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Seonghoon Cho**

May, 2024

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This article complements a standard New Keynesian dynamic stochastic general equilibrium (DSGE) model with central bank digital currency (CBDC) in which private banks issue two types of deposit: debit and (interest-bearing) deposit. These two instruments are used as liquidity and an asset to households, respectively. Our setup makes clear that CBDC directly competes with traditional money: physical cash and debit, but indirectly with deposit. Introduction of CBDC can have a significant effect on the optimal debit balance in equilibrium. The magnitude and direction in changes in households' debit holding critically hinge on the households' preference for holding CBDC, elasticity of substitutions among cash, debit and CBDC, the potentially non-zero CBDC interest rate, and the optimal response of banks. However, the interest-bearing deposit moves in the opposite direction, offsetting the changes in debit, thus the total bank liabilities and loan are barely affected in the economy with CBDC. This implies that the efficacy of CBDC on output and welfare, if any, is quantitatively only marginal, relative to the findings in the previous studies with only one type of deposit.

Keywords: Central Bank Digital Currency, Welfare

JEL Classification: C32; E43; E52

I. Introduction

There has been a growing body of studies aiming at introducing and analyzing central bank digital currency (CBDC). While the literature is yet to grow, it seems that there has been no consensus on the consequences that CBDC will bring into the reality. From a macroeconomic perspective, important issues include 1) would CBDC be irrelevant or neutral for the economy? 2) if not, what are the central arguments about positive or negative effects of CBDC on the real economy or welfare, 3) what does CBDC compete with? This article attempts to answer the third question, which we believe has been less clearly investigated and is the key to understanding the non-equivocal answers to the first two questions.

Keister and Sanches (2021) effectively demonstrate, using a model built upon the Lagos and Wright (2005), that CBDC would be by and large immaterial. Brunnermeier and Niepelt (2019) derive the conditions under which CBDC is irrelevant. Barontini and Holden (2019) and Auer et al. (2021) are those who emphasize that the credit channel and interest rate channel of private banks are adversely affected as their deposits and loans must compete with CBDC, thus CBDC may lead to a fall in output. On the other hand, introduction of CBDC induces competitiveness in the banking sector and expanding bank intermediation, thereby increasing output on various grounds. Andolfatto (2021), Barrdear and Kumhof (2021), Williamson (2022), Chiu et al. (2023) and Burlon et al. (2022) belong to this line of research.

There are several important factors responsible for these heterogeneous results for the efficacy of CBDC: competitiveness in loan and/or deposit markets, various frictions such as regulations on reserve and capital requirements for banks, borrowing constraints for households, definition of liquidity service, monetary policy with respect to CBDC as well as the primary interest rate, and fiscal policy among others.[1)]

1) Banks' exogenous cost structure associated with loans and deposits are also important in some studies, but we abstract from these management cost approach accounting for the effect of

In this article, we pay more attention to exactly what sort of liquidity or asset CBDC competes with. Many of the aforementioned studies assume that banks issue a single type of – interest-bearing – deposit, and the bank deposit provides the liquidity services just like the real money balance in the utility (See, for instance, Burlon et al. (2022)), or it is treated as an asset for households. While there exists a variety of deposits possessing these two characteristics with different weights in reality, two types of deposit are explicitly considered in this study: non-interest-bearing demand deposit and interest bearing time and savings deposit. For brevity, these two types of bank deposit will be dubbed "debit" or "checking account", and "deposit", respectively in what follows.[2] From this distinction, it is now evident that physical cash, debit and CBDC can be exchanged at par. That is, CBDC is directly competing with traditional money, cash and debit, but indirectly with deposit, just like any other asset. However, this does not imply that the three types of "money" or liquidity are perfect substitutes. While the frictionless exchangeability of these three instruments comes from the supply side of liquidity, households do treat these three instruments as imperfect substitutes on various grounds: convenience, safety, anonymity, etc.

Our setup makes clear the roles of debit and deposit for the transmission of CBDC into the economy. Introduction of CBDC directly leads to a significant change in households' demand for debit balance. The first effect may be termed as a composition effect in liquidity: as long as households are willing to hold CBDC – because it is a new instrument providing liquidity services –, the preference or relative weights of holding traditional money will obviously decrease, which implies an exogenous fall in debit balance for banks. Second, for a given weight of households' holding CBDC, an increase in the CBDC interest rate, a potentially new and powerful monetary policy, would force banks to re-optimize the interest rates on debit, deposit and loan. In this case, the debit balance can

CBDC in this study.

