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Consumer choices under new payment methods

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Abstract

This study suggests a payment portfolio model that includes new payment methods that have emerged from the development of cryptocurrency markets and central bank digital currencies (CBDCs). Our model analyzes the optimal payment choice for consumers under various macroeconomic conditions. We determine that an individual economic agent chooses payment methods under specific conditions by incorporating policy interest rates on CBDCs and stablecoins used on cryptocurrency exchanges. We analyze the impacts of CBDCs and stablecoins on the choice of whether to use cash or deposits. We also examine how the agent changes her portfolio compositions in response to exogenous macroeconomic policies. If a government replaces cash with a CBDC, the convenience of digital currency would not affect consumer choices. The higher the government's interest rate on CBDCs, the more consumers will use CBDCs than deposits.

Keywords: Central bank digital currency, Cryptocurrency, Payment portfolio model, Stablecoin

JEL classification: E41, E58, E58, G28

Introduction

Distributed ledger and blockchain technologies, which have emerged with advances in information technology, have created cryptocurrencies such as Bitcoin. Because of the proliferation and rapid rise in the value of many of these cryptocurrencies, some observers have questioned whether these new cryptocurrencies will eventually replace existing fiat currencies. It has also sparked debate about the digitalization of money, prompting several central banks to consider introducing new digital currencies, commonly known as central bank digital currencies (CBDCs). The CBDC is a central bank-issued digital currency denominated in the national unit of account (Kiff et al. 2020).[1] Research on, and issuance, of CBDCs is a global trend. About eighty percent of central banks worldwide are currently conducting extensive research on CBDCs (Boar and Wehrli 2021).

[1] Refer to the "Central bank digital currencies: Foundational principles and core features," a 2020 joint report by the Bank of Canada, European Central Bank, Bank of Japan, Sveriges Riksbank, Swiss National Bank, Bank of England, Board of Governors of the Federal Reserve, and Bank for International Settlements (https://www.bis.org/publ/othp33.pdf).

Moreover, some developing countries are introducing and piloting CBDCs. For example, the Commonwealth of the Bahamas has adopted a CBDC as its national currency.[2]

CBDCs have several distinct characteristics as a result of digitalization, including the ability to pay or charge interest on the CBDCs, allowing for negative interest rates if desired (Jia 2020). Policy researchers are studying CBDCs, which have distinct characteristics from cash, to evaluate the effectiveness of new monetary policies. Owing to CBDCs' special characteristics, they not only replace physical currencies but also influence deposit demands. Unfortunately, the existing CBDC studies oversimplify individual payment portfolio changes because of the lack of research on related payment portfolio models. Also, stablecoin, which represents a newly emerging payment instrument,[3] is not considered in policy research. As cryptocurrency exchanges emerge and the demands for cryptocurrency increase, the interest in cryptocurrencies, such as stablecoins, is also increasing. Stablecoins can be used as a payment instrument.

Related to CBDCs and stablecoins, previous studies have narrowly focused on the changes associated with the specific characteristics of these new payment instruments (Auer et al. 2020; Kumhof and Noone 2018). For instance, the previous studies only consider the fragmentary properties of CBDCs, such as their interest rates and abilities to provide transparency and avoid anonymity in transactions (Agur et al. 2022). Although most portfolio theory studies focus on asset selection, only a few analyze payment portfolio models. Unlike other financial instruments, such as stocks and bonds, money is a general payment method that stores nominal value and serves as a medium of exchange. As technology has advanced, the types of available payment methods have expanded from cash to checks, credit cards, debit cards, and direct transfers, thus increasing the need to consider payment portfolios (Schuh and Stavins 2013, 2014). Moreover, because many new payment assets, such as CBDCs and cryptocurrencies, are expected to emerge soon, the number of assets to be included in future payment asset portfolios will likely increase accordingly. Therefore, the introduction of cryptocurrencies and their use as payment assets should be considered in finance and investment studies.

In this paper, we (1) investigate economic agents' demands for newly emerging payment assets and discuss how payment asset properties influence their decisions; and (2) shed light on how demands for the assets' properties interact with exogenous shocks (e.g., regulatory changes in cryptocurrency exchanges). Our study contributes to the literature by analyzing an agent's optimal portfolio under new payment systems. First, we classify and present the types and properties of payment assets, including those of new currencies that have emerged as technology advances. Several empirical studies consider agents' payment asset choices, but only a few delve deeper into the characteristics of each payment asset (Bagnall et al. 2016; Borzekowski and Kiser 2008; Borzekowski et al. 2008; Klee 2008; Qu et al. 2022). CBDC issuances are being considered globally; thus, developing a new portfolio model with CBDCs is important. Moreover, although stablecoins are used only for trading crypto-assets now, they can be more commercialized and used on various payment platforms in the near future. Therefore, our analysis aids in the

[2] Using CBDCs is important for some developing countries with a chronic current account deficit problem because, in countries with severe inflation, currency replacement can generally stabilize the domestic economy (Foster et al. 2021).

[3] We discuss the details of stablecoin's definitions and characteristics in "Stablecoins" and "Stablecoins" sections.

classification and analysis of future payment assets' characteristics. Second, we focus on the features of these payment assets to explain the substitutions between payment assets when the exogenous conditions change. Analyzing the relationships between these features and an agent's portfolio can help guide future policy studies investigating how an agent's choices change when either the characteristics of payment assets or the agent's preferences change. Considering the possible impacts on payment asset properties, we discuss the agents' subjective utility factors and policy variables such as the interest rate. Moreover, we provide macroeconomic implications such as banking crises and financial stability by considering the impact of a CBDC issuance on agents' payment asset choices and presenting the effects of changes in the interest rate gap between CBDCs and deposits. While previous studies on payment asset portfolios have not examined the role of policy interest rates in depth, our study incorporates policy interest rates directly into the model, which yields policy implications for financial market specialists, such as government departments and central and commercial banks.

The remainder of this paper is structured as follows. "Newly emerging payments" section discusses CBDCs, cryptocurrencies, and stablecoins. "Payment assets and their properties" section summarizes and explains the relevant research on payment assets. "Payment portfolio model" section introduces the model and addresses the problem of consumer portfolio selection. Finally, "Conclusions" section discusses the results and concludes the study.

Newly emerging payments

CBDCs

More countries are considering using distributed ledger technologies to issue CBDCs.[4] Distributed ledger technologies can be divided into two categories according to the accessibility of the ledger records. One method involves transaction participants in transaction verification and ledger records using a permissionless blockchain. The other employs a permissioned blockchain, which restricts transaction verification and ledger recording rights to a small group of trusted participants (Helliar et al. 2020). A central bank should consider an important point when issuing a CBDC to ensure payment completeness; therefore, using the permissioned blockchain is more suitable. In the case of proof of work (PoW) or proof of stake (PoS), which are the main consensus algorithms used in the proofing of a permissionless blockchain, a fork in which two or more blocks are connected to one block in the blockchain can occur (Shahsavari et al. 2019). When a fork occurs, even if a block is newly created through a legitimate transaction, it may be disconnected from the main blockchain and canceled (Sayeed and Gisbert 2019). As a result, payment completeness cannot be guaranteed, and the purpose of CBDC issuance may not be fully realized.

CBDC issuance is expected to reduce the use of cash currencies. However, central banks in Japan, the United Kingdom, and Europe are pushing for the issuance of CBDCs. They argue that the purpose of CBDC issuance is to supplement, rather than replace,

[4] A survey by the Bank of Korea (2020) specified that Canada, East Caribbean, European Central Bank, Hong Kong, Japan, Sweden, Singapore, and Thailand are promoting the issuance of CBDCs using the distributed ledger technologies.

cash currencies (Bank of Europe 2020; Bank of Japan 2020; European Central Bank 2020).

Considering new payment assets, we also discuss CBDC interest rates, which are not covered in existing payment portfolio studies (Bian et al. 2021). As previously stated, central banks can charge or pay interest on CBDCs, which is an important property for an agent's payment asset choices and an important feature for central banks. Our model has implications for analyzing the impact of central banks' monetary policies on individual portfolio choices by taking the CBDC interest rate into account.

Cryptocurrencies

As consumer interest in cryptocurrencies grows, so will consumer demand for these currencies, as evidenced by the NASDAQ listing of Coinbase, a global cryptocurrency exchange, and the New York Stock Exchange listing of Bakkt, a Bitcoin futures exchange. In particular, cryptocurrencies such as Bitcoin are still being integrated into the financial system. Similar to existing payment assets, such as cash, CBDCs, and deposits, cryptocurrencies have their own properties in transactions. As such, incorporating cryptocurrencies into payment asset portfolio models allows us to perform sophisticated analyses. Nonetheless, cryptocurrency is frequently regarded as an asset rather than money (Baur et al. 2018; Katsiampa 2017). Because of its price volatility, the cryptocurrency does not serve as a store of value, and its use as a widely accepted currency remains uncertain. Therefore, to include cryptocurrencies in the payment portfolio model, we must only incorporate those that can be used as money.

Generally, cryptocurrencies can be classified according to their form of compensation from mining or their purposes. There are several mining methods, such as PoW and PoS, but we do not go into detail about mining because the main focus of our research is the purpose of using cryptocurrency. Although mining methods are important components of the demand for cryptocurrencies, the demand for mining methods has little impact on the cryptocurrencies discussed in this study. In other words, cryptocurrency must be able to function as money to be classified as a payment asset.

Stablecoins

In a payment portfolio, analyzing cryptocurrencies with low price volatility and constant value is necessary. Stablecoins, which have their values pegged to fiat currencies, such as the US dollar, fit this description as long as the peg holds. One such example is the Libra project (now Diem), which was previously promoted by Meta (Facebook). Unlike general crypto-assets, stablecoins are designed to be pegged to the value of real currencies. However, because the peg is only a promise within the crypto-asset system, a separate discussion about the stability and reliability of stablecoins is required. For stablecoins to function as a reliable medium of exchange in the crypto-asset market, their stability must be supported through sufficient reserves. Currently, the most widely used stablecoin in terms of liquidity is Tether, an asset mainly used for monetary transactions between cryptocurrency market exchanges (Kristoufek 2021). Tether is designed so that one unit supposedly always has the same value as one US dollar, implying that it is a payment asset in terms of volatility. In this regard, our study focuses on stablecoins, specifically Tether coins, in a portfolio model.

Payment assets and their properties

This section explains the payment portfolio model's principles by categorizing payment assets and describing their properties. Bian et al. (2021) propose a simple payment portfolio model that identifies the portfolio chosen by an agent using three payment assets (i.e., cash, deposits, and CBDC). For simplicity, they did not consider the CBDC with policy interest rates, but they noted that the issuance of a CBDC may affect deposit demand due to its properties as legal tender and digital currency. However, in other works of literature, the imposition of an interest rate is mentioned as an alternative to Friedman's rule, as one of the most important features of CBDCs.[5] Moreover, the imposition of an interest rate on a CBDC, which functions as money, is a key feature that can influence deposit demand (Andolfatto 2021; Agur et al. 2022; Son and Ryu 2022; Williamson 2022b). Therefore, this interest rate must be considered when analyzing the crowding-out effect. Our study modifies their framework and extends the analysis by adding a stablecoin as a payment asset and subdividing the properties of the payment assets. Moreover, we define payment assets as those with sufficient liquidity and low volatility, which are used in daily transactions. We consider four types of payment assets: cash, deposits, CBDCs, and stablecoins. Among these assets, CBDCs and stablecoins are not widely used in daily transactions but may be used in the future; thus, they are included in the model. A description of each of these types is as follows.

Cash

Cash is a payment asset issued by a central bank. As a physical currency, it is still used worldwide as a means of value exchange in physical transactions, such as buying and selling commodities in real-world markets. Furthermore, classic macroeconomic models, such as cash in advance and money in utility models, generally use cash as a basic type of money. As cash is typically issued by a central bank, it has the property of legal tender, meaning its use as a medium of exchange in the country or currency area of issue is legally guaranteed. Another property of cash is that it provides anonymity to users. Generally, cash transactions do not leave traces. Therefore, cash can also be used as an asset for illegal transactions, such as money laundering (Chao et al. 2019; Kahn 2018; Kim et al. 2021; Wright et al. 2017). Additionally, as mentioned by Borgonovo et al. (2021), transactions that guarantee anonymity are important for protecting privacy. This is because the maintenance of privacy has become more important and more difficult in the information age (Acquisti et al. 2015). In short, we assume that cash has two utility-contributing properties as a payment asset: it serves as a legal tender and provides anonymity.

Deposits

Deposits are representative interest-bearing payment assets. They are often linked with a debit card and are used for simple payments (Kim et al. 2010). The simple payment function of deposits is related to their electronic characteristics, and we consider this

[5] According to the Friedman (1969) rule, if money is costless to create, the net interest on money should be zero to achieve a socially optimal level of money balances. By controlling its interest rate, the central bank can achieve optimal money balances by paying an interest rate on CBDC equal to the return on the real bond (Barrdear and Kumhof 2021; Bordo and Levin 2017; Williamson 2022a).

property utility-contributing, as it enables people to transact conveniently and reduces transaction costs. In general, electronic payment assets such as deposits can alleviate the physical inconvenience of cash transactions. Ching and Hayashi (2010) describe the utility-enhancing characteristics of digital currency. They conduct a hypothetical experiment in which they remove credit card loyalty rewards and conclude that consumers mostly substitute credit for debit cards, with a marginal increase in cash demand. This demonstrates that consumers consider the convenience of using a digital currency when selecting payment assets. Moreover, Humphrey et al. (2001) investigate substitution elasticities of cash, debit cards, and checks to analyze the relationship between payment systems and social costs following the advent of electronic payments. They argue that the electronic payment system has a strong influence on consumer choices by revealing that a debit card is a strong substitute for a check card.

Credit cards are linked to bank accounts and can be used by consumers who pay monthly interest. Here the interest is the user fee a consumer pays using a credit card. Because debit and credit cards have different characteristics, even when both are linked to a bank account, different effects appear. Credit cards have the utility-contributing property that enables people to consume exceeding their current cash holdings, but they may reduce a consumer's utility, as interest may be charged. Additionally, because a consumer's utility can vary depending on a credit card's method for charging interest, it is difficult to consider credit cards in portfolio analyses (Shy and Wang 2011). Credit card fees and the related status elicit yet another utility-contributing feature-social image (Bursztyn et al. 2018). Considering all of these discussions in a unified framework is difficult, and the implications are, at best, vague. Therefore, for simplicity, we assume that debit cards are the only products linked to deposits. Based on these discussions, we consider the digital nature of a payment asset a utility-contributing property and assume that the deposits are digital currencies with interest-bearing properties.

CBDCs

A CBDC is a virtual currency issued by a central bank; thus, similar to cash, it can be classified as a legal tender. Additionally, because the CBDC is issued electronically, such as deposits, it is a digital currency and convenient to use as a payment asset. Furthermore, as with deposits, interest can be charged on a CBDC. Although only a few countries use CBDCs as fiat currency, research into these currencies is ongoing worldwide. CBDCs are classified into several types based on their intended use. We focus on general-purpose CBDCs because they are expected to be used by general consumers (Cœuré and Loh 2018). Moreover, because wholesale CBDCs that can be used for interbank transactions are not significantly different from the existing financial system (Bindseil 2020), analyzing them is not relevant to this study. Bian et al. (2021) do not consider CBDC interest rates because they are always lower than deposit interest rates. Nonetheless, interest rates are a significant factor in many CBDC studies. For instance, Andolfatto (2021) and Davoodalhosseini (2022) claim that central banks can consider a monetary policy using CBDCs as a general policy when issuing these currencies. Jia (2020) mentions that interest rates can be imposed on reserves as an alternative means of achieving an optimal quantity of money, as suggested by Friedman (1969). Commonly, existing studies explain the monetary policies that central banks can use when issuing CBDCs and their effects by focusing on interest. In other words, because central banks and academic research widely consider the interest rates on CBDCs in various countries, it is essential to develop a model that best reflects them. However, the CBDC interest rate can crowd out the demand for deposits; hence, the CBDC interest rates are expected to be lower than those on deposits to prevent such situations (Chiu et al. 2022; Keister and Sanches 2022). Therefore, by considering these factors, we extend the discussion on interest rates. Although not covered in detail in our study, the government's compulsory retention policy and negative interest rate policy (NIRP) are also worth considering. These policies have the potential to alter a consumer's portfolio exogenously. Finally, in our model, we consider three important properties of CBDCs: digital currencies, legal tender, and interest.

Stablecoins

Cryptocurrencies such as Bitcoin and Ethereum are considered non-substitutable for traditional currencies because of their price volatility. In contrast to other risky cryptocurrencies, a stablecoin is issued to serve as a currency by maintaining the same value as real money while providing convenience via blockchain technology. Depending on the product to which their values are matched, stablecoins can be classified as fiat-money-linked, cryptocurrency-linked, or commodity-value-linked. We consider a stablecoin to be a payment asset in this study; therefore, we focus on a fiat-money-linked stablecoin with the same fixed value as money. Although various types of fiat-money-linked stablecoins exist, stablecoins are described based on Tether, which is the most widely traded stablecoin in global cryptocurrency markets, in this study.

Since the government does not issue stablecoins, we do not regard them as legal tender. As in the case of Terra stablecoin, the value of stablecoins may not be guaranteed when a financial crisis occurs or a shock arrives in cryptocurrency markets. In such situations, as the exchange of stablecoins into fiat currencies, such as dollars, increases, a phenomenon similar to a bank run can occur accordingly. In other words, stablecoins, like deposits, may be at risk of failing to store their value during the crisis, which is related to the fact that stablecoins are not legal tender. Stablecoins provide anonymity because they use distributed ledgers, which make tracking transactions difficult. Furthermore, because transaction participants may not know each other's personal information, stablecoins may provide greater anonymity than cash. However, because the privacy difference between cash and stablecoins is not as great as the difference between these two payment assets and others, we assume that the utility of anonymity is identical for both. Given that stablecoins are often used for transactions linked to other cryptocurrencies' parity in decentralized markets, they also contribute to the efficiency and price discovery of the cryptocurrency market in general (Ante et al. 2021; Lyons and Viswanath-Natraj 2021).[6] The demand for stablecoins for parity will gradually decrease if the crypto-asset market becomes more efficient. Additionally, since the demand for payment assets for the purchase of volatile assets can be sufficiently considered through

[6] However, a counterpart empirical study discussing price shows that the large demand for Tether stablecoin can drive the price of Bitcoin (Griffin and Shams, 2020). This phenomenon can create bubbles in the price of Bitcoin and contribute to the price distortion.

deposits and stablecoins, we only consider the following two properties of the stablecoins: digital currencies and anonymous assets.

Payment portfolio model

This section analyzes the process by which an agent chooses payment assets. As previously stated, the agent is faced with the utility maximization problem of constructing a portfolio using four payment methods: cash, deposits, a CBDC, and a stablecoin. In this regard, the agent's problem can be expressed using Eq. (1):

$$\begin{aligned} &\max U = U(Cash, Deposits, CBDC, Stablecoin) \\ &s.t. Q = Cash + Deposits + CBDC + Stablecoin, \end{aligned} \tag{1}$$

where Q denotes total payment asset holdings. For simplicity, we will assume the agent's utility function is quasilinear in terms of payment asset properties. However, using a quasilinear utility function, we may not accurately study consumers' interest-bearing asset preferences.

Because the interest for CBDC determined by the central bank is considered in the model as an additional policy variable and the changes in the agent's portfolio composition are analyzed accordingly, this function allows us to analyze asset substitutions. In other words, a quasilinear utility function must mathematically derive a solution when discussing the interest rate. In this context, we assume that the utilities of certain properties, such as legal tender, anonymity, and digital currency, are natural logarithmic functions with diminishing marginal utility.[7] However, we assume that the utility of the interest rate follows a linear function. Interest rates have various properties related to assets and returns as utility-contributing features. In other words, the utility from reinvesting the return imposed on the CBDC or a deposit can also be interpreted as a utility provided by interest rates. Based on these discussions, the agent's utility function is specified as

$$U(Q_L, Q_A, Q_D, Q_I) = \ln\left(Q_L^l Q_A^a Q_D^d\right) + \beta\left\{R_{CBDC}\varphi + R_{Deposits}(1-\varphi)\right\}Q_I, \tag{2}$$

where Q_i denotes the total holding amounts of payment assets with property i. Let $i \in \{L, A, D, I\}$, where L, A, D, and I denote the legal tender, anonymity, digital currency, and interest, respectively. Equations (1) and (2) represent the same utility function; however, their expressions are different. In Eq. (1), the utility function specifies the asset that the agent can choose. Nevertheless, the agent does not directly obtain utility from the asset but from the asset's features. Equation (2) reflects this discussion. Each of l, a, and d denotes the exponent of Q_i, except Q_I, and satisfies the zero-substitution elasticity, as the properties are not substitutes. We assume $0 < \min(l, a, d)$ and $\max(l, a, d) < 1$. For example, because cash and the CBDC are both legal tender, Q_L equals 6 when the agent holds three units of each.Q_I enters the utility function differently. $R_{Deposits}$ and R_{CBDC} denote the interest rates imposed on deposits and the CBDC, respectively, and β is a

[7] We only use variables that have a direct impact on the agent's portfolio selection. In a real-world transaction, the counterparty may prefer to use a specific payment asset (Faccio and Masulis 2005). This phenomenon can affect the agent's ability to close the transaction and, as a result, the portfolio selection. However, for simplicity, we do not include this possibility in our portfolio selection model.

Table 1 Utility-contributing features of the payment assets

	Legal tender	Anonymity	Digital currency	Interest
Cash	1	1	0	0
Deposits	0	0	1	$R_{Deposits}$
CBDC	1	0	1	R_{CBDC}
Stablecoin	0	1	1	0

This table shows the relationships between the properties that influence an agent's portfolio choices

discount factor that satisfies $\beta > 0$. Here, the discount factor is defined as follows: l, a, and d are the agent's subjective variables, whereas the interest rates, $R_{Deposits}$ and R_{CBDC}, are exogenous variables. Therefore, the discount factor adjusts the numerical gap between the subjective and exogenous variables. φ denotes the holding ratio of the CBDC among the assets of interest and $\varphi = \frac{CBDC}{Deposits+CBDC}$. Table 1 summarizes Q_i for each payment asset.

A value of 1 indicates that the payment asset has the corresponding property. A value of 0 means that the payment asset does not have the corresponding property. The categorical classification of a payment asset's features refers to the asset's relative strength with the corresponding feature. Accordingly, classifying a specific asset's feature as 0 indicates that the asset is inferior to the asset that has the corresponding feature. For example, the value guaranteed by the central bank means that CBDC and cash have more credit than other payment assets. This guarantee boosts economic agents' trust in, and demand for, fiat currency. Therefore, cash and CBDC carry less risk and volatility than deposits and stablecoins. Interest rates, unlike other properties, do not have a binary value because they reflect actual monetary policy. Furthermore, because deposits have greater credit counterparty risk, the interest rate on a CBDC is lower than that on deposits; we assume $R_{CBDC} < R_{Deposits}$. However, when NIRP is charged on the CBDC, it may be that $R_{CBDC} < 0$.

An agent can simultaneously consider issuing a risky asset portfolio and a payment asset portfolio. In a risky asset portfolio, since the portfolio choice problem is related to composing risky assets, considering the interest rate is related to the expected return (Huang and Kou 2014). In a payment asset portfolio, however, since we consider the agent's utility maximization problem, considering, the interest rate is related to consumer utility. As a result, the difference in interest rates between the two portfolios influences an agent's payment asset selection decisions. The agent's utility maximization problem can be represented as follows using Eq. (2) and Table 1:

$$\max U(Q_L, Q_A, Q_D, Q_I) = \ln\left(Q_L^l Q_A^a Q_D^d\right) + \beta\left\{R_{CBDC}\varphi + R_{Deposits}(1-\varphi)\right\}Q_I, \quad (3)$$

$$s.t.\begin{cases} Q_L = Cash + CBDC \\ Q_A = Cash + Stablecoin \\ Q_D = Deposits + CBDC + Stablecoin \\ Q_I = Deposits + CBDC \\ Q = Cash + Deposits + CBDC + Stablecoin \end{cases} \quad (4)$$

The five constraints in Eq. (4) are the most fundamental and general equations that reflect the characteristics of the currencies discussed in "Payment assets and their properties" section. These equations are also subject to variation because the properties of payment assets can vary depending on a country's monetary policies or laws. We use these equations as the baseline model in our study to explain how exogenous shocks like changes in laws or monetary policies affect an agent's decision. For the sake of simplicity, we will assume that the variables associated with payment assets are continuous and differentiable.

Baseline model

In the baseline model, we present solutions that maximize the objective function in Eq. (3) under Eq. (4) constraints.[8] Equations (5), (6), (7), and (8) summarize the inner solution of the optimal payment portfolio in the baseline model. For convenience, let $R_{Deposit} = R$.

$$Cash^* = Q - \frac{D}{(R - R_{CBDC})\beta}, \tag{5}$$

$$Deposits^* = 2Q - \frac{A}{R\beta} - \frac{L + D}{(R - R_{CBDC})\beta}, \tag{6}$$

$$CBDC^* = -Q + \frac{L + D}{(R - R_{CBDC})\beta}, \tag{7}$$

$$Stablecoin^* = -Q + \frac{A}{R\beta} + \frac{D}{(R - R_{CBDC})\beta}. \tag{8}$$

Here holding a certain number of all four types of payment assets satisfies $\min(Cash^*, Deposits^*, CBDC^*, Stablecoin^*) > 0$. Therefore, the necessary and sufficient conditions for holding all the payment assets can be represented as follows:

$$\frac{A}{R\beta} + \frac{L + D}{(R - R_{CBDC})\beta} < 2Q, \tag{9}$$

$$\frac{D}{(R - R_{CBDC})\beta} < Q < \frac{L + D}{(R - R_{CBDC})\beta}, \tag{10}$$

$$Q < \frac{D}{(R - R_{CBDC})\beta} + \frac{A}{R\beta}, \tag{11}$$

where the inequalities depict the circumstances of agents demanding deposits, cash, CBDC, and stablecoin If these conditions are not met, some assets may be excluded from the portfolio (i.e., demand for some assets may be zero), which is the corner solution case. We address this discussion in "Corner solutions for the baseline model" section.

[8] All solutions in this study were derived using Python. The python codes are available upon request.

Portfolio equations Suggest that the optimal choice is related to the magnitude of the agent's preferences. For example, the convenience of a digital currency and the difference in interest rates between deposits and CBDCs affect cash demand, while anonymity, interest rate, digital currency, and legal tender affect deposit demand. As a result, the set of preferred payment assets may vary depending on the agent's preferences. We analyze changes in the composition of the payment portfolio based on this principle when the properties of the payment assets change. Let partial derivatives of the agent's portfolio choice with respect to each property of payment assets be denoted by subscript L, D, A, and I, respectively.

First, when the demand for legal tender increases, an agent's preferences are the same, as follows:

$$\begin{cases} Deposits_L < 0 \\ Cash_L = Stablecoin_L = 0 \\ 0 < CBDC_L \end{cases} \tag{12}$$

In this case, the demand for deposits (CBDC) decreases (increases). In other words, an increase in the preference for legal tenders results in the agent substituting CBDC for deposits. Owing to the quasilinear utility function, the demand for deposits that have no utility-contributing factors other than digital ones, except for interest, decreases. As a result, decreased holdings of digital currency can be offset by increased demand for CBDC or a stablecoin. Because CBDC is a legal tender and digital currency, an agent prefers it to stablecoins or cash. As a result, the demand for CBDC rises while the demand for deposits falls.

Second, when the demand for anonymous assets increases, the agent's preferences are the same, as follows:

$$\begin{cases} Deposits_A < 0 \\ Cash_A = CBDC_A = 0 \\ 0 < Stablecoin_A \end{cases} \tag{13}$$

Here, the agent substitutes the stablecoin for the deposits. As the preference for anonymous assets grows, so does the demand for cash and stablecoins. Nonetheless, the demand for cash does not change in this case because the marginal utility of digital currency rises as the demand for deposits falls. Therefore, the agent prefers the stablecoin, an anonymous asset, to cash.

Next, when the demand for digital currency increases, the agent's preferences remain the same, as follows:

$$\begin{cases} Cash_D = Deposits_D < 0 \\ 0 < CBDC_D \\ 0 < Stablecoin_D \end{cases} \tag{14}$$

In this case, demand for cash and deposits falls, whereas demand for CBDC and stablecoin rises. Even though deposits, CBDC, and stablecoin are all digital currencies, the interpretation of the decrease in demand for deposits is as follows. Because the utility function with respect to the interest rate is assumed to be linear, the agent's optimal choice is primarily influenced by the properties of anonymity and legal tender. Deposits are inferior to CBDC and stablecoin in terms of anonymity and legal tender among digital currency assets. As a result, demand for deposits falls as demand for CBDC and stablecoin rises.

Finally, a change in interest rates levied on the deposits and the CBDC has the following effects. First, if the interest rate charged to the deposits increases, an agent's preferences are the same, as follows:

$$\begin{cases} CBDC_R < 0 \\ Stablecoin_R < 0 \\ 0 < Cash_R < Deposits_R \end{cases} \tag{15}$$

Here, the demand for deposits and cash increases, whereas the demand for CBDC and stablecoin decreases. The increase in the interest rate for deposits means substitutions occur between the CBDC and deposits, which are the same interest-bearing assets. Here, the marginal utility of the legal tender increases because of the reduced demand for the CBDC. Therefore, the demand for cash increases, and at this time, the demand for stablecoin partially decreases as an anonymous asset is held. However, when the interest rate imposed on the CBDC increases, because an agent's preferences are the same, $Deposits_{R_{CBDC}} < Cash_{R_{CBDC}} < 0 < Stablecoin_{R_{CBDC}} < CBDC_{R_{CBDC}}$, the demand for the CBDC increases the most. As in the previous case, the increase in interest rates imposed on the CBDC results in the substitution between the CBDC and deposits in the agent's portfolio. The marginal utility of legal tender decreases as an agent's CBDC holding increases, and thus the demand for cash decreases. As a result, as the demand for anonymous assets grows, so does the demand for stablecoins. It is important to note that a change in an agent's preference for a specific payment asset property does not necessarily result in a change in every asset in the portfolio.

Corner solutions for the baseline model

Previously, we analyzed a case in which an agent has all types of payment assets. The agent's asset selection may vary depending on his/her preferences for payment asset properties, as shown in Eqs. (9), (10), and (11). In other words, there are some situations in which a few assets are not chosen for a portfolio, and these are referred to as corner solutions.[9] Corner solutions occur when any inequality condition is not satisfied. Using Eqs. (9), (10), and (11), we can derive the following corollary that shows the conditions of an agent having all types of payment assets:

$$\frac{L-D}{(R-R_{CBDC})\beta} < \frac{A}{R\beta} < Q < \frac{L+D}{(R-R_{CBDC})\beta}. \tag{16}$$

First, only if $\frac{L-D}{(R-R_{CBDC})\beta} < \frac{A}{R\beta}$ condition is not satisfied $\left(\text{i.e., } \frac{A}{R\beta} \leq \frac{L-D}{(R-R_{CBDC})\beta} < Q < \frac{L+D}{(R-R_{CBDC})\beta}\right)$, the demand for the stablecoin may be zero, $Stablecoin^* = 0$. From Eqs. (10) and (11), the necessary and sufficient conditions of the

[9] Here, we analyze the situation in which corner solutions occur. However, since these solutions describe unusual situations, they may undermine the discussion on the real-world economy. Therefore, the numerical results of the specific asset composition are not addressed in this case. Of course, depending on the government's policy, there may be situations where results such as those shown as corner solutions appear. An analysis of these cases is presented in detail in the sections below. The details for the other solutions are available upon request.

agent having cash and stablecoin are $\frac{D}{(R-R_{CBDC})\beta} < Q$ and $Q < \frac{D}{(R-R_{CBDC})\beta} + \frac{A}{R\beta}$, respectively. Nevertheless, under these conditions, $\frac{A}{R\beta} \leq \frac{L-D}{(R-R_{CBDC})\beta}$, and the conditions for an agent holding all payment assets must satisfy $\frac{D}{(R-R_{CBDC})\beta} < Q < \frac{D}{(R-R_{CBDC})\beta} + \frac{A}{R\beta} \leq \frac{D}{(R-R_{CBDC})\beta} + \frac{L-D}{(R-R_{CBDC})\beta}$. Therefore, inequality $\frac{D}{(R-R_{CBDC})\beta} < Q \leq \frac{L}{(R-R_{CBDC})\beta}$ should be satisfied. Here, using Eq. (9), $\frac{A}{R\beta} + \frac{L+D}{(R-R_{CBDC})\beta} < \frac{A}{R\beta} + \frac{D}{(R-R_{CBDC})\beta} + Q < 2Q$ should be satisfied. When this condition is satisfied, $\frac{A}{R\beta} + \frac{D}{(R-R_{CBDC})\beta}$ should be lower than Q, which denotes that the demand for stablecoin is zero. One possible interpretation is that the preference for anonymous assets, digital currency, and legal tender is strongly related to the demand for stablecoins. Because stablecoins with anonymity as a unique feature are only digital currencies, an economic agent does not hold them if the demand for anonymous assets is too low. Additionally, the high demand for legal tenders makes the agents hold cash or CBDC instead of stablecoins.

Second, if the $\frac{A}{R\beta} < Q$ condition is not satisfied (i.e., $\frac{L-D}{(R-R_{CBDC})\beta} < Q \leq \frac{A}{R\beta} < \frac{L+D}{(R-R_{CBDC})\beta}$), the demand for deposits may be zero, $Deposits^* = 0$ From Eqs. (9) and (10), the necessary and sufficient conditions of the agent with deposits and CBDC are $\frac{A}{R\beta} + \frac{L+D}{(R-R_{CBDC})\beta} < 2Q$ and,$Q < \frac{L+D}{(R-R_{CBDC})\beta}$ respectively. Nevertheless, if the condition $\frac{A}{R\beta} < Q$ is not satisfied, the contradictions occur between Eqs. (9) and (10). Here, if Eq. (9) is not satisfied, whereas Eq. (10) is satisfied, the demand for deposits becomes zero. That is, if the preference for anonymous assets is sufficiently strong or the deposit interest rate is sufficiently low, economic agents may not demand any deposits. As discussed in "Baseline model" section, stablecoins are preferred over deposits when there is a large demand for anonymous assets. Moreover, when the deposit interest rate is as low as the CBDC's, the economic agent prefers the CBDC, which is legal tender to the depositor.[10] However, if Eq. (9) is satisfied and Eq. (10) is not, there are two possible contradiction cases: $Q \leq \frac{D}{(R-R_{CBDC})\beta}$, and $\frac{L+D}{(R-R_{CBDC})\beta} \leq Q$. The former causes a contradiction when Eq. (9) is satisfied, under $Q \leq \frac{A}{R\beta}$. The latter also causes a contradiction because we have already assumed that condition $\frac{A}{R\beta} < \frac{L+D}{(R-R_{CBDC})\beta}$ is satisfied.

Third, if the $\frac{D}{(R-R_{CBDC})\beta} < Q$ condition is not satisfied (i.e., $\frac{D}{(R-R_{CBDC})\beta} \geq Q$), the demand for cash may be zero,$Cash^* = 0$ This may occur when the demand for digital currencies increases or the difference in interest rates between interest-bearing assets decreases.[11]

Fourth, if the $\frac{L-D}{(R-R_{CBDC})\beta} < Q$ condition is not satisfied, there are two possible cases: $Q \leq \frac{L-D}{(R-R_{CBDC})\beta} < \frac{A}{R\beta} < \frac{L+D}{(R-R_{CBDC})\beta}$, or $\frac{A}{R\beta} < Q \leq \frac{L-D}{(R-R_{CBDC})\beta} < \frac{L+D}{(R-R_{CBDC})\beta}$. In the former case, because $Q \leq \frac{L-D}{(R-R_{CBDC})\beta} < \frac{A}{R\beta} < \frac{L+D}{(R-R_{CBDC})\beta}$ is satisfied, the agent demands CBDC and stablecoins. With respect to the demand for deposits, because $Q \leq \frac{L-D}{(R-R_{CBDC})\beta} < \frac{L}{(R-R_{CBDC})\beta}$ and $Q < \frac{D}{(R-R_{CBDC})\beta} + \frac{A}{R\beta}$ are satisfied, the condition of an agent demanding deposits, $\frac{A}{R\beta} + \frac{L+D}{(R-R_{CBDC})\beta} < 2Q$, cannot be satisfied. Therefore,

[10] We do not discuss the specific portfolio selection here, since the situation above is a rare occurrence ($Deposits^* = 0$). Nevertheless, we focus on agent selection by presenting the factors that may affect the demand for deposits. The related discussion is presented in "Same interest rate on deposits and the CBDC" section.

[11] A more detailed discussion of this case is presented in "Model without a CBDC" section.

the demand for deposits becomes zero, $Deposit^{*}=0$. This can happen when demand for legal tender is high but the interest rate on deposits or demand for digital currency is low. These examples reflect the agent's perception of the deposit as a less appealing asset. In the latter case, the stablecoin's demand is zero, $Stablecoin^{*}=0$. This result is similar to the first case.

Fifth, only if the $Q<\frac{L+D}{(R-R_{CBDC})\beta}$ condition is not satisfied (i.e., $\frac{A}{R\beta}\leq\frac{L-D}{(R-R_{CBDC})\beta}<\frac{L+D}{(R-R_{CBDC})\beta}\leq Q$), the demand for the CBDC becomes zero, $CBDC^{*}=0$. This can happen if there is a low demand for legal tender or digital currency, high interest rates on deposits, or a low interest rate on the CBDC. Because all of these properties can have a direct impact on CBDC demand, a low preference for them by an economic agent can result in no demand for CBDC.

Model without a CBDC

Although many central banks around the world encourage the issuance of CBDCs, the need for them is still being debated academically. In other words, some countries do not issue CBDCs, which we can investigate. Here, an agent's problem can be represented as follows:

$$\max U(Q_L,Q_A,Q_D,Q_I)=\ln\left(Q_L^{l}Q_A^{a}Q_D^{d}\right)+\beta R_{Deposits}Q_I, \tag{17}$$

$$s.t.\begin{cases}Q_L=Cash\\ Q_A=Cash+Stablecoin\\ Q_D=Deposits+Stablecoin\\ Q_I=Deposits\\ Q=Cash+Deposits+Stablecoin\end{cases} \tag{18}$$

In the absence of a CBDC, Eq. (18) depicts the constraints reflecting the properties of payment assets. Furthermore, in contrast to Eq. (3), the deposit is the only currency that pays interest because the CBDC does not exist, Eq. (17) describes this discussion. As a result, the deposit is interest-bearing property is unique, and the CBDC's holding ratio among the assets of interest should be zero.$\varphi=0$ Additionally, cash is the only legal currency. Here, an economic agent's optimal payment asset portfolio can be analyzed as follows:

$$Cash^{*}=Q\left(\frac{L}{D+L}\right), \tag{19}$$

$$Deposits^{*}=Q-\frac{A}{R\beta}, \tag{20}$$

$$Stablecoin^{*}=-Q\left(\frac{L}{D+L}\right)+\frac{A}{R\beta}. \tag{21}$$

Equations (19), (20), and (21) show the inner solution when the CBDC does not exist. Here, the necessary and sufficient condition for the agent holding all payment assets is shown in Eq. (22):

$$Q\left(\frac{L}{D+L}\right) < \frac{A}{R\beta} < Q. \tag{22}$$

We assume Eq. (22) is satisfied and examine the inner solution. The demand for cash is affected by the digital currency and legal tender properties in the above equations, the demand for deposits is affected by anonymity and interest-bearing properties, and the demand for stablecoin is affected by legal tender, digital currency, anonymity, and interest-bearing properties. When the central bank does not issue a CBDC, it is similar to when consumers can trade crypto-assets and the government encourages stablecoin transactions. Here, when the agent's preference for legal tender increases, the agent's preferences are the same, as follows:

$$\begin{cases} Stablecoin_L < 0 \\ Deposits_L = 0 \\ 0 < Cash_L \end{cases} \tag{23}$$

The agent here substitutes cash for stablecoin. Because cash is a legal tender, unlike a stablecoin, the substitution between these assets is intuitively obvious. However, the agent does not substitute cash for deposits, although deposits are illegal tender. This situation can be interpreted as the agent's utility from the interest rate increasing linearly. The substitution does not occur because the properties of the deposits differ from those of cash. Moreover, as the demand for cash increases, the agent's marginal utility of anonymous assets decreases, and thus the demand for the stablecoin decreases.

Second, when the agent's preference for anonymous assets increases, the agent's preferences are the same, as follows:

$$\begin{cases} Deposits_A < 0 \\ Cash_A = 0 \\ 0 < Stablecoin_A \end{cases} \tag{24}$$

Here, the agent substitutes stablecoins for deposits. Since the demand for deposits decreases as the agent's preference changes, the marginal utility of the digital currency increases; therefore, an agent prefers stablecoins to cash.

Third, when the agent's preference for digital currency increases, the agent's preferences are the same, as follows:

$$\begin{cases} Cash_D < 0 \\ Deposits_D = 0 \\ 0 < Stablecoin_D \end{cases} \tag{25}$$

In this case, the agent may substitute stablecoins for cash. As the demand for cash falls as the demand for digital currency rises, the agent's marginal utility of anonymous assets rises, thereby increasing the demand for stablecoins while decreasing the demand for deposits.

Fourth, if the interest rate on the deposits increases, the agent's preferences are the same, as follows:

$$\begin{cases} Stablecoin_R < 0 \\ Cash_R = 0 \\ 0 < Deposits_R \end{cases} \tag{26}$$

Therefore, a transfer from stablecoins to deposits occurs. This result implies a substitution effect resulting from a decrease in the demand for stablecoins in line with an increase in the demand for deposits because both deposits and stablecoins are both digital currencies.

The above cases are situations under the conditions of an agent having all types of payment assets. However, the corner solution cases are as follows. Since the asset properties are all utility-contributing, a condition $Q\left(\frac{L}{D+L}\right) < Q$ is already satisfied. Therefore, corner solutions occur when,$Q\left(\frac{L}{D+L}\right) \geq \frac{A}{R\beta}$ or $Q \leq \frac{A}{R\beta}$. First, if $Q\left(\frac{L}{D+L}\right) \geq \frac{A}{R\beta}$, the demand for a stablecoin may be zero, $Stablecoin^* = 0$. The conditions occur in the following situations: when the demand for anonymous assets is low, when the demand for legal tender is high, or when the interest rate imposed on deposits is high. These circumstances usually result in the stablecoin being substituted for other payment assets, which can make the demand for stablecoin zero. Second, if $Q \leq \frac{A}{R\beta}$, then the demand for deposits may be zero, $Deposit^* = 0$. Contrary to the previous case, if the demand for anonymous assets is high or the interest rate is low, the substitution between deposits and other assets may occur.

Model without cash

The central bank may ultimately replace cash with the CBDC, owing to digital money's convenience and policy efficiency. Therefore, we discuss the case in which the CBDC entirely replaces cash. That is, all payment assets are digital currencies and the agent's problem can be represented as follows:

$$\max U(Q_L, Q_A, Q_D, Q_I) = \ln(Q_L^l Q_A^a Q_D^d) + \beta\{R_{CBDC}\varphi + R_{Deposits}(1-\varphi)\}Q_I, \tag{27}$$

$$s.t.\begin{cases} Q_L = CBDC \\ Q_A = Stablecoin \\ Q_D = Deposits + CBDC + Stablecoin \\ Q_I = Deposits + CBDC \\ Q = Deposits + CBDC + Stablecoin \end{cases} \tag{28}$$

Here, the constraints in Eq. (28) reflect the properties of the payment assets, excluding cash. Unlike Eq. (4), CBDC is the only legal tender, and all payment assets are digital currencies in this case since there is no cash. Accordingly, an economic agent's optimal payment asset portfolio can be analyzed as follows:

$$Deposits^* = Q - \frac{A}{R\beta} - \frac{L}{(R - R_{CBDC})\beta}, \tag{29}$$

$$CBDC^* = \frac{L}{(R - R_{CBDC})\beta}, \tag{30}$$

$$Stablecoin^* = \frac{A}{R\beta}. \tag{31}$$

Equations (29), (30), and (31) show the inner solution in the situation where the CBDC replaces all cash. Here, the necessary and sufficient condition for holding all types of payment assets is shown in Eq. (32):

$$0 < \frac{L}{(R - R_{CBDC})\beta} + \frac{A}{R\beta} < Q. \tag{32}$$

Let the condition presented in Eq. (32) be satisfied, and analyze the inner solution cases. Unlike the previous analysis, the demand for digital currencies does not affect the portfolio composition in the above equations. Since cash is no longer available, all payment assets are digital currencies, meaning an increase or decrease in the agent's demand for a digital currency cannot affect the asset portfolio composition. Namely, the marginal utility of each payment asset for the digital currency property is zero: $CBDC_D = Deposits_D = Stablecoin_D = 0$. In this case, if the demand for legal tender increases, the agent's preferences are the same, as follows:

$$\begin{cases} Deposits_L < 0 \\ Stablecoin_L = 0 \\ 0 < CBDC_L \end{cases} \tag{33}$$

Here, the agent substitutes CBDC for the deposits. This result is caused by the utility function. Since all payment assets are digital currencies and the interest rate linearly affects the utility, the agent may substitute the CBDC for deposits.

Second, when the agent's preference for anonymous assets increases, the agent's preferences are the same, as follows:

$$\begin{cases} Deposits_A < 0 \\ CBDC_A = 0 \\ 0 < Stablecoin_A \end{cases} \tag{34}$$

Here, the agent substitutes the stablecoin for the deposits. This result is the same as that in "Baseline model" section, but for a different reason. As the demand for stablecoin increases, the marginal utility of anonymous assets decreases. Nevertheless, because the decreasing marginal utility of a digital currency does not affect an agent's choice, legal tender or interest-bearing properties are important. As the utility function satisfies quasi-linearity, the agent prefers the CBDC to deposits.

Finally, the portfolio changes when the interest rate increases as follows, First, if the interest rate charged on deposits increases, the agent's preferences are the same, as follows:

$$\begin{cases} CBDC_R < 0 \\ Stablecoin_R < 0 \\ 0 < Deposits_R \end{cases} \tag{35}$$

Here, the demand for deposits rises, whereas demand for CBDC and stablecoin falls. Substitutions between CBDC, stablecoins, and deposits may occur intuitively as interest rates on deposits rise. However, if the interest rate imposed on the CBDC increases, the agent's preferences are the same, as follows:

$$\begin{cases} Deposits_{R_{CBDC}} < 0 \\ Stablecoin_{R_{CBDC}} = 0 \\ 0 < CBDC_{R_{CBDC}} \end{cases} \tag{36}$$

Here, the agent substitutes only between the CBDC and deposits. The intuitions behind these results are as follows. In the former case, deposits, unlike other payment assets, do not have the properties of anonymity or legal tender. As a result, an increase in interest rates has substitution effects on all other payment assets. Conversely, in the latter case, because the demand for CBDC, which is legal tender, rises, the demand for a stablecoin that provides anonymity remains unchanged, and only the demand for deposits decreases.

However, the corner solution cases are as follows. From Eqs. (29), (30), and (31), demand for the CBDC and stablecoin always exists. In other words, the corner solution can only occur when $Q \leq \frac{L}{(R-R_{CBDC})\beta} + \frac{A}{R\beta}$. In this case, the demand for deposits may be zero: $Deposits^* = 0$. An agent has a different type of payment asset than a deposit when there is a high demand for legal tender or an anonymous asset. Furthermore, if the deposit interest rate is too low, as it is close to that of the CBDC, there is no incentive for the agent to hold deposits. In short, an agent does not hold deposits as the incentive to do so diminishes.

Without anonymity on stablecoins

Since exchanges using cryptocurrencies are based on blockchain technologies, tracking transactions is quite difficult; therefore, money transactions using cryptocurrencies seem to be anonymous. Accordingly, illegal activities occur on many cryptocurrency exchanges (Foley et al. 2019). Money laundering or tax evasion can reduce social welfare when compared to an economy where the central bank can control anonymity (Kwon et al. 2022). Therefore, the central bank has an incentive to provide a legal mechanism for requesting the submission of personal account transactional records to domestic cryptocurrency exchanges. If such a mechanism is developed, the stablecoin's anonymity may be lost. Under this condition, the agent's problem can be represented as the following:

$$\max U(Q_L, Q_A, Q_D, Q_I) = \ln\left(Q_L^l Q_A^a Q_D^d\right) + \beta\left\{R_{CBDC}\varphi + R_{Deposits}(1-\varphi)\right\}Q_I, \tag{37}$$

$$s.t. \begin{cases} Q_L = Cash + CBDC \\ Q_A = Cash \\ Q_D = Deposits + CBDC + Stablecoin \\ Q_I = Deposits + CBDC \\ Q = Cash + Deposits + CBDC + Stablecoin \end{cases} \tag{38}$$

Here, the constraints in Eq. (38) reflect the properties of the payment assets when the stablecoin has no anonymity. Here, cash is the only anonymous payment asset, while stablecoin is only a digital currency. In this context, the optimal portfolio of an economic agent can be analyzed as follows. Because stablecoin's only utility-contributing feature is that it is a digital currency, it may be a subpar asset when compared to other payment assets such as CBDC or deposits. In other words, because the marginal utility of the stablecoin is always lower than that of the CBDC or deposits, the demand for the stablecoin becomes zero, $Stablecoin^* = 0$. However, it is unlikely that this demand will be zero in the real world. In contrast to this model, stablecoin demand accounts for a sizable portion of the cryptocurrency market. This result, however, theoretically demonstrates that anonymity explains a significant portion of the demand for cryptocurrencies such as stablecoins.

Same interest rate on deposits and the CBDC

In this subsection, we analyze the direct policy effect of charging interest on the CBDC on the demand for deposits. As mentioned previously, the CBDC is generally expected to have a lower interest rate than the deposits. When we assume that the same interest rate is charged on CBDCs and deposits, the impact of issuing CBDCs on deposits can be easily understood. Here, the agent's problem can be represented as follows:

$$\max U(Q_L, Q_A, Q_D, Q_I) = \ln(Q_L^l Q_A^a Q_D^d) + \beta R Q_I, \tag{39}$$

$$s.t. \begin{cases} Q_L = CBDC \\ Q_A = Stablecoin \\ Q_D = Deposits + CBDC + Stablecoin \\ Q_I = Deposits + CBDC \\ Q = Deposits + CBDC + Stablecoin \end{cases} \tag{40}$$

Since the interest rates on the CBDC and deposits are the same, in Eq. (39), the interest rates are denoted as $R_{Deposits} = R_{CBDC} = R$, which means the agent feels the same utility from either interest. In this regard, the theoretical result is that the agent does not hold any deposits, $Deposits^* = 0$. Because the CBDC and deposits are both digital currencies, the agent strongly prefers to hold a legal tender, CBDC. In other words, a deposit can be an inferior asset to the CBDC. This result is also related to existing studies that state that levying an interest rate above a certain level on a CBDC may negatively affect commercial bank profitability (Andolfatto 2021; Bindseil 2019; Jun and Yeo 2021).

Conclusions

We examine an agent's selection of an optimal payment asset portfolio by focusing on changes in exogenous conditions. Based on the properties of four payment assets, we derive the agent's optimal portfolio selection. Furthermore, we demonstrate how agents' choices change as the properties of payment assets change. With the emergence of diverse payment methods, the distinguishing characteristics of each payment asset have become important in determining the demand for that asset. When a CBDC entirely replaces cash, the agent's asset reallocation method may also change, since characteristics such as being a digital currency do not affect the agent's portfolio choice. Additionally, we show that when properties like anonymity are removed, the demand for cryptocurrencies can plummet dramatically. The issuance of a CBDC, the interest rate that can be paid or charged on the CBDC (to allow better central bank control over interest rates, including negative interest rates), and the anonymity regulation on cryptocurrency exchanges are all economic actions that central banks and governments may consider. Policymakers must therefore understand how an agent's payment portfolio changes in each case. In this regard, the exogenous conditions studied in our study suggest real-world conditions, and there are policy implications such as the crowding-out effect of CBDC or the effect of cryptocurrency exchange regulation. Finally, our research has implications for commercial bank profitability, which is a critical issue in the context of CBDCs. We examine the substitution effects of a CBDC and deposits from various angles, taking into account properties such as legal tender and interest rates. However, the portfolio change method according to changes in exogenous conditions analyzed in this study has room for improvement in future studies. Chain effects of monetary policy, such as interest rate policy, can also affect the features of payment assets. If a future study empirically analyzes these aspects, the theoretical limitations of this current study can be supplemented.

Abbreviations

CBDC	Central bank digital currency
NIRP	Negative interest rate policy

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