases in the number of stores that accept cryptocurrency payments and situations whereby the cryptocurrency issuer designs the cryptocurrency to be attractive to people and conducts an airdrop. We find that a cryptocurrency can attain a monetary function in two cases. One such case occurs when 20% of all agents accept the cryptocurrency for payment and 50% of the agents are aware of this fact. The second case occurs when the issuer continuously airdrops a cryptocurrency to a specific person while maintaining the total volume of the cryptocurrency within a range that prevents it from losing its attractiveness.

Keywords: Cryptocurrency, Blockchain, Social acceptance of cryptocurrency, Emergence of currency

Introduction

The first cryptocurrency was Bitcoin, and it was invented as a payment method that did not involve a third party (Nakamoto 2008). An increasing number of stores are now accepting payments in the form of cryptocurrencies; thus, there are more opportunities for consumers to make payments using cryptocurrencies. Currently, 60% of Worldpay's merchants are interested in accepting cryptocurrency as a form of payment (Crypto.com 2022). It has been noted that Bitcoin is a close substitute for cash in the shadow economy (Marmora 2021).

The development of blockchain technology has enabled us to issue original cryptocurrencies, which are also called tokens. The ERC-20 token standard, which is based on Ethereum, is a prime example of this phenomenon, as it enables us to issue original cryptocurrencies by writing ERC-20-compatible codes and deploying them to the Ethereum

Springer Open

© The Author(s) 2022. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

main-net. Notably, the number of cryptocurrencies continues to grow, with more than 18,000 cryptocurrencies existing as of March 2022 (CoinMarketCap 2022).

In recent years, numerous fintech-related research works, especially cryptocurrencies, have been conducted (Xu et al. 2019; Kou et al. 2021; Li et al. 2022; García-Corral et al. 2022). Cryptocurrencies have been increasingly used as assets, contributing to growing interest among people. These interests go beyond individuals, as many hedge funds and asset managers incorporate cryptocurrency-related assets into their trading strategies. The number of research papers on cryptocurrency trading has been increasing over the years (Fang et al. 2022). Attaining a currency function would be a topic of interest for cryptocurrency holders and traders.

This study addresses the question of whether cryptocurrencies can function as "currency." In an academic context, currency, also known as money, is defined as a commonly accepted medium of exchange (Hazlett and Luther 2020). We investigate whether cryptocurrencies can function as currency under this definition, that is, whether cryptocurrencies can serve as a means of payment when purchasing various goods at many stores. Furthermore, as the number of original cryptocurrencies is increasing, it is important to determine what paths issuers can take to enable their cryptocurrencies to function as currency. Some cryptocurrencies are designed to define their own economic zone, which is referred to as a token economy. Establishing whether a cryptocurrency can have a monetary function within its scope of use in the token economy is essential for issuers.

Research concerning whether cryptocurrencies are or can become currencies in general has been conducted (Yermack 2015; Hazlett and Luther 2020; Kunal et al. 2021; Luther 2016; Folkinshteyn and Lennon 2016; Hazlett and Luther 2019) in particular argue that cryptocurrency is a currency in some parts of society (Hazlett and Luther 2020). However, another study has concluded that it is difficult for cryptocurrencies to be widely used as currency owing to network effects (Luther 2016). Furthermore, studies have investigated whether cryptocurrencies have sufficient ability to play the role of currency in situations wherein cryptocurrencies are used for payment in certain parts of society (Cachanosky 2019; Schilling and Uhlig 2019). Issuers want their cryptocurrencies to function as currency, but merely a few studies have addressed the question of how these cryptocurrencies can acquire a monetary function. This study aims to determine whether issuers can take steps to stimulate cryptocurrencies to acquire a monetary function. This research advances the work of Shibano and Mogi (2021).

Two major scenarios are discussed in this study. The first scenario investigates whether increasing the number of stores that accept cryptocurrency goods for payments and raising the awareness of people to such stores can enable cryptocurrencies to attain a monetary function. This situation is related to a sales effort on the part of the issuer to convince existing stores to accept payments in this form and public relations activities. The second scenario studies the conditions of airdrop cases whereby the issuer devises attractive services that make people want to acquire and save cryptocurrencies.

The conditions under which a cryptocurrency becomes a currency are analyzed using the Yasutomi model (Yasutomi 1995a, b, 2000, 2003). The Yasutomi model is a multi-agent simulation model for analyzing the emergence of money. The Yasutomi model assumes rational behavior on the part of the agent as an active entity and shows that money, which is a medium of exchange, naturally emerges among goods. The benefit of this model is that it allows computer simulations to be conducted to investigate the emergence of currency, and conditions can be assigned to agents and goods as part of the simulation. Once the code is written, complex manual calculations become unnecessary, and the code can be executed many times under different conditions with slight modifications. In other words, the advantage of this model is its ability to perform simulations of the consequences of issuers' actions repeatedly and under a variety of assumed conditions. We modify the original Yasutomi model by introducing a fiat money good that represents fiat currency and a cryptocurrency good. We can simulate cases in which the cryptocurrency good either becomes a second currency, which circulates in addition to the original fiat money good, or acquires a monetary function in place of the fiat money good.

The remainder of this paper is organized as follows: Section "Introduction" describes the purpose and significance of this study. Section "Literature review" introduces some related existing studies. Section "Simulation model" describes the model used in the study: the modified Yasutomi model. Section "Simulation analysis" presents and explains the results of the analysis of the two scenarios using the proposed model. Section "Discussion" presents a discussion of the issues raised in Section "Introduction" in terms of what can be learned from the results obtained in Section "Simulation analysis". Finally, Section "Conclusion" summarizes the conclusions of this study.

Literature review

Research pertaining to the emergence of currencies in general, and not merely cryptocurrencies, has an extensive history. Kiyotaki and Wright (1989) analyze which commodities would endogenously become media of exchange, using a search-theoretic model (Kiyotaki and Wright 1989, 1993). Marimon et al. (1990) further Kiyotaki and Wright's model by introducing classifier systems for agents to learn. Babutsidze and Iacopetta (2019) perform computer simulations using two models based on the Kiyotaki and Wright model, one in which the agent's behavior is fully rational and the other in which the agent's rationality is bounded, and confirm that currencies emerge in both cases. Kunigami et al. (2010) propose a doubly structural network model, consisting of the social networks and inner recognition networks of the agents, and analyze the emergence of currency using this model. The Yasutomi model (Yasutomi 1995a, b, 2000, 2003) used in this study is a multi-agent simulation that shows that in an economic environment where goods are exchanged between agents, one of such goods has a monetary function. The Yasutomi model itself is further researched by Górski et al. (2010) and Drożdż et al. (2013). The Yasutomi model has been applied to several studies. For instance, Tsujino and Hashimoto (2010) analyze the mechanism involved in the creation, stability, and collapse of key currencies in international financial markets using a variant of the Yasutomi model. Ito et al. (2012) analyze the mechanism by which a local currency is generated as a second currency using a model based on the Yasutomi model. Using the Yasutomi model, Takahashi et al. (2019) show that if the saving behavior of agents is restricted, then multiple currencies are generated and total consumption is increased.

Additionally, studies have investigated whether cryptocurrencies are money or can become money. On the one hand, Yermack (2015) argues that Bitcoin does not behave in a manner similar to a currency according to three aspects of the definition of money:

currency functions as a medium of exchange, a unit of account, and a store of value. On the other hand, Hazlett and Luther (2020) argue that economists define money as a commonly accepted medium of exchange, and from that perspective, Bitcoin can be considered as money in the context of a small domain. Herein, money is also defined as a commonly accepted medium of exchange. Luther (2016) investigates whether cryptocurrencies can become currencies using the model developed by Dowd and Greenaway (1993) in terms of network effects and switching costs. He concludes that cryptocurrencies are unlikely to be widely accepted, except under conditions of government support or financial instability (Luther 2016). Folkinshteyn and Lennon (2016) conduct a qualitative analysis of Bitcoin as a currency and blockchain as a financial technology using the technology acceptance model framework, discussing the risk and usefulness of these factors for developers and end users.

Some studies have conducted economic analyses by assuming that cryptocurrencies are used as money. Cachanosky (2019) uses the equation of exchange ($MV - Py$) and finds that Bitcoin lacks the ability to adjust its supply, and this fact inhibits Bitcoin from becoming a well-functioning currency. Schilling and Uhlig (2019) use a mathematical model to analyze the coexistence of Bitcoin and the dollar and discuss monetary policy implications.

However, little research has been conducted to investigate how cryptocurrencies can function as currency. The problem relating to people's acceptance of cryptocurrencies can be investigated via psychological approaches, and this is helpful with respect to the question of what interventions can be implemented to cause people to accept payments in the form of cryptocurrencies. Abraham et al. (2019) find that cultural and psychological factors influence Bitcoin penetration and acceptance at both national and individual levels. Kim (2021) analyzes Bitcoin usage via a model based on the theory of planned behavior and discusses suggestions for Bitcoin marketers.

Simulation model

The Yasutomi model is a barter exchange and multi-agent simulation model that shows that a currency emerges among homogeneous goods. Agents in the model have four characteristics: *utility*, *possession*, *demand*, and *view*. Agents produce and consume goods such that each agent produces only one type of good and exchanges it with others to obtain utility goods. These exchanges are conducted on a one-to-one basis, according to which two agents exchange goods that they demand from each other. When agents possess utility goods, they consume them. In particular, the concept of "demand" is important. This concept refers to an agent's behavior such that if many other agents demand a certain good, the agent also demands that good, which enables the models to simulate the smooth exchange of goods. If there were no demand, exchanges would only occur when agents possess utility goods for one another. Because each agent has only one utility good, it is unlikely that many such exchanges would occur. An agent's view expresses the agent's recognition of how much a target good is demanded by other agents. A good is considered to have acquired a monetary function if it continues to have a very high average value for all agents in terms of view relative to other goods. In this study, the state of a good such that it has a monetary function is defined as a commonly accepted medium of exchange. Goods with high levels of view are demanded by agents, and the demanded goods are exchanged for other goods. A good with a high average value can be said to be commonly accepted. More details pertaining to the Yasutomi model can be found in Yasutomi (1995a, 2000) and Ito et al. (2012).

The modified Yasutomi model used in this study includes four additions to the original Yasutomi model. First, we introduce a fiat money good. Unlike other goods, the fiat money good offers no utility; therefore, it is neither consumed nor produced. In the original Yasutomi model, currency has the same characteristics as other general goods: it offers utility and can be produced and consumed. The consumption and production of currency are generally interpreted as the disposal and production of paper money by the central bank (Yasutomi 2000), but the subjects of this study are microeconomic actors, such as individuals, households, and retailers. Therefore, the fiat money good is assumed to differ from general goods in that it is neither consumed nor produced but rather serves as a medium of exchange for which there is only demand. Second, we introduce the notion of *the degree of rarity*. When an agent chooses a new utility good, only goods of this type whose market quantity is less than or equal to the rarity threshold r can be selected. In other words, an agent randomly selects goods whose sum of possessions is less than or equal to r. If a good is available in excessive quantities, it is unlikely to be selected as a utility. Using water as an example, Turgot (1769) notes that people do not perceive the value of goods that are distributed in excessive quantities and thus do not gain utility from such goods (Turgot 1769; Kawamata 2010). We use a uniform r for all goods, not merely for cryptocurrency goods. The third addition is the introduction of a cryptocurrency good that is not subject to selection as a utility, same as the fiat money good. However, depending on how the service is designed by the issuer, the possession of cryptocurrencies may provide some services or satisfy an agent's desire to own it. In such cases, the cryptocurrency should be selected as a utility. Fourth, the modified model includes a cryptocurrency agent that produces a cryptocurrency good. Such an agent can be a smart contract, an issuer, or product operators engaged in the design, distribution, and circulation of cryptocurrencies. If the cryptocurrency good is selected as a utility and consumed, the total amount of this good would decrease. Therefore, to prevent the cryptocurrency good from disappearing from the market, a cryptocurrency agent that can produce cryptocurrency goods is introduced. In other words, the cryptocurrency agent is only introduced when the cryptocurrency good can be selected as a utility. Goods that are neither fiat money nor cryptocurrency goods are general goods, while agents that are not cryptocurrency agents are general agents.

Modified Yasutomi model

Let A be a set of all agents and G be a set of all goods. Assume that A and G contain N general agents and N types of goods, respectively. Each agent is denoted by $i \in A$ and each good is denoted by $\phi \in G$. $\phi = 0$ is a fiat money good, $\phi = N + 1$ is a cryptocurrency good, and $i = N + 1$ is a cryptocurrency agent. For example, if a fiat money good is introduced and there are neither cryptocurrency goods nor cryptocurrency agents, then $A = \{1, 2, \ldots, N\}$ and $G = \{0, 1, 2, \ldots, N\}$, where $\#(A) = N$ and $\#(G) = N + 1$. General agents are assumed to be homogeneous and to exhibit no differences. The values of general goods are also assumed to be homogeneous.

Constants

First, the constants used in the model are explained. The constants are determined at the beginning and do not change during the simulation. N is the number of general agents as well as the number of general goods. T represents the total number of turns during a simulation, and $\tau \leq T$ represents the number of turns before the introduction of the cryptocurrency good. For example, if $T = 6000$ and $\tau = 3000$, then a simulation is performed without the cryptocurrency good until the 3000th turn. From turns 3001–6000, the simulation includes the cryptocurrency good. After turn τ, a cryptocurrency agent may also be introduced, in addition to the cryptocurrency good. The fiat money good is assumed to have a monetary function from the beginning of the simulation; therefore, a large initial value for the view of the fiat money good is set for all agents, and it is denoted by $V_{currency}$. The threshold for view is denoted by m, and if an agent's view of a good exceeds m, the agent demands the good, even if it offers no utility. This arrangement expresses the behavior of agents who demand goods for the sake of exchange and not merely for utility. To add noise (Yasutomi 2003), utility is randomly reset with a degree of probability ϵ even if it is not consumed. r is the rarity threshold such that if the total amount of a good in the market (the sum of possessions) is greater than r, the good is never selected as a utility by all agents. These constants must be appropriately set to execute the simulation correctly. Unless otherwise specified, the constants are set to the following values:

$$N = 50,\ T = 6000,\ \tau = 3000,\ V_{currency} = 0.5,\ m = 0.078,\ \epsilon = 0.001.$$

The values of N and m used in this study are based on Yasutomi (2000). The values of T and τ are described in Section "Simulation analysis". All values, including $V_{currency}$ and ϵ, are verified to execute the simulation in Subsection "Verification of the basic case". r is used in Subsection "Cryptocurrency Airdrop", and the value is properly set for each scenario.

Subsequently, the four characteristics of agent $i \in A$ are described.

Utility

$u_{i,\phi}$ is the utility of good ϕ for agent i, indicating that i wants to consume ϕ. $u_{i,\phi}$ satisfies the following conditions:

$$u_{i,\phi} = 0 \ or\ 1,\ u_{i,i} = 0,\ \sum_{\phi} u_{i,\phi} = 1,\ u_{i,0} = 0 \text{ for } i \in A,\ \phi \in G.$$

If $u_{i,\phi} = 1$, agent i desires good ϕ. Conversely, $u_{i,\phi} = 0$ implies that i does not desire ϕ. For any i, $u_{i,i} = 0$ indicates that the good produced by agent i is not desired by i. $\sum_{\phi} u_{i,\phi} = 1$ indicates that an agent desires only one good at a time. Because $u_{i,0} = 0$, the fiat money good $\phi = 0$ is not chosen as a utility. Agents can derive utility from the cryptocurrency good $\phi = N + 1$ if a cryptocurrency agent exists such that $i = N + 1$, but not otherwise. The utility good for each agent is randomly selected from among the goods, except for its production, indicating $\phi \in G \setminus \{i\}$.

If an agent possesses its utility good, the entire quantity of the good is consumed. "Consumption" indicates that the good is withdrawn from the market. For example, such a situation is equivalent to an agent taking the action of eating food. Because the fiat money good cannot be selected as a utility, it is not consumed. With respect to the cryptocurrency good, it is possible to determine whether this good can be selected as a utility at the onset of a simulation.

Possession

$p_{i,\phi}$ denotes the amount of a good ϕ owned by agent i. $p_{i,\phi}$ satisfies the following condition:

$$p_{i,\phi} = 0 \text{ or a natural number for } i \in A,\ \phi \in G.$$

At the beginning of a simulation, each agent owns its production and the fiat money good, so $p_{i,\phi} = 1$, where $\phi = i, 0$, and $p_{i,\phi} = 0$ for the other goods, $\phi \neq i, 0$.

Demand

Let $d_{i,\phi}$ be a demand for the good ϕ of agent i. The agent demands its utility good and goods that other agents demand. $d_{i,\phi}$ satisfies the following condition:

$$d_{i,\phi} = 0 \text{ or a natural number for } i \in A,\ \phi \in G.$$

While a utility good is obtained for consumption, the purpose for which a demand good is obtained is either consumption or for use as a medium of exchange. Agents recognize the value of such goods and offer to exchange them.

At the beginning of the simulation, $d_{i,\phi}$ is 0 for non-fiat goods $\phi \neq 0$ and 1 for the fiat money good $\phi = 0$.

View

$v_{i,\phi}$ represents agent i's view of the demand for good ϕ by other agents. $v_{i,\phi}$ satisfies the following condition:

$$0 \leq v_{i,\phi} \leq 1,\ \sum_{\phi} v_{i,\phi} = 1.$$

At the beginning of the simulation, $v_{i,\phi}$ is $\frac{1-V_{currency}}{\#\{G\}-1}$ for non-fiat goods $\phi \neq 0$, and $v_{i,0}$ is $V_{currency}$ for the fiat money good $\phi = 0$. In addition, for threshold m, where $v_{i,\phi} > m$, agent i demands ϕ because i perceives that someone else in the future will receive ϕ even if it does not offer any utility.

Procedures

Following the initialization process, Steps 1 through 6 are considered to constitute one trade t, and #{A} of t is considered to constitute one turn. Figure 1 shows the flowchart for the procedure.

All agents are selected once each turn. The initialization process is implemented only once at the beginning of a simulation. Cryptocurrency goods and cryptocurrency agents are introduced on turn $\tau + 1$. Accordingly, economic activity continues with only fiat money until turn τ.

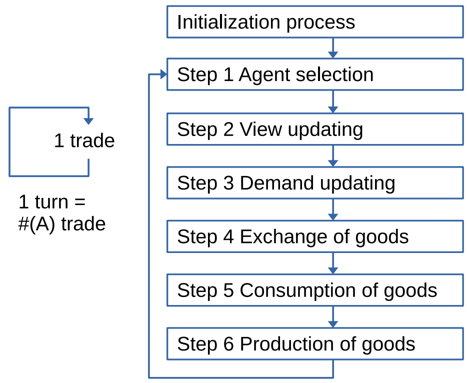

Fig. 1 Flowchart of procedure

Initialization process

Let $V_{currency}$ be the initial value of the view for the fiat money good $\phi = 0$. For all agents except cryptocurrency agent $i \in A \setminus \{N+1\}$, the utility good is determined using the method outlined in Subsection "Choice of utility".

For non-fiat money goods, the possession and demand values are set to zero, and the view is set to $\frac{1-V_{currency}}{\#(G)-1}$. The fiat money good $\phi = 0$ is assumed to be possessed and demanded by everyone; therefore, the relevant values are set to 1. The initial value of the view is $V_{currency}$. In the equations, for each $i \in A$, let $\phi = k$ be the randomly selected utility of agent i. Thus,

$$
\begin{aligned}
u_{i,\phi} &= 0 \ \text{ for } \phi \in G \setminus \{k\}, \\
u_{i,k} &= 1, \\
p_{i,\phi} &= d_{i,\phi} = 0 \ \text{ for } \phi \in G \setminus \{0\}, \\
p_{i,0} &= d_{i,0} = 1, \\
v_{i,\phi} &= \frac{1 - V_{currency}}{\#(G) - 1} \ \text{ for } \phi \in G \setminus \{0\}, \\
v_{i,0} &= V_{currency}.
\end{aligned}
$$

Choice of utility

For all agents $i \in A$, let $G_u(i) = G \setminus \{0, i\}$ be the set of all goods, except for the fiat money good ($\phi = 0$) and the production of the agent ($\phi = i$). Utility is set to 1 for a randomly selected $\phi \in G_u(i)$ and 0 for all other goods. For cryptocurrency goods, utility is always 0 if there are no cryptocurrency agents; therefore, $G_u(i) = G \setminus \{0, i, N+1\}$. Otherwise, $N+1$ is included in $G_u(i)$. If the rarity threshold r exists, good ϕ, whose total amount exceeds r, or $\sum_{i \in A} p_{i,\phi} > r$ is not selected as a utility. Such goods are removed from $G_u(i)$.

Step 1: agent selection

An agent pair $i, j \in A$ is chosen to be involved in the exchange for each trade. Agent i is randomly selected from the group of agents that has not been selected in this turn.

An agent possessing the greatest amount of a good that offers utility to i is selected as trade partner j. If multiple agents have the same amount of this good, one of these agents is randomly selected.

Step 2: view updating

Agent i increases its view by $1/\#(G)$ for the good it demands, that is,

$$\text{if } d_{i,\phi} > 0 \text{ then } v_{i,\phi} = v_{i,\phi} + \frac{1}{\#(G)}, \text{ for } \phi \in G.$$

In addition, agents i and j share their views. Accordingly, i updates the view of all goods to the average value of both agents, that is,

$$v_{i,\phi} = \frac{v_{i,\phi} + v_{j,\phi}}{2}, \text{ for } \phi \in G.$$

Thus, $v_{i,\phi}$ is normalized such that $\sum_\phi v_{i,\phi} = 1$. Let $S_v(i)$ denote $\sum_\phi v_{i,\phi}$; then,

$$v_{i,\phi} = \frac{v_{i,\phi}}{S_v(i)} \text{ for } \phi \in G.$$

The same process is applied to agent j.

Step 3: demand updating

For goods possessed by the opposing agent j, if these goods offer utility to agent i or have a view greater than or equal to constant m, then i demands the possession of all such goods from j. Furthermore, these agents do not demand any other goods; hence, their demand is set to 0. To summarize,

$$\text{if } p_{j,\phi} > 0 \text{ and } (u_{i,\phi} = 1 \text{ or } v_{i,\phi} \geq m) \text{ then } d_{i,\phi} = p_{j,\phi}, \text{ otherwise } d_{i,\phi} = 0, \text{ for } \phi \in G.$$

The same process is applied to agent j.

Step 4: exchange of goods

In this step, goods are exchanged based on the demand. For the total amount of goods demanded by agents i and j, or $S_d(i) = \sum_\phi d_{i,\phi}$ and $S_d(j) = \sum_\phi d_{j,\phi}$,

(1) if $S_d(i) = 0$ or $S_d(j) = 0$, then the agents do nothing.
(2) If $S_d(i) = S_d(j)$, then the agents exchange the difference of their demands for each good. Therefore,

$$p_{i,\phi} = p_{i,\phi} + d_{i,\phi} - d_{j,\phi} \text{ for } \phi \in G$$
$$p_{j,\phi} = p_{j,\phi} + d_{j,\phi} - d_{i\phi} \text{ for } \phi \in G.$$

Because all goods demanded are available to each agent at this time, the demands are set to 0 for all ϕ of agents i, j. Thus,

$$d_{i,\phi} = d_{j,\phi} = 0 \text{ for all } \phi \in G.$$

(3) If $S_d(i) > S_d(j)$, then agent i takes one unit of a good that j possesses in the smallest amount (> 0) and reduces its demand by one. If there are multiple such goods, one good is randomly selected. This situation can be implemented as follows: let k be the smallest amount of a good possessed by j whose demand from i is not 0; then,

$$\begin{aligned} p_{i,k} &= p_{i,k} + 1 \\ d_{i,k} &= d_{i,k} - 1 \\ p_{j,k} &= p_{j,k} - 1, \end{aligned}$$
where $d_{i,k} > 0$.

This process is repeated $S_d(j)$ times. Then, the agents exchange their goods to satisfy the demand for j as follows:

$$\begin{aligned} p_{i,\phi} &= p_{i,\phi} - d_{j,\phi}, \\ p_{j,\phi} &= p_{j,\phi} + d_{j,\phi}, \\ d_{j,\phi} &= 0 \end{aligned}$$
for $\phi \in G$.

(4) If $S_d(i) < S_d(j)$, then process (3) is executed by replacing i, j.

Step 5: consumption of goods

Agent i consumes all the utility goods that it owns. Therefore,

$$\text{if } u_{i,\phi} = 1 \text{ and } p_{i,\phi} > 0, \text{ then } p_{i,\phi} = 0 \text{ for } \phi \in G.$$

After consumption, the utility good is randomly reset. If agent i does not consume the utility good, then the utility is randomly reset with a certain low degree of probability ϵ. The utility good is selected using the method outlined in Subsection "Choice of utility".

The same process is applied to agent j.

Step 6: production of goods

If agent i owns no units of its production i, then agent i produces and possesses one unit of good i.

$$\text{If } p_{i,i} = 0 \text{ then } p_{i,i} = 1.$$

The same process is applied to agent j.

Verification of the basic case

As a basic case, a simulation in which only the fiat money good is introduced and neither the cryptocurrency good nor cryptocurrency agents are introduced is performed. No rarity threshold is introduced. In this case, the fiat money good is introduced as a factor that differs from general goods, which is a different assumption from that of the original Yasutomi model. Hence, we first examine whether the fiat money good behaves as a currency, assuming that $\tau = 3000$.

The Yasutomi model is a simulation model that features stochastic events, and the results may differ, even if the model is implemented under the same conditions. Therefore, it is necessary to draw a conclusion statistically after performing the simulation multiple times. Thirty trials are conducted to determine whether the fiat money good functions as a currency.

The results presented in Fig. 2 illustrate the time series change in the average value of view, which is one of 30 cases. The fiat money good 0 (the blue line) continues to have a single high value from the beginning of the simulation until the 3000th turn, indicating that it functions as a currency. In all the 30 cases, it is confirmed that the fiat money good functions as a currency by the 3000th turn. Thus, the fiat money good functions as a currency in the basic model with a 100% probability.

Simulation analysis

In this section, by using the modified Yasutomi model, we analyze whether the cryptocurrency good can acquire a monetary function by considering two scenarios that may result from actions taken by the issuer. First, the number of retail stores that accept the cryptocurrency good as a form of payment is increased to investigate whether the cryptocurrency gains a monetary function as this number increases. Second, we examine whether an airdrop of the cryptocurrency good leads to the cryptocurrency acquiring a monetary function under the condition that the attractive services devised by the issuer can cause many people to desire to acquire and save the cryptocurrency.

To identify whether the cryptocurrency good has a monetary function, we observe whether the average value of its view continues to be extremely large relative to those of other goods. Although it is possible to verify the results graphically, they are validated based on numerical data because we implement numerous simulations. We perform several simulation trials and establish that, in most cases, when a good does not acquire a monetary function, its view is less than 0.01. A good that acquires a monetary function exhibits a much higher view. If a good's average view is greater than 0.05, we

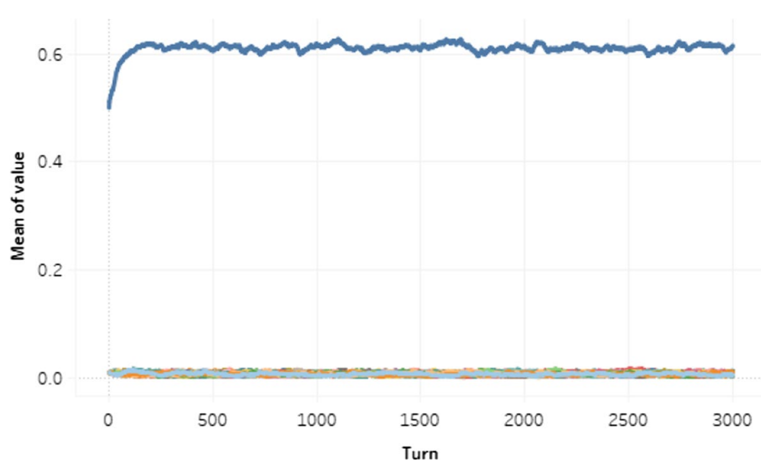

Fig. 2 The basic case: Time series change of the mean of view. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. The fiat money good maintains a high value from beginning to end, indicating that the monetary function is preserved

define the good as having a "much higher" view. The period from 3001 to 6000 turns is divided into 6 periods consisting of 500 turns each. If the average view in a period is greater than or equal to 0.05, the good acquires a monetary function within that period. If a good acquires a monetary function in one period and retains this function in all subsequent periods, such a good is assumed to have acquired a monetary function. In addition, if both the cryptocurrency good and the fiat money good acquire a monetary function, then the cryptocurrency currency good is recognized as a second currency. On the contrary, if the cryptocurrency good acquires a monetary function, while the monetary function of the fiat money good is lost, the cryptocurrency good becomes the only currency. The simulation results are summarized in Table 3. In all the simulations conducted in this study, it is noted that no goods other than the cryptocurrency good and the fiat money good acquired a monetary function.

In this study, $\tau = 3000$ is set, and the cryptocurrency good is introduced at the 3001st turn. The simulation is then advanced until $T = 6000$ turns. The values of T and τ are significant. If the number of turns is too low, additional iterations of the simulation can result in the emergence of a currency. Conversely, if the number of turns is too high, the simulations are time-consuming and thereby inefficient. We maintain that 3000 turns are a sufficient period for the emergence of currency in the original Yasutomi model, which includes neither cryptocurrency goods nor fiat money goods. In 30 trials of the original Yasutomi model conducted by 3000 turns, a currency emerged in all 30 trials. Therefore, $\tau = 3000$ and $T = 6000$ are the chosen values because these parameters allow for a sufficient period of 3000 turns following the introduction of the cryptocurrency good.

Standard case

First, we consider four standard cases in which the cryptocurrency good is introduced without an increase in the number of stores accepting payments in the form of cryptocurrency or the performance of an airdrop. We show that the cryptocurrency good does not have a monetary function in all cases. In Standard Case-1 (SC-1), at turn $\tau + 1 = 3001$, one unit each of the cryptocurrency good $\phi = N + 1 = 51$ is distributed to all $N = 50$ agents for a total of 50 units. In SC-2, in addition to $N = 50$ agents, a cryptocurrency agent is introduced that produces a cryptocurrency good. Furthermore, we consider SC-3 and SC-4, in which the rarity threshold r is set to 25 and 2, respectively. Simulations are implemented until $\tau = 3000$ turns for each r, the cryptocurrency agent is subsequently introduced without changing r, and the simulations continue until $T = 6000$ turns. In SC-2, SC-3, and SC-4, the cryptocurrency good is not distributed but is rather produced by the cryptocurrency agent in the same way as other goods. The cryptocurrency good can be selected as a utility and circulated in the market. For each case, 30 simulations are performed, and we find that the cryptocurrency good never becomes a currency, while the fiat money good continues to be a currency. The results of SC-1 to SC-4 are shown in Table 3.

Increasing the number of stores accepting payment in the form of cryptocurrency

In this section, we examine the percentage of retail stores in an economy that must accept cryptocurrency payments and the percentage of people who must be aware that they can use cryptocurrencies in stores for the cryptocurrency good to acquire a monetary function. For example, if approximately half of the retail stores in a city accept a form of cryptocurrency payment, other stores in the city tend to accept such a form of payment from customers because it can be used in approximately half of the stores in their living area. The issuer of the cryptocurrency can increase the number of these stores by convincing them to accept payment in this form, as well as increase the number of people who are aware of this fact via public relations activities.

We represent this situation via the modified Yasutomi model. However, whether stores can be expressed as agents in the model is debatable. The original Yasutomi model views agents as participants in economic activities, such that each agent produces, desires, and exchanges its own goods. We argue that the four elements included in the model—utility, possession, demand, and view—are appropriate for representing the characteristics of stores. Possession is interpreted as the goods owned and sold in a store. Demand indicates the goods that stores accept in exchange for selling the goods in their possession. View is the same as in the case of individuals, that is, it measures the store's recognition to exchange one good for others. Utility can be considered as a good that is consumed by the stores themselves. Some stores require air conditioners, cash registers, and office automation equipment. Acquiring such goods in exchanges with other agents would be equivalent to purchases. Stores can engage in exchanges with individual customers, wholesalers, or other stores, all of which are expressed by agents. Thus, we argue that it is reasonable to consider retail stores as agents in the Yasutomi model.

In this scenario, stores that accept payments in the form of cryptocurrency are modeled as having a demand for the cryptocurrency good. Such stores are allowed to receive the cryptocurrency good from other agents in exchange for the goods they possess. The demand for cryptocurrency goods in stores that accept them is set to 1.

The issuer's publicity campaigns to inform the public that some stores accept payment in the form of cryptocurrency correspond to increases in view for agents other than the stores that accept payment in the form of cryptocurrency. This occurrence increases such agents' perception that the cryptocurrency good can be accepted instead of other goods in the context of exchanges with other agents. The view increment is set to $1/\#(G)$ per store that accepts payments in the form of cryptocurrency, and the view is then normalized.

The demand and view of each agent are updated at turn $\tau + 1 = 3001$. As in the case of the fiat money good, we also assume that the cryptocurrency good is not selected as a utility. In this case, the cryptocurrency good is not consumed, so there is no need to produce it, and there is no need to introduce the cryptocurrency agent.

For the extreme case $1 - A$, we change the demand and view of the cryptocurrency good $\phi = N + 1$ for all agents of A. The demand is set to 1, and the view is increased by $\#(A)/\#(G)$ and then normalized. In addition, one unit of the cryptocurrency good is distributed to all agents so that the cryptocurrency circulates in the market to the same degree as the fiat money good. In this case, we perform 30 simulations with $T = 6000$ under the same conditions to check for changes in the average view of each good. One of these simulations is depicted in Fig. 3.

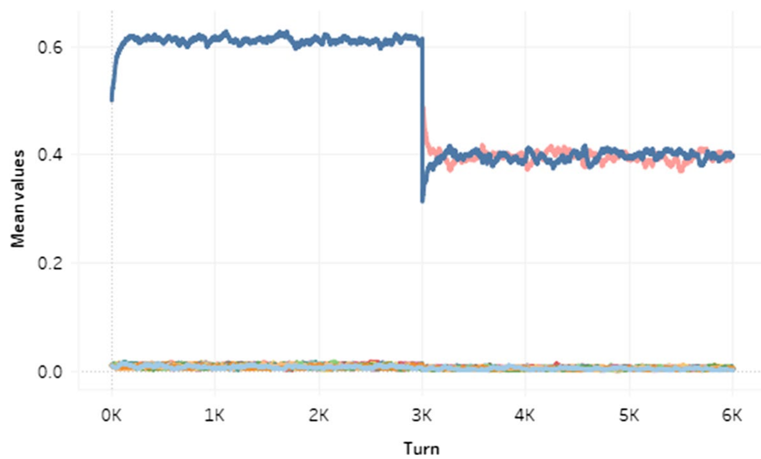

Fig. 3 Introduction of the cryptocurrency payments, case 1-A: Time series change of the mean of view. Case 1-A is a case in which cryptocurrency is not selected as a utility (no cryptocurrency agent), 1 unit is distributed to 50 people, all 50 people demand the cryptocurrency, and the view of 50 people is increased. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. After turn 3001 of the cryptocurrency good introduction, both the fiat money good and the cryptocurrency good acquire a monetary function

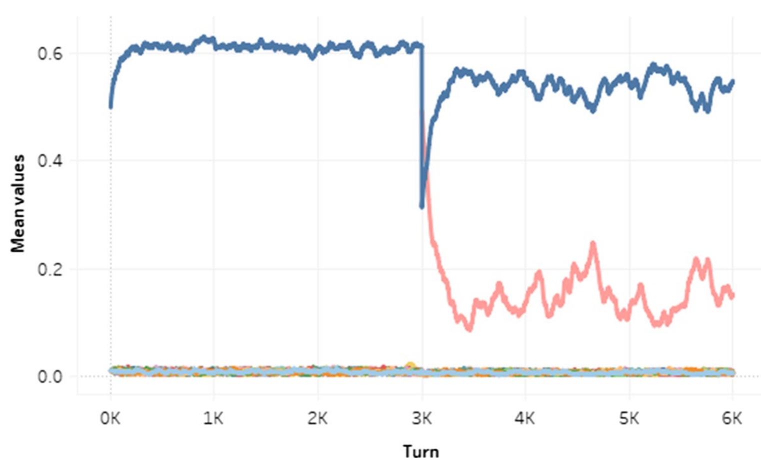

Fig. 4 Introduction of the cryptocurrency payments, case 1-A-2: Time series change of the mean of view. Case 1-A-2 is a case in which cryptocurrency can be selected as a utility (with the cryptocurrency agent), 1 unit is distributed to 50 people, all 50 people demand the cryptocurrency, and the view of 50 people is increased. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. After turn 3001 of the cryptocurrency good introduction, the cryptocurrency good acquires a certain monetary function, which remains approximately 0.15, but this is far removed from that of the fiat money good

The mean view of cryptocurrency good rises to approximately 0.50 on the 3001st turn, and it remains approximately 0.40. In this case, the cryptocurrency good and the fiat money good have approximately the same mean view, indicating that the cryptocurrency good becomes a second currency. The same results are obtained in the other 29 trials.

Next, we study the results of case $1-A-2$, according to which the cryptocurrency good can be selected as a utility, with the other conditions remaining the same as in Case $1-A$. In this case, a cryptocurrency agent is introduced in the 3001st turn to produce

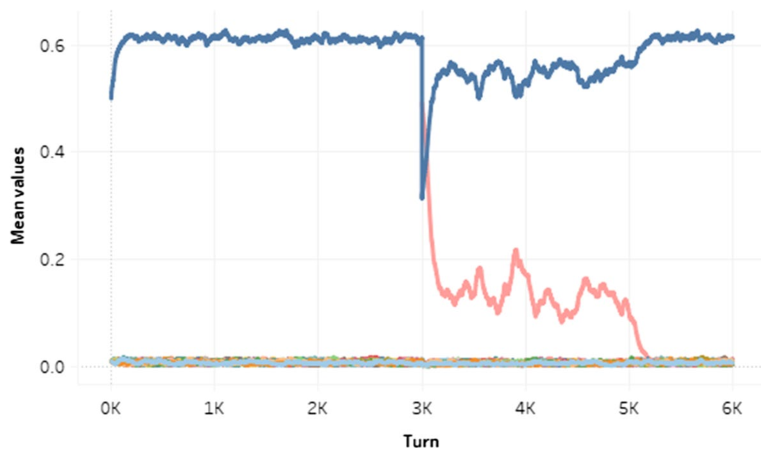

Fig. 5 Introduction of the cryptocurrency payments, case 1-A-2: Time series change of the mean of view. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. Although the conditions are the same as those used in Fig. 4, the monetary function may ultimately be lost

the cryptocurrency good. Figures 4 and 5 show the average view of each good in two of the 30 simulation trials.

The average view of the cryptocurrency good, at approximately 0.15, is larger than that of the other general goods, but it is not as high as that of the fiat money good (approximately 0.55). In some trials, such as that illustrated in Fig. 5, the view value of the cryptocurrency good eventually falls to the same level as those of other general goods, and so, the cryptocurrency does not qualify to become a currency. In 19 out of 30 trials, the cryptocurrency good becomes a second currency, with an average view of 0.15, while the average view of the fiat money good is 0.55.

If the cryptocurrency good can be selected as a utility, its monetary function is weakened, and there are cases in which this good does not become a currency. However, if the cryptocurrency good is not selected as a utility, it becomes a currency in 100% of cases. Furthermore, we assume that the cryptocurrency good is not selected as a utility good. We start with scenarios in which 5 or 10 of the 50 agents' demands are increased, as they represent retail stores of 10–20% of the agents that accept payments in the form of cryptocurrency. Next, we assume that a view of 25 or 40 agents, representing 50% and 80% of the total, respectively, is increased. It is reasonable to assume that as the number of stores accepting the cryptocurrency good increases, the value of view also increases; thus, we increase the number of $1/\#(G)$ multiplied by the number of stores accepting the cryptocurrency. Simulations are performed for the four cases listed in Table 1. For each case, the table lists the number of agents (among the 50) whose demand is set to 1, the number of agents (among those remaining) whose view is increased, and the amount by which view is increased. For example, the case of 1-B means, "For 5 out of 50 agents, demand is set as 1. For 25 of the remaining agents, the view is increased by 5/52 and then normalized." In all cases, normalization is performed after increasing the number of views.

We conduct 30 simulation trials for each of these 4 cases and find that none of the trials in 1-B results in the cryptocurrency good becoming a currency. In the case of 1-C,

Table 1 Introduction of the cryptocurrency payment cases (the cryptocurrency good is not selected as a utility)

Case	Number of agents (among 50) whose demand is set to 1	Number of agents (among those remaining) whose view is increased	Increased amount of view	Number of trials when both the cryptocurrency and the fiat money become a currency	Number of trials in which only the cryptocurrency becomes a currency
1-B	5	25	5/52	0	0
1-C	5	40	5/52	15	0
1-D	10	25	10/52	30	0
1-E	10	40	10/52	30	0

These are the cases for the introduction of the cryptocurrency payments scenario. 30 simulation trials are conducted for each case. The second column represents the number of stores that accept payment in the form of cryptocurrency. The third column represents the number of people who know that some stores accept payment in the form of cryptocurrency. The forth column represents the number of stores accepting cryptocurrency known to each people

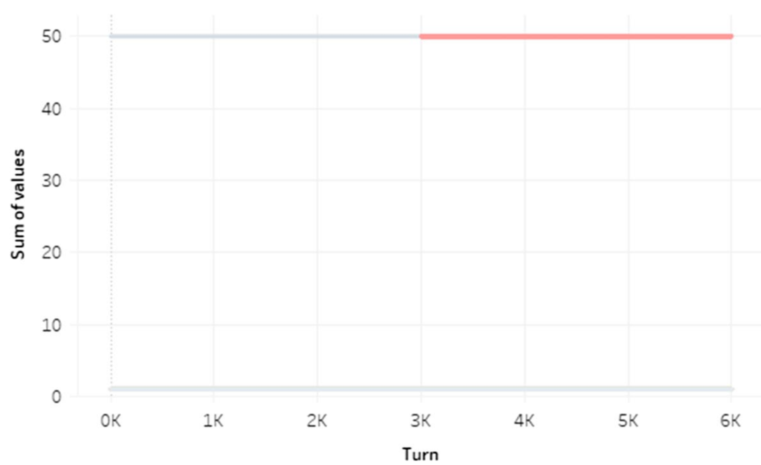

Fig. 6 Introduction of the cryptocurrency payments, case 1-A: Time series change of the sum of possession. The red line is the cryptocurrency good and other colors are remaining goods. After turn 3001 of the cryptocurrency good introduction, the total number remains constant at 50 throughout all turns

the cryptocurrency good becomes a second currency in 15 out of 30 trials. The cryptocurrency good becomes a second currency in all 30 trials for Cases 1-D and 1-E.

In this section, we analyze whether cryptocurrencies can acquire a monetary function by increasing the number of stores that accept cryptocurrency payments. In all cases where the cryptocurrency good is introduced, the monetary function is not acquired in place of the original fiat currency but rather functions as a second currency in addition to the fiat currency. Even if we increase the number of stores that accept payments in the form of cryptocurrency to 10% of the total and public awareness of these stores to 80% of the people, there is only a 50% chance that the cryptocurrency will become a currency. Moreover, if we increase the number of stores accepting payments in the form of cryptocurrency to 20% of the total, the cryptocurrency becomes a currency if 50% of people are aware of this fact. For individuals

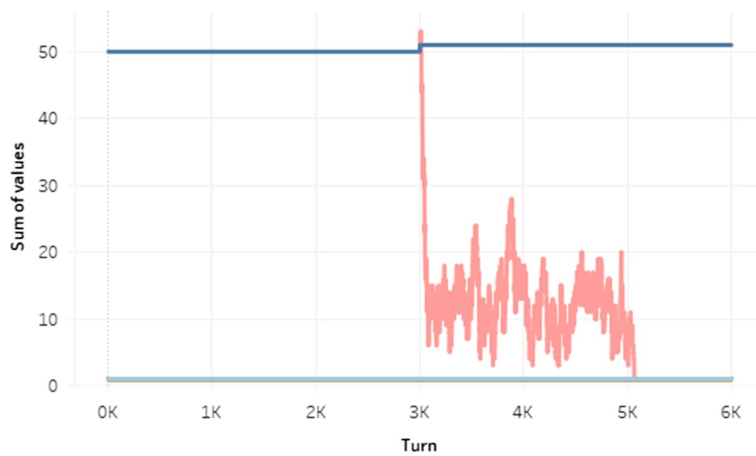

Fig. 7 Introduction of the cryptocurrency payments, case 1-A-2: Time series change of the sum of possession. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. This case represents the total amount of goods for the same simulation as that of Fig. 5. After the introduction of cryptocurrency good, the total amount decreases drastically, remains below 25, and then disappears. Compared with Fig. 5, the time of disappearance coincides with the time when the view is decreased

aiming to view cryptocurrency as a currency, this section suggests introducing the cryptocurrency to 20% of all agents and to increase awareness among 50% of all the agents. Note that the cryptocurrency should not be selected as a utility, that is, the consumers should not want it per se as they do fiat money.

In this scenario, the monetary function is easier to acquire if the cryptocurrency is not selected as a utility. Figure 6, which outlines the transition of possession, shows that the sum of possession of 1-A is constant, while in Fig. 7, that of 1-A-2 plummets after the airdrop distribution and remains below 25, that is, approximately half of the total.

As the simulation progresses, despite the even distribution of the cryptocurrency good at the 3001st turn, the amount of this good that is possessed by each agent varies thereafter, such that some agents can possess multiple units of the cryptocurrency good. Then, the agent who gains utility from the cryptocurrency good chooses an agent who possesses a large amount of the cryptocurrency good as a partner. The utility-seeking agent demands all the units of the cryptocurrency good owned by the partner agent in Step 3. After the exchange in Step 4, the utility-seeking agent obtains several units of the cryptocurrency good and consumes them, resulting in the disappearance of the consumed units from the market. If demand remains after this exchange, the view of the cryptocurrency good in Step 2 of the following t increases. The cryptocurrency agent produces at most one unit of the good during each trade t. Because the amount of the cryptocurrency good that is consumed is much higher than the amount that is produced in each trade, the total amount of the cryptocurrency reduces over time. As the total quantity of the cryptocurrency good decreases, the number of agents with multiple units of the cryptocurrency good decreases.

The quantity possessed by the partner agent of an agent who selects cryptocurrency as a utility also decreases. This change results in a small increase in demand, and no demand remains at the time of the exchange. This situation does not lead to an increase in view in Step 2 of the following *t*. However, as approximately 25 units remain, the average level of view is lower than that found in 1-A but higher than in cases where cryptocurrency goods are not distributed or prior to the 3000th turn.

Cryptocurrency airdrop

In this scenario, we investigate whether a monetary function can be acquired by distributing the cryptocurrency. To ensure the liquidity of the cryptocurrency in the early stages of its issuance, an airdrop method is often used to distribute the cryptocurrency free of charge to a limited number of users. The conditions for distribution, including the amount of the cryptocurrency, the number of receivers, whether the target agent should be randomly set or fixed, and whether the cryptocurrency should be distributed periodically at each turn or only at the beginning of each issue, are considered. We also consider whether the cryptocurrency should be selected as a utility.

In the modified Yasutomi model, we represent an airdrop by forcibly increasing the possession of the cryptocurrency good among some agents. This distribution process is performed just prior to Step 1 at the start of trade *t* during the airdropping turn.

Simulations are performed for the five cases listed in Table 2. Here, it is assumed that the cryptocurrency good can be selected as a utility; therefore, the simulations are conducted with the inclusion of the cryptocurrency agent. For each case, the table indicates whether an airdrop is conducted at every turn or only in the first turn, the number of cryptocurrency units distributed per airdrop, the number of agents receiving distribution at each time, and whether the target agents are fixed or randomly selected each time in cases where the distribution is made at every turn. For example, the case of 2-A means, "Distribute one unit of the cryptocurrency good to one fixed person each turn."

The cases study two major process variations. First, Cases 2-A and 2-B assume the distribution of each turn. While 2-A assumes a distribution to the same person at each turn, 2-B assumes a distribution to randomly selected persons at each turn. In both cases, only one unit of the cryptocurrency good is distributed per turn, and there

Table 2 Airdrop cases with parameters varied assuming the cryptocurrency good can be selected as a utility

Case	Airdrop conducted at every turn or only in the first turn	Number of units of cryptocurrency distributed per airdrop	Number of agents receiving distribution at each time	Whether target agents are fixed or randomly selected	Number of trials when both the cryptocurrency and the fiat money become a currency	Number of trials in which only the cryptocurrency becomes a currency
2-A	Every turn	1	1	Fixed	0	30
2-B	Every turn	1	1	Random	0	0
2-C	First turn only	1000	1	–	3	0
2-D	First turn only	1000	25	–	5	0
2-E	First turn only	1000	50	–	14	0

These are the cases for the airdrop scenario. 30 simulation trials are conducted for each case. Here, it is assumed that the cryptocurrency good can be selected as a utility

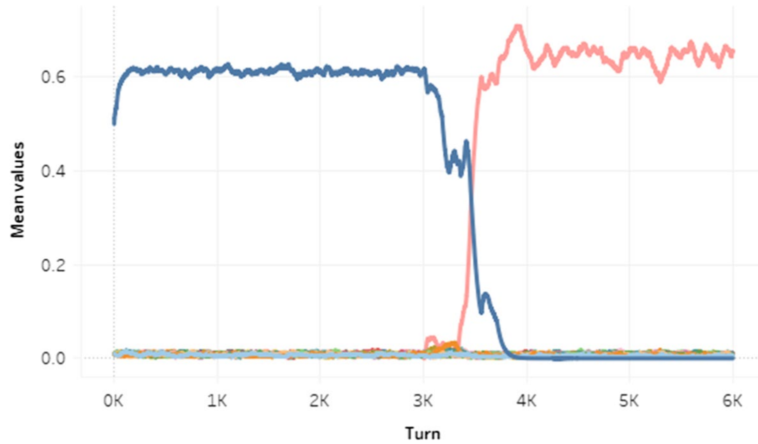

Fig. 8 Airdrop, case 2-A: Time series of the mean of view. Case 2-A is a case in which cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1 unit is distributed to one specific person each turn. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. After turn 3001 of cryptocurrency good introduction, the view increases rapidly and the cryptocurrency acquires a monetary function. On the other hand, the view of the fiat money good decreases in response and loses its function as money

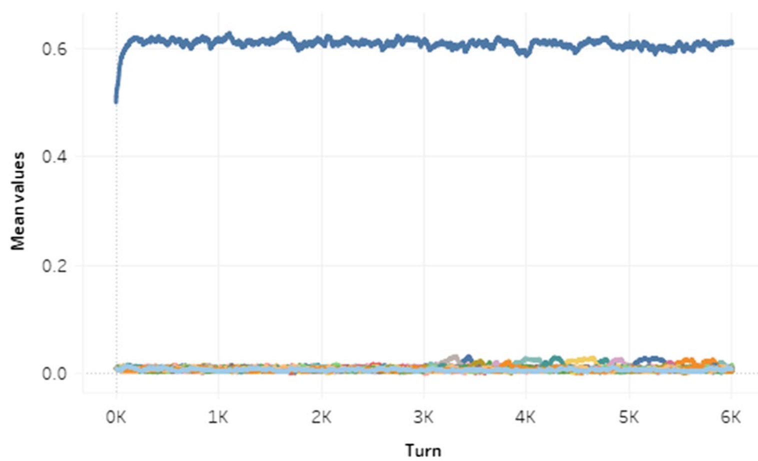

Fig. 9 Airdrop, case 2-B: Time series of the mean of view. Case 2-B is a case in which cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1 unit is distributed to a random person each turn. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. In this case, the monetary function of the fiat money good remains unchanged after turn 3001 of the cryptocurrency good introduction

is no upper limit for the total distribution. Second, Cases 2-C, 2-D, and 2-E assume a one-time distribution of 1000 units of the cryptocurrency good to one person, half of all the agents (25 people), and all the agents (50 people), respectively. In 2-A, the cryptocurrency good acquires a monetary function in all the 30 trials. Furthermore, the fiat money good loses its function as a currency, thereby leaving cryptocurrency as the only remaining currency. Conversely, in Case 2-B, wherein the target person for the distribution is randomly selected each time, the cryptocurrency good does not function as a currency, even once, throughout the 30 trials. For a cryptocurrency to gain a monetary function, distributions must be targeted at a specific person instead of selecting a random persons at each turn. Figures 8 and 9 show the average view values for Cases 2-A and 2-B, respectively.

However, in Cases 2-C, 2-D, and 2-E, the cryptocurrency good does not become the only currency in any of the 30 trials, but functions as a second currency 3, 5, and 14 times, respectively. When the cryptocurrency good gains a monetary function, its average view is approximately 0.14, which is not as high as the average view of the fiat money good of 0.6. Nonetheless, cryptocurrency goods retain a certain monetary function. As the number of people receiving distributions increases, the percentage of trials in which cryptocurrency acquires a monetary function also increases. This finding indicates that the more people receive cryptocurrency distributions, the greater the possibility that the cryptocurrency becomes a second currency. Case 2-A-2 is a variant of Case 2-A, in which the cryptocurrency good cannot be chosen as a utility. In the simulations in this case, the cryptocurrency good does not gain a monetary function even once. This result contrasts with that of Case 2-A, according to which the cryptocurrency has a 100% probability of becoming a currency. Thus, for cryptocurrencies to acquire monetary functions via airdrops, we find that the best scenario occurs when the cryptocurrency has an attractive design, namely, when it is chosen as a utility good and airdropped continuously to one specific person.

Figure 10 shows the transitions in the total volume of all goods in one iteration of Case 2-A, and the cryptocurrency good's volume is shown in red. Total volume is expressed as the total amount of the good possessed by all agents.

This indicates that a very large amount of the cryptocurrency good is in circulation compared to other goods. While 50 units of the fiat money good and approximately 1 unit each of all the other goods are in circulation, up to 278 units of the cryptocurrency good are in circulation. When the quantity in circulation is this large, it is unnatural for the cryptocurrency good to retain utility in the same manner as other goods. To adjust for this situation, a rarity threshold r is introduced under the

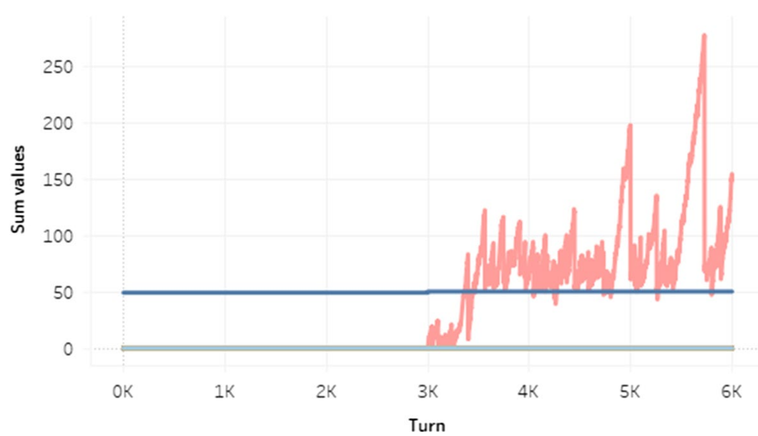

Fig. 10 Airdrop, case 2-A: Time series transition in the sum of possession of each good. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. A larger amount of the cryptocurrency good exists than that of other goods

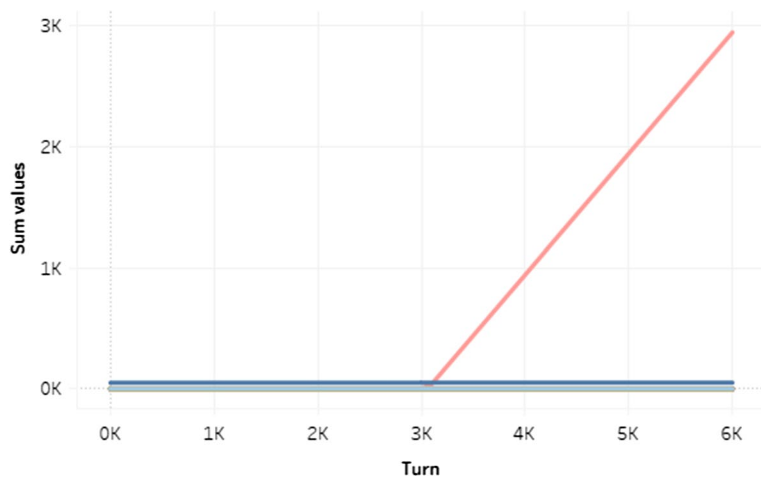

Fig. 11 Airdrop, case 2-F: Time series transition in the sum of possession of each good. Case 2-F is a case in which the rarity threshold is set to 25, cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1 unit is distributed to one specific person each turn. Blue line is the fiat money good, red line is the cryptocurrency good, and other colors represent remaining goods. Since the cryptocurrency is not consumed even when the airdrop is completed each turn, it continues to increase monotonically

Fig. 12 Airdrop, case 2-F: Time series change in the sum of the utility. Red line is the cryptocurrency good, and other colors represent remaining goods. Immediately following turn 3001 of the cryptocurrency good introduction, utility increases slightly, but then utility disappears

simulation conditions. Thus, it is necessary to perform an airdrop for which the distribution volume is adjusted to remain below r. We further our analysis by considering two additional contexts: one in which too many agents possess the cryptocurrency good, such that no agents continue to gain utility from it, and the other in which the cryptocurrency good is rare and the agents desire it. These cases are represented by setting r to 25 and 2, respectively.

Case 2-F, in which r is set to 25 and the other conditions remain the same as in Case 2-A, is investigated. $r = 25$ is also introduced during the 3000 turns whereby only the fiat money good is included. Consequently, the cryptocurrency good does not become a currency, even once, across the 30 trials. The time series changes in possession and utility are shown in Figs. 11 and 12. The amount of cryptocurrency goods in circulation exceeds $r = 25$ at approximately 3080 turns and then continues to increase until 6000th turn. The good does not appear to retain any utility after the approximate 3080th turn. If there is no utility, there is no increase in demand; thus, the view does not increase. Subsequently, Case 2-G is considered, and in this case, the cryptocurrency good is distributed at every turn to a specific agent but not distributed if its total amount exceeds $r = 25$. In all the 30 trials, the cryptocurrency good acquires a monetary function. In 28 out of the 30 trials, it is the only currency. Subsequently, we examine two additional cases in which r is set to 2. In Cases 2-H and 2-I, $r = 2$ and the other conditions remain the same as in Cases 2-F and 2-G, respectively. In both cases, the cryptocurrency good never gains a monetary function.

These results indicate that if r is relatively large, the cryptocurrency good can acquire a monetary function by performing airdrops within a range that does not exceed r, that is, maintaining the total amount at a level below which the cryptocurrency good can be selected as a utility causes the cryptocurrency to become a currency. On the contrary, if r is low, the cryptocurrency good can never acquire a monetary function. Eventually, it is important to make the cryptocurrency attractive to more people and not merely to those who desire it because of its rarity.

We discuss these results in terms of the changes in the amount of the cryptocurrency goods that is possessed. If distribution to a single agent continues, the possession of a cryptocurrency good is concentrated; however, if a target agent is randomly selected at each turn, the possession is dispersed. In Step 1, as a counterpart to the agent for whom the cryptocurrency good is selected as utility, the agent who is the target of the airdrop and who thus has the largest amount of the cryptocurrency good is selected. The larger the amount of the cryptocurrency good that is owned by the counterpart, the more demand remains after the exchange, and the larger the amount of demand that is carried over to the next t, leading to an increase in view.

Discussion

The results of the simulations show the orientation that issuers should adopt. The sales activity target should be to introduce the cryptocurrency in stores that correspond to 20% of the population in the targeted economic zone, and public relations activities should be aimed at making 50% of the targeted people aware of these stores. Alternatively, it is found that cryptocurrency should be designed in such a manner that users desire to save it, and that the cryptocurrency should then be continuously airdropped to a specific person. In this case, it is necessary to design a cryptocurrency that inspires many people to desire to possess it, not because the cryptocurrency is rare but because they desire it even if half of the people in the economic zone own it. The findings of this study are useful to not only issuers but also, for example, national or local governments that are interested in introducing existing cryptocurrencies as national or local currencies. If the issuer is a start-up company that does not have physical stores and exhibits little sales power, it is difficult to realize the former situation; hence, the latter option should be chosen. In particular, the conclusion that it is better to continuously airdrop to a specific person rather than to a larger number of people is surprising. In many existing projects, we believe that the most frequently adopted airdrop strategy tends to be the distribution of small amounts to many people so that more people will use the cryptocurrency.

Even if the cryptocurrency is designed to be attractive, it is unlikely that this attraction will persist in the long run. Therefore, the airdrop scenario is only effective during the early stages of issuance. In the long run, issuers should consider introducing them to retail stores.

This study contributes to the field of research that bridges the gap between studies that focus on whether cryptocurrencies are monies and economic analysis that assumes a situation in which cryptocurrencies are used as money. In the field of research pertaining to ways of allowing cryptocurrencies to acquire a monetary function, we use a multi-agent simulation model, that is, the Yasutomi model, which is an economically rational model of behavior, to obtain certain findings. Further progress in this context may lead to the introduction of an increasing number of cryptocurrencies into our society. This situation would lead to more opportunities to apply existing economic analyses to situations in which cryptocurrencies are used as money. For practitioners, the modified Yasutomi model may be useful as a means of determining whether their sales and public relations plans can stimulate the cryptocurrency to acquire a monetary function. The result of the model is not necessarily accurate; however, it can be one of the factors involved in making these judgments.

Subsequently, we discuss the caveats regarding and limitations of the findings of this study. In the Yasutomi model, only basic economic activities are considered. This model includes no concept for expressing the value of goods, and bartering always occurs on a one-to-one basis. However, in the real world, the market price of cryptocurrencies fluctuates, and the price of goods varies from one product to another. Note that the average level of view, whether high or low, is not relevant in determining whether the value of the good is high.

Additional research is needed to determine whether the findings of this study are applicable in the real world. One issue is the incorporation of the concept of price into the model, as discussed above. It is also interesting to investigate how the price of a cryptocurrency is affected when it functions as a currency because in the case of a proof-of-work blockchain, such as Bitcoin, this issue is also linked to the energy consumption problem. Recently, regulations have been established to determine the proper treatment of cryptocurrencies on exchanges. By using this model, it may be possible to analyze the possibility of restricting the behavior of exchanges to prevent a cryptocurrency from functioning as money in certain economic zones, such as the shadow economy. For example, in response to a regulation that requires all customers to verify their identities, the model could be modified to prevent exchanges with individuals who cannot verify their identity and to determine whether the cryptocurrency can acquire a monetary function in this case.

However, there is also a social need to regulate cryptocurrencies in areas where they have already acquired a monetary function, which would require such cryptocurrencies to lose their monetary function. We believe that it is important to conduct additional research to investigate how to regulate cryptocurrencies that already function as currencies in a way that causes them to lose their monetary function in inappropriate areas, such as the shadow economy.

In addition, it is possible to acquire on-chain transaction data as real data. Using such data, it may be possible to identify the economic zones of a cryptocurrency and analyze whether it functions as money in such zones.

Conclusion

In this study, the modified Yasutomi model is used to determine whether cryptocurrencies can acquire a monetary function. We analyze two scenarios representing the potential actions of a cryptocurrency issuer. The first scenario involves an increase in the number of retail stores in which cryptocurrency can be used as a form of payment and a corresponding increase in the number of people that are aware of the existence of such stores. The second scenario involves airdropping cryptocurrencies and making them attractive, thereby causing people to desire to obtain and save them.

We find that cryptocurrencies can function as a second currency when 20% of all agents accept it for payment and when 50% of agents are aware of this fact. In addition, cryptocurrency can replace a fiat currency by being designed to be attractive and by the use of continuous airdrops to a specific person while ensuring that the volume of the cryptocurrency remains within a specified range so that its attractiveness is not lost. It is necessary to design the cryptocurrency in such a way that many people desire it for reasons other than that it being rare.

Even if the cryptocurrency is designed to be attractive, it is unlikely that this attraction will persist in the long term. Therefore, at the time of issuance, airdrops to a specific person should continue, while ensuring that the total volume remains within a given range, to ensure that the cryptocurrency remains attractive. Simultaneously, sales activities should be conducted to increase the number of stores that accept payments in the form of such cryptocurrency. Before the cryptocurrency loses its attractiveness, the issuer should create a situation in which the number of stores accepting payments in the form of the cryptocurrency is at least 20% of the total number of people. However, determining whether the results obtained in this study can be applied in the real world is a task for future research.

Appendix

See Table 3.

Table 3 All simulation results

No.	Category	Case	Number of trials when both the cryptocurrency and the fiat money become a currency	Number of trials in which only the cryptocurrency becomes a currency	Average view of cryptocurrency during the period in which it is a currency	Average view of fiat money during the period in which it is a currency
SC-1	Standard case	Cryptocurrency good is distributed to 50 people at turn 3001. No introduction of the cryptocurrency agent.	0	0	–	0.61
SC-2	Standard case	Cryptocurrency agent is introduced at turn 3001.	0	0	–	0.61
SC-3	Standard case	Rarity threshold is set to 25, and the cryptocurrency agent is introduced at turn 3001.	0	0	-	0.61
SC-4	Standard case	Rarity threshold is set to 2, and the cryptocurrency agent is introduced at turn 3001.	0	0	–	0.61
1-A	Introduction of the cryptocurrency payments case	Cryptocurrency is not selected as a utility (no cryptocurrency agent), 1 unit is distributed to 50 people, all 50 people demand the cryptocurrency, and the view of 50 people is increased.	30	0	0.40	0.40
1-A-2	Introduction of the cryptocurrency payments case	Cryptocurrency can be selected as a utility (with the cryptocurrency agent), 1 unit is distributed to 50 people, all 50 people demand the cryptocurrency, and the view of 50 people is increased.	19	0	0.15	0.55

Table 3 (continued)

No.	Category	Case	Number of trials when both the cryptocurrency and the fiat money become a currency	Number of trials in which only the cryptocurrency becomes a currency	Average view of cryptocurrency during the period in which it is a currency	Average view of fiat money during the period in which it is a currency
1-B	Introduction of the cryptocurrency payments case	Cryptocurrency is not selected as a utility (no cryptocurrency agent), 1 unit is distributed to 50 people, 5 out of 50 people demand the cryptocurrency, and the view of 25 people is increased.	0	0	-	0.61
1-C	Introduction of the cryptocurrency payments case	Cryptocurrency is not selected as a utility (no cryptocurrency agent), 1 unit is distributed to 50 people, 5 out of 50 people demand the cryptocurrency, and the view of 40 people is increased	15	0	0.39	0.51
1-D	Introduction of the cryptocurrency payments case	Cryptocurrency is not selected as a utility (no cryptocurrency agent), 1 unit is distributed to 50 people, 10 out of 50 people demand the cryptocurrency, and the view of 25 people is increased	30	0	0.39	0.40
1-E	Introduction of the cryptocurrency payments case	Cryptocurrency is not selected as a utility (no cryptocurrency agent), 1 unit is distributed to 50 people, 10 out of 50 people demand the cryptocurrency, and the view of 40 people is increased	30	0	0.39	0.40

Table 3 (continued)

No.	Category	Case	Number of trials when both the cryptocurrency and the fiat money become a currency	Number of trials in which only the cryptocurrency becomes a currency	Average view of cryptocurrency during the period in which it is a currency	Average view of fiat money during the period in which it is a currency
2-A	Airdrop case	Cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1 unit is distributed to one specific person each turn	0	30	0.57	-
2-A-2	Airdrop case	Cryptocurrency is not selected as a utility (no cryptocurrency agent) and 1 unit is distributed to one specific person each turn	0	0	-	0.61
2-B	Airdrop case	Cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1 unit is distributed to a random person each turn	0	0	–	0.61
2-C	Airdrop case	Cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1000 units are distributed to one person at turn 3001.	3	0	0.14	0.60
2-D	Airdrop case	Cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1000 units are distributed to 25 persons at turn 3001	5	0	0.13	0.59
2-E	Airdrop case	Cryptocurrency can be selected as a utility (with the cryptocurrency agent) and 1000 units are distributed to 50 persons at turn 3001	14	0	0.14	0.57

Table 3 (continued)

No.	Category	Case	Number of trials when both the cryptocurrency and the fiat money become a currency	Number of trials in which only the cryptocurrency becomes a currency	Average view of cryptocurrency during the period in which it is a currency	Average view of fiat money during the period in which it is a currency
2-F	Airdrop case	Rarity threshold is set to 25, cryptocurrency can be selected as a utility (with the cryptocurrency agent), and 1 unit is distributed to one specific person each turn	0	0	–	0.60
2-G	Airdrop case	Rarity threshold is set to 25, cryptocurrency can be selected as a utility (with the cryptocurrency agent), and 1 unit is distributed to a specific person each turn only when the total number is within the rarity threshold	2	28	0.82	0.39
2-H	Airdrop case	Rarity threshold is set to 2, cryptocurrency can be selected as a utility (with the cryptocurrency agent), and 1 unit is distributed to one specific person each turn.	0	0	–	0.61
2-I	Airdrop case	Rarity threshold is set to 2, cryptocurrency can be selected as a utility (with the cryptocurrency agent), and 1 unit is distributed to one specific person each turn only when total number is within the rarity threshold	0	0	–	0.61

30 simulation trials are conducted for each case

Acknowledgements
This work has been supported by Endowed Chair for Blockchain Innovation and the Mohammed bin Salman Center for Future Science and Technology for Saudi-Japan Vision 2030 (MbSC2030) at The University of Tokyo.

Author contributions
KS. designed and performed research and wrote the article; GM supervised the research. Both authors have read and agreed to the published version of the manuscript

Funding
Not applicable.

Availability of data and materials
Not applicable.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 5 January 2022 Accepted: 12 September 2022
Published online: 26 September 2022

References

Abraham J, Sutiksno DU, Kurniasih N, Warokka A (2019) Acceptance and penetration of bitcoin: the role of psychological distance and national culture. SAGE Open 9(3):2158244019865813
Babutsidze Z, Iacopetta M (2019) The emergence of money: computational approaches with fully and boundedly rational agents. Computat Econ 1–24
Cachanosky N (2019) Can bitcoin become money? The monetary rule problem. Aust Econ Pap 58(4):365–374
CoinMarketCap (2022). https://coinmarketcap.com/. Accessed 30 Mar 2022
Crypto.com (2022) Crypto for Payments: Consumers are Hungry - Will Merchants be Able to Fill their Appetite? https://crypto.com/research/crypto-for-payments-consumers-are-hungry-merchants-fill-appetite. Accessed 19 Apr 2022
Dowd K, Greenaway D (1993) Currency competition, network externalities and switching costs: towards an alternative view of optimum currency areas. Econ J 103(420):1180–1189
Drożdż S, Gębarowski R, Górski AZ, Kwapień J, Oświęcimka P (2013) Multiscaling edge effects in an agent-based money emergence model. arXiv preprint arXiv:1312.4803
Fang F, Ventre C, Basios M, Kanthan L, Martinez-Rego D, Wu F, Li L (2022) Cryptocurrency trading: a comprehensive survey. Financ Innov 8
Folkinshteyn D, Lennon M (2016) Braving bitcoin: a technology acceptance model (tam) analysis. J Inform Technol Case Appl Res 18(4):220–249
García-Corral FJ, Cordero-García JA, de Pablo-Valenciano J, Uribe-Toril J (2022) A bibliometric review of cryptocurrencies: how have they grown? Financ Innov 8
Górski AZ, Drozdz S, Oswiecimka P (2010) Modelling emergence of money. Acta Physica Polonica A 117(4)
Hazlett PK, Luther WJ (2020) Is bitcoin money? And what that means. Q Rev Econ Finance 77:144–149
Ito N, Horiguchi K, Tani K, Maeda Y (2012) Multi-agent simulation on emergence of another money system. The IEICE Trans A 95(9):707–715 (**in Japanese**)
Kawamata M (2010) An axiomatic analysis of the theories of values and prices in turgot's "valeurs et monnaie." Shakai-shirin 57(3):59–89 (**in Japanese**)
Kim M (2021) A psychological approach to bitcoin usage behavior in the era of covid-19: focusing on the role of attitudes toward money. J Retail Consum Serv 62:102606
Kiyotaki N, Wright R (1989) On money as a medium of exchange. J Polit Econ 97(4):927–954
Kiyotaki N, Wright R (1993) A search-theoretic approach to monetary economics. Am Econ Rev 63–77
Kou G, Olgu Akdeniz Ö, Dinçer H, Yüksel S (2021) Fintech investments in european banks: a hybrid it2 fuzzy multidimensional decision-making approach. Financ Innov 7
Kunal K, Ramprakash C, Xavier M, Arun CJ (2021) A comprehensive study of blockchain based cryptocurrency as a medium of exchange. Int J Future Gener Commun Netw 14(1):4907–4912
Kunigami M, Kobayashi M, Yamadera S, Yamada T, Terano T (2010) A doubly structural network model: bifurcation analysis on the emergence of money. Evol Inst Econ Rev 7(1):65–85
Li Y, Jiang S, Li X, Wang S (2022) Hybrid data decomposition-based deep learning for bitcoin prediction and algorithm trading. Financ Innov 8
Luther WJ (2016) Cryptocurrencies, network effects, and switching costs. Contemp Econ Policy 34(3):553–571
Marimon R, McGrattan E, Sargent TJ (1990) Money as a medium of exchange in an economy with artificially intelligent agents. J Econ Dyn Control 14(2):329–373
Marmora P (2021) Currency substitution in the shadow economy: International panel evidence using local bitcoin trade volume. Econ Lett 205:109926
Nakamoto S (2008) Bitcoin: A peer-to-peer electronic cash system
Schilling L, Uhlig H (2019) Some simple bitcoin economics. J Monet Econ 106:16–26
Shibano K, Mogi G (2021) An analysis on the acquisition of monetary functions of cryptocurrency using Yasutomi model. In: Proceedings of the 83rd National Convention of IPSJ 2, 05 (**in Japanese**)

Takahashi H, Ito N, Maeda Y (2019) On the emergence of multiple monies in yasutomi model caused by inhibition of excessive savings. Technical Committee on Circuits and Systems/Technical Committee on Information and Communication Technologies for Safe and Secure Life
Tsujino M, Hashimoto T (2010) Emergence, stabilization and collapse of key currency in international financial market model, In: IPSJ SIG Technical Report, vol 80 (**in Japanese**)
Turgot A-R-J (1769) Valeurs et monnaies
Xu M, Chen X, Kou G (2019) A systematic review of blockchain. Financ Innov 5
Yasutomi A (1995) The emercence and collapse of money. Meeting Abstracts of the Physical Society of Japan 1995.3(0), pp 653–654
Yasutomi A (1995) The emergence and collapse of money. Physica D 82(1–2):180–194
Yasutomi A (2000) Kahei No Fukuzatsusei: Seisei to Hokai No Riron (Complexity of Money: Theory of Emergence and Collapse). Sobunsha, Tokyo, Japan (**in Japanese**)
Yasutomi A (2003) Itinerancy of money. Chaos: Interdiscip J Nonlinear Sci 13(3):1148–1164
Yermack D (2015) Is bitcoin a real currency? An economic appraisal. In: Handbook of digital currency. Elsevier, pp 31–43

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Submit your manuscript to a SpringerOpen journal and benefit from:

- ► Convenient online submission
- ► Rigorous peer review
- ► Open access: articles freely available online
- ► High visibility within the field
- ► Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com