2) Check or checkable accounts actually do pay but low interest, bank also charge a sort of fee in some cases. But what matters is that these types of demand deposit can be used as a transaction purpose without any restriction just like physical cash. For this reason, we assume that debit does not pay interest, although we allow it to be positive when CBDC is introduced.

actually increase. However, there is a strong general equilibrium effect from the households: when there is a change in debit balance, the deposit moves in the opposite direction, rather than adjusting consumption and leisure (labor supply), so that the total liability of banks does not vary too much. This is important because the loan, capital and output will not be changed dramatically. The change in the composition on debit and deposit does affect the reserve holding, but it would not matter quantitatively.

The main result of this paper is that introduction of CBDC would have real effects on the economy and consequently households' welfare, but the effects would be only marginal. Central to our results is the distinction of banks' liability net of banks' capital into two: debit as a liquidity providing instrument and deposit as an asset. Most existing studies claiming a sizable efficacy of CBDC does not distinguish these two types of banks' liability. For example, if the liability – again abstracting from banks' capital –consists of a single (interest-bearing) deposit, the macroeconomic effects of CBDC would be directional: either increasing or decreasing deposit. Henceforth, the implications for the economy and households' welfare would be much bigger than ours. Another important result is that the introduction of CBDC does not directly improve competitiveness of the banking industry for two reasons, contrary to a common argument supportive of CBDC.

Many existing studies do not distinguish these two types of deposit. One exception is Chiu et al. (2023), although the criterion distinguishing banks' deposit is not exactly the same as ours. In their model, checkable deposit and time deposit are explicitly considered and CBDC directly competes with checkable deposit. But it is difficult to compare the specification of the model and the results with those of Chiu et al. (2023) on the same ground. The most important distinction is that the substitution between CBDC and checkable deposit are imperfect in our model whereas they are perfect in Chiu et al. (2023). Second, the checkable deposit is basically interest-bearing as well as the time deposit. In our case, we distinguish deposit as the one that does not pay interest (debit) and pay interest (deposit: savings and time deposit) prior to the introduction of CBDC. Third, the modeling approach follows a standard DSGE model with a banking sector à la

Gerali et al. (2010) and Ulate (2021) whereas it is based on the New-monetarist approach in Lagos and Wright (2005).

The main results turn out to be robust against different specifications and different parameter values. In some studies, fiscal policy is found to be one of the main factors amplifying the effect of CBDC. For instance, while the seigniorage revenue is pretty much marginal in the absence of CBDC, it can be sizable when CBDC balance is several times higher than the physical cash amount issued. Indeed, one of the most important arguments of Burlon et al. (2022) is that the optimal level of CBDC issuance can be over 50% of the nominal GDP. If this additional seigniorage revenue is used to finance government spending, the output may increase. To this end, two different types of fiscal policies are examined in order to examine whether the main result of this paper comes from a particular type of fiscal policy: endogenous fiscal policy as just described above and exogenous fiscal policy in which government spending is simply assumed to be proportional to output. Also lump sum tax or distortionary tax schemes are examined. It turns out that the impact of CBDC introduction is basically irrelevant of the tax policy specification. Practically speaking, it is questionable that such a sizable seigniorage revenue automatically belongs to an important source of Government financing. Moreover, the optimal level of CBDC holding can increase as a consequence of CBDC policy, but the real cash balance can absorb such an effect in our model, therefore, the fiscal role in accounting for the efficacy of CBDC is very limited.

This paper proceeds as follows. Section 2 presents a full-fledged DSGE model with the central bank digital currency, which accommodates several specifications adopted by recent related studies that have drawn attention in the literature. In Section 3, the equilibrium is fully characterized and the two types of welfare measures are discussed. A detailed calibration procedure is explained in Section 4. Section 5 presents the main results of this paper as well as a robustness analysis. Section 6 concludes.

II. The CBDC Model

We formally present our baseline model in this section, with a special emphasis on defining households' liquidity, a banking section with a distinction of two different deposits. The remaining sectors of the model are based on a canonical New-Keynesian framework.

1. Households

A standard money-in-the-utility (MIU) approach is extended to a "liquidity-in-the-utility "(LIU) specification. Liquidity service at time t, denoted by X_t, is provided by the three instruments: a physical cash (currency) (M_t), a private debit (or checking) account (CH_t) balance and a CBDC account balance (H_t). A representative household chooses her consumption (C_t), labor supply (N_t) and the level of liquidity to maximize

$$E_t \sum_{s=t} \beta^{s-t} \left(\frac{\left(C_t - b\hat{C}_{t-1}\right)^{1-\sigma} - 1}{1-\sigma} - \phi_t \frac{N_t^{1+\eta^N}}{1+\eta^N} + \xi_t \ln X_t \right) \tag{1}$$

where β is the time discount factor, σ is the inverse of the elasticity of substitution, η^N is the inverse of the Frisch elasticity. $\hat{C}_{t-1}$ is the level of habit formed at time $t-1$ and b is the degree of habit dependence.[3] ϕ_t and ξ_t are respectively the preference shocks associated with labor supply and liquidity. In the absence of the banking sector and CBDC, the MIU specification is obtained as a special case as X_t is simply the real cash balance. In our setup, the debit account and the CBDC balance play central roles in addition to the physical money balance. Specifically X_t is given by:

$$X_t = \left(a_t^m m_t^{\frac{\varepsilon-1}{\varepsilon}} + a_t^{ch} ch_t^{\frac{\varepsilon-1}{\varepsilon}} + a_t^h h_t^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}. \tag{2}$$

3) The habit formation is referred to as internal if $\hat{C}_{t-1} = C_{t-1}$, but it is external if $\hat{C}_{t-1}$ is the average level of consumption at time $t-1$ ex-post. We have considered both specifications and find that the results are not sensitive. To this end, we assume a external specification.

where m_t, ch_t and h_t are the real cash , debit account and CBDC holding, i.e., $M_t/P_t, CH_t/P_t$ and H_t/P_t where P_t is the price level. The subjective preferences on each type of money are the relative weights denoted by a_t^m, a_t^{ch} and a_t^h, the sum of which is unity.

The budget constraint faced by the household is in real terms given by:

$$
\begin{aligned}
C_t + (m_t + ch_t + h_t) + d_t &= w_t N_t + \left(\frac{1}{1+\pi_t} m_{t-1} + \frac{R^{CH}_{t-1}}{1+\pi_t} ch_{t-1} + \frac{R^{H}_{t-1}}{1+\pi_t} h_{t-1} \right) \qquad (3) \\
&\quad + \frac{R^{D}_{t-1}}{1+\pi_t} d_{t-1} + \pi_t^T - T_t \\
\pi_t^T &= (1-\varpi)\pi_t^B + \pi_t^F \qquad (4)
\end{aligned}
$$

where w_t is the real wage per each unit of labor supply (in hours), d_t is the (interest-bearing) deposit at the private banks. In this paper, deposit will be interchangeably referred to as savings account by abuse of terminology. T_t is the real tax and π_t^T is the total profits transferred from the monopolistically competitive banks and the final goods producers. A fraction of the bank profit $\varpi\pi_t^B$ will be retained by the banks and added to the bank capital. R^{CH}_{t-1}, R^{H}_{t-1} and R^{D}_{t-1} are the gross nominal interest rate on the debit, CBDC and deposit, respectively.

One of the key differences from the literature is that only debit account balance provides the liquidity service just like real cash. Changes in the CBDC holding or the CBDC interest rate lead to a sizable change in the optimal holding of debit account balance. This change is, however, almost offset by change in optimal deposit holding. Hence, there is only a composition effect on banks' liabilities, which does induce banks to adjust the deposit interest rate and reserve holding. However, the total loan size is barely adjusted. In contrast, deposit is in the utility function of the households in Burlon et al. (2022). Therefore, any change in deposit caused by CBDC is transferred to change in loan, which implies a nontrivial change in capital, thereby output. Theoretically, however, it is reasonable to include liquidity services facilitating transactions in the household utility, rather than asset like deposit, which may exaggerate the real impact of the CBDC.

2. Banks

It is assumed that there exists a continuum of private banks of which measure is assumed to be unity. A private bank is assumed to be subject to monopolistic competition in two segmented deposit(savings) and loan markets. In the absence of CBDC, private banks are assumed to pay no interest for debit account holders. When the CBDC is introduced by the central bank, however, they make a decision on the debit interest rate after observing the CBDC interest rate, which is exogenous to banks. If the debit account and the CBDC account are perfect substitutes, the debit interest rate should equal the CