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CENTRAL BANK DIGITAL CURRENCY AND CASH: CHOICE BASED ON BAUMOL'S THEORY

Abstract:

With the rapid growth of the digital economy, digital currency has emerged as a prominent area of research. Central Bank Digital Currency (CBDC), issued by the central bank and backed by its liability, has garnered significant attention. This article builds upon Baumol's money demand theory to conduct an extensive analysis of the factors influencing the choice between cash and CBDC, as well as the selection of currency usage. It finds that the decision to adopt either cash or CBDC is often driven by the lower holding costs associated with the latter. Additionally, various factors such as public perception, government policies, and social acceptance contribute to the prolonged coexistence of cash and CBDC. Although CBDC in their current state may not completely replace traditional currencies, they are projected to have a substantial impact on the future of financial transactions.

Keywords:

Digitalization, central bank digital currency, CBDC, cash, Baumol's money demand theory

1 Introduction

The choice between cash and Central Bank Digital Currency (CBDC) has become a topic of increasing interest and importance in the modern financial landscape (Fan, 2021). As digital payment systems continue to evolve and gain prominence, there is a need to understand the implications of transitioning from traditional cash-based transactions to a digital currency issued by central banks.

Cash is a form of credit currency issued by a national organization or authorized by the government. It typically consists of banknotes and coins and is backed by the credit of the country (Du and Ji, 2022). In the field of accounting, cash can be classified into broad and narrow senses. Narrowly defined, cash refers to the physical currency in circulation. In a broader sense, cash encompasses not only the physical currency in circulation but also bank deposits and other monetary funds (Liu and Chen, 2012). For the purpose of this study, the term "cash" specifically refers to cash in the narrow sense.

Table 1: Comparison between central bank digital currency and cash

	CBDC	Cash
issuance department	central bank	central bank
stable value	1:1official currency	1:1official currency
anonymity	controlled anonymity	complete anonymity
legal validity	legal currency	legal currency
Possibility of trading without access to the Internet	need the Internet	no need

Source: Own adjustment

Central Bank Digital Currency is a digital currency issued by the central bank named after the national unit of account, which represents the liability of the central bank (Kosse and Mattei, 2022). Like physical cash, CBDCs can also be used for everyday payments and can be exchanged for the same price as the currency of commercial banks (Armelius, 2021).

The digitization of payments has witnessed remarkable growth in recent years, driven by advancements in technology and changing consumer preferences (Barontini and Holden, 2019). Digital payment methods such as mobile wallets, online banking, and cryptocurrencies have gained widespread adoption, offering convenience, speed, and enhanced security (Wang, 2022). However, despite the rise of digital transactions, physical cash remains a significant medium of exchange in many economies. Cash provides certain advantages, including universal acceptance, anonymity, and immediate settlement, which have contributed to its continued relevance (Fan and Yin, 2020).

Despite the growing interest in CBDC and the choice between cash and digital currency, there is a notable research gap in terms of comprehensive studies that analyze the factors influencing this choice. Existing literature has primarily focused on the benefits and drawbacks

of CBDC or addressed specific aspects of digital payments without fully exploring the decision-making process between cash and CBDC. Therefore, this research aims to address this research gap by providing a comprehensive analysis of the factors influencing the choice between cash and CBDC, considering both individual and systemic perspectives. By doing so, this study seeks to contribute to the existing literature and offer valuable insights for academia, policymakers, central banks, financial institutions, and the general public.

The primary objectives of this research are to: Comprehensively analyze the factors influencing the choice between cash and CBDC. And provide recommendations for policymakers and stakeholders on the optimal path forward in terms of the choice between cash and CBDC.

This study is significant for several reasons. On the one hand, it addresses the research gap by providing a comprehensive analysis of the factors influencing the choice between cash and CBDC. By exploring individual preferences, societal factors, and economic considerations, this research contributes to a deeper understanding of the decision-making process. On the other hand, this research offers recommendations for policymakers and stakeholders based on theoretical findings, aiding in the decision-making process regarding the adoption of CBDC.

2 Review of Literature

There is no difference between central bank digital currency and cash in terms of attributes and functions. Both are legal tender and are backed by national credit. Both transactions are wallet-type payment instruments, with no interest during the holding period and large holding costs (Yang, 2022).

Currently, while the use of cash may be decreasing, we are still very far away from a cashless society. So why haven’t digital payments completely replaced physical cash? (Johannes, 2019). Many scholars have conducted research on the the factors influencing the choice between cash and CBDC.

When conducting research from the perspective of payment instrument selection, the cost structure of payment instruments has always been an important focus. Different payment instruments have different cost structures, and the main parts of the cost structure include two aspects: first, explicit costs such as price; second, implicit costs such as time, convenience and other factors (Arango et al., 2015). By comparing the performance of electronic money, signature cards and cash in different transaction scenarios and analyzing their cost structures, it was found that electronic currency has certain advantages when it comes to small-amount transactions. Users tend to choose signature cards when it comes to large-amount transactions, and only use cash when the delivery tools of both parties to the transaction do not match (Shy and Tarkka, 2002). By constructing a general equilibrium model for analysis, it was found that the unique cost structures of different payment instruments determine their different

payment ranges (Callado et al., 2010). It was also found that transaction volume is an important factor affecting users' choice of payment instruments (Fujiki and Tanaka, 2018).

The main factors that influence the choice of payment instruments are not only the cost structure of the payment instrument itself, but also the characteristics of the users. Research has found that age (Schuh and Stavins, 2010) and income (Trütsch, 2016) have a significant impact on the choice of payment tools. Middle-to-high-income young women who are well-educated and like to travel are more likely to use credit cards rather than cash (Fu, 2017). For corporate users, companies with better financial management and business capabilities are more likely to use non-cash payment tools (Fu, 2018).

There are also scholars who study the choice of payment instruments based on some non-cost factors. The perceived interaction between users and payment instruments, technology trust and expectations, and the market influence of service providers also affect the choice of payment instruments (Oliveira et al., 2013). The impact of perceived network externalities on mobile payments also has a significant positive impact on the choice of payment tools (Ajao and Abu-Shanab, 2015).

Since the emergence of central bank digital currency, the extent to which non-cash payment instruments can replace cash has been a focus of debate.

Some scholars believe that non-cash payment tools will greatly reduce the space for cash, and may even lead to a "cashless society" to a large extent. As early as the last century, some scholars predicted that under the impact of the new generation of electronic device technology, a "checkless society" would arrive in 1980, and a "cashless society" would follow closely (Reistad, 1967). From the perspective of payment costs, the payment costs of existing non-cash payment instruments such as bank cards are still declining, while in contrast, the cost of cash payments is rising (Gresvik and Haare, 2009). In addition to the payment cost perspective, by analyzing from the perspective of cash holding motives and it was found that electronic currency has an almost complete substitution effect on speculative cash holdings, while there is an incomplete substitution effect on cash holdings with transactional and precautionary motives (Wang and Feng, 2017).

Some scholars hold different opinions. They believe that despite the great advantages of CBDC, cash still occupies an indispensable and important position in the global economic system. The liquidity of cash has an advantage in payments, especially in small payment scenarios (Kalckreuth and Schmidt, 2013). This view is confirmed in data studies of Germany, Austria, Canada and France, which show that in payment scenarios below 3 euros, the usage rate of cash exceeds 90% (Arango et al., 2017). And from the perspective of payment instrument pricing, scholars studied the impact of pricing on the substitution effect of payment instruments and found that cash still has certain advantages in many specific payment scenarios (Li et al., 2019).

According to a comprehensive analysis of existing research results, the focus of research on payment instrument selection has primarily been on the substitution mechanism and factors influencing the adoption of payment instruments. However, this line of research predominantly examines the replacement of cash with account-based payment tools, with limited attention given to digital currencies. There is a significant research gap that needs to be addressed by examining the cost structure of digital currencies and quantifying their non-cost factors. Such an analysis would serve as a crucial theoretical foundation for future studies on the impact of digital currencies on the payment market.

3 Mathematics

3.1 Theoretical Framework

Keynes's money demand theory emphasizes that individuals' demand for holding money arises from three motivations: transaction motivation, precautionary motivation and speculative motivation. Keynes refers to this overall demand for money as liquidity preference, represented by the symbol L, which serves as the money demand function. Specifically, the money demand for transaction and precautionary motives increases with income, while the money demand for speculative motive decreases with the interest rate. Hence, the total money demand, denoted as M, can be divided into two components: M_1, which satisfies the transaction and precautionary motives, and M_2, which satisfies the speculative motive.

In mathematical terms, if Y represents income, r represents the interest rate, L_1 represents the functional relationship between M_1 and Y, and L_2 represents the functional relationship between M_2 and r, Keynes's money demand theory can be expressed as follows:

$$M = M_1 + M_2 = L_1(Y) + L_2(r) = L(Y,r) \quad (1)$$

American economist William Jack Baumol made a significant contribution to transactional money demand theory by introducing interest rates, building upon Keynes's money demand theory. This theory demonstrates the view that, the demand for transactional money is affected by the interest rate, thus revising Keynes' view that the demand for transactional money is not sensitive to the interest rate. Baumol's model is based on the theory that economic behavior aims to maximize returns, so there is no need for all the money used for transactions to be in the form of cash in the time gap between the acquisition and expenditure of monetary income. Rational individuals will aim to minimize the cost of holding cash by choosing the minimum amount necessary.

Baumol's model relies on three key assumptions:

Fixed Income and Fixed Interval: Individuals have fixed incomes within each period, and the interval between incomes remains constant. The monetary demand for expenditure is known and occurs at a uniform rate;

Cash Investment in Short-term Bonds: Individuals utilize cash intended for transactions to purchase short-term bonds, seeking to earn interest. Short-term bonds offer easy liquidity and high security.

Fixed Time Interval and Amount of Bond Liquidation: The time interval and amount for liquidating each short-term bond are fixed, ensuring predictable cash flows and facilitating efficient management of cash holdings.

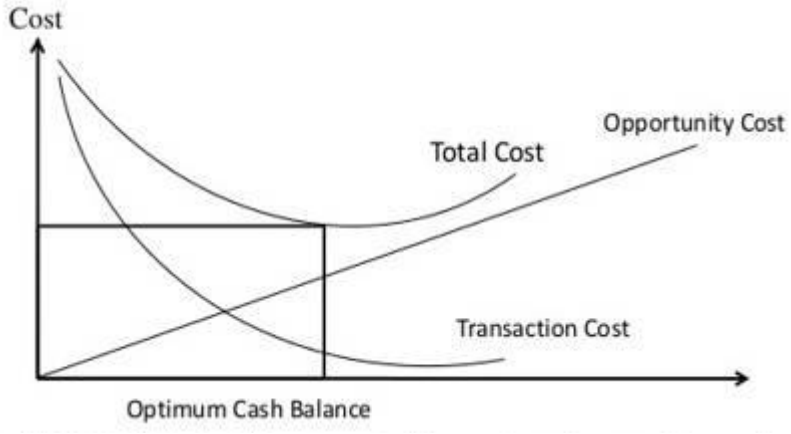
Baumol's model, often referred to as the Baumol model or the square root law.

$$M = \sqrt{\frac{tcy}{2r}} \quad (2)$$

In this formula, M represents transactional demand for money, tc represents the transaction cost between cash and bonds, y is the income at the beginning of the month, and r is the monthly interest rate.

According to this formula, Baumol combined opportunity cost and transaction cost to put forward a model of cash management. Transaction cost is fees for converting financial instruments into cash. Holding cash implies forgoing the interest income that could be earned through investment, resulting in opportunity costs. The total cost is equal to transaction cost plus opportunity cost. When the total cost is lowest, the cash balance is optimal.

Figure 1: Baumol's model: Tradeoff between holding cost and transaction cost



Source: https://images.app.goo.gl/cHNKAEXqaqtGBTAK9

Starting from the inventory theory, Baumol believes that the cash balance people use for transactions is not only related to the size of the transaction, but also related to the opportunity cost and market interest rate. If we represent the total cost of cash inventory as C, the following relationship holds:

$$C = b * \frac{y}{k} + r * \frac{k}{2} \quad (3)$$

There are two costs associated with cash inventory: The first is the handling fee, denoted as b, incurred when liquidating financial instruments. Let's assume that initial amount of money (or valuation of a financial instrument) is represented by k, and the total expenditure is denoted as y. Within an expenditure period, the total handling fee is $b*\frac{y}{k}$. The second is the interest cost (opportunity cost) sacrificed by holding cash. The average transaction balance during the expenditure period can be represented by $\frac{k}{2}$. Assuming the interest rate is represented by r, the interest cost is therefore $r*\frac{k}{2}$.

By optimizing the trade-off between handling fees and interest costs, we can minimize the total cost.

$$C^* = \sqrt{2bry} \quad (4)$$

And by taking the derivative of C, we can further derive that when the total cost is minimized, the amount of each financial instruments liquidation should be $k=\sqrt{\frac{2by}{r}}$. Consequently, the average cash balance on hand is $\frac{1}{2}\sqrt{\frac{2by}{r}}$.

3.2 Theoretical Analysis

In Baumol's model, the cost of holding cash includes fees for obtaining cash and the opportunity cost of holding cash instead of earning interest. The fee cost, denoted as b, encompasses charges incurred when converting financial instruments to cash, as well as time and transportation costs associated with obtaining and returning cash from the bank. Additionally, holding banknotes incurs storage costs, such as the need for a secure storage place like a safe. Generally, storage costs do not significantly increase with the amount of banknotes held and can be considered a one-time fixed cost, represented by z. Therefore, the total cost of banknote inventory can be expressed as:

$$C_{cash} = b * \frac{y}{k} + r * \frac{k}{2} + z \quad (5)$$

To minimize the cost of banknote inventory, the expression becomes:

$$C_{cash}^{*} = \sqrt{2bry} + z \quad (6)$$

Assuming a fixed exchange rate between CBDC and cash, the costs of holding CBDC differ from those of cash. Firstly, the handling fee for acquiring CBDC, denoted as b', only includes the service fee for obtaining digital currency, as it can be acquired through digital terminals without the need for physical travel. Secondly, the storage cost of digital currency is negligible since it can be stored on devices like mobile phones and computers that users commonly

possess. Therefore, there is no need for additional equipment for storing digital currency. Finally, the usage of digital currency may incur certain costs, such as limitations in its initial scope of application or distrust in new currencies. These costs are collectively referred to as scale costs, represented by x. Scale costs are typically higher in the early stages but gradually decrease, sometimes even reaching zero, as digital currencies become more widely adopted. The total cost of holding digital currency can be expressed as:

$$C_{CBDC} = b' * \frac{y}{k'} + r * \frac{k'}{2} + x \quad (7)$$

The minimum solution for the cost of holding digital currency is:

$$C_{CBDC}^{*} = \sqrt{2b'ry} + x \quad (8)$$

4 Results and Discussion

The issue of choosing between cash and CBDC is actually a matter of comparison between the cost of holding banknotes and the cost of holding digital currency. Usually users will choose the currency with lower holding cost. We can get the following table:

Table 2: Analysis on the selection of CBDC and cash

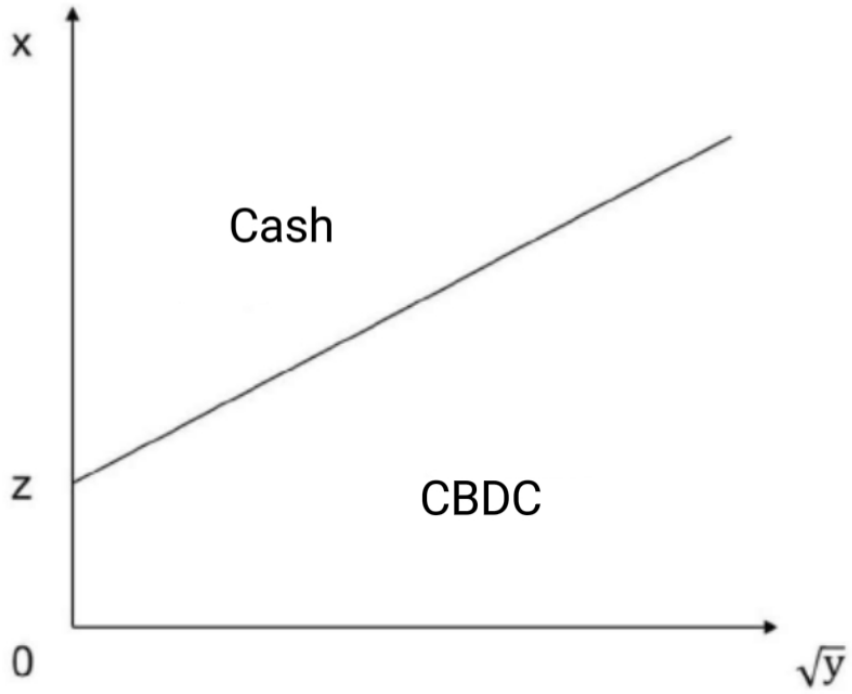
$C_{cash}^{*} > C_{CBDC}^{*}$	$\sqrt{2bry} + z > \sqrt{2b'ry} + x$	Choose CBDC
$C_{cash}^{*} = C_{CBDC}^{*}$	$\sqrt{2bry} + z = \sqrt{2b'ry} + x$	Both are fine
$C_{cash}^{*} < C_{CBDC}^{*}$	$\sqrt{2bry} + z < \sqrt{2b'ry} + x$	Choose cash

From $\sqrt{2bry} + z = \sqrt{2b'ry} + x$, the currency selection boundary of CBDC and cash can be derived:

$$X = \sqrt{2r}\ (\sqrt{b} - \sqrt{b'}\ )\ \sqrt{y} + z \quad (9)$$

The currency selection boundary of CBDC and cash can be viewed as a function $\sqrt{y}$ against x, with a slope of $\sqrt{2r}\ (\sqrt{b} - \sqrt{b'}\ )$ and an intercept of z. From the previous analysis, we can see that b > b', so the slope of the currency selection convenience is positive and is an upward-sloping straight line. As shown in Fig. 2.

Figure 2: Currency selection boundary between central bank digital currency and cash



Source: Own adjustment

If personal income y increases, it is likely that $\sqrt{y}$ will increase accordingly, and some users will switch from holding paper currency to holding digital currency. With higher income, individuals may find it inconvenient to withdraw large amounts of paper currency due to the increased number of trips to the bank, leading to higher costs associated with holding banknotes. In contrast, the holding cost of digital currency may not increase significantly due to the ease of digital transactions. Therefore, individuals may be more inclined to hold digital currency. Furthermore, advancements in technology, the stability of digital currency, and increased adoption of digital payment methods can contribute to the preference for digital currency, x will be greatly reduced. The decline of x can further incentivize individuals to switch from holding paper currency to digital currency.

Some scholars have conducted research on the costs and benefits of phasing out banknotes (Wen, 2016). They suggest that the process should start with large-denomination banknotes and gradually expand to include all coins and banknotes, except for small denominations. However, it is important to note that banknotes have a strong presence in the public image of governments and nations. Therefore, it is likely that banknotes and digital currencies will coexist for a considerable period of time. Although current cryptocurrencies are still far from becoming widely accepted as real currencies, they are undoubtedly a growing trend. As technology continues to evolve and acceptance of cryptocurrencies increases, it is plausible that they will play a significant role in the future of currency. However, the coexistence of traditional banknotes and digital currencies is expected in the foreseeable future.

5 Conclusion

In conclusion, this study aimed to investigate the factors influencing the choice between cash and Central Bank Digital Currency (CBDC) based on Baumol's money demand theory.

The findings of the study indicate that several factors play a significant role in shaping payment preferences. The convenience and accessibility of payment methods emerged as important factors, with individuals and businesses showing a preference for options that offer ease of use and widespread acceptance. Transaction costs, including fees and time required for transactions, also influenced payment choices, with lower costs associated with greater adoption of digital payment methods.

Furthermore, trust in digital payment systems and the perceived security of CBDC were found to be crucial factors influencing the choice between cash and CBDC. Individuals and businesses demonstrated a higher inclination towards using CBDC when they had confidence in the security and reliability of the digital infrastructure.

The study also identified demographic variations in payment preferences. Younger individuals tended to be more receptive to CBDC adoption, reflecting their higher familiarity and comfort with digital technologies. Income levels were found to influence payment preferences as well, with higher-income individuals showing a greater inclination towards digital payment methods.

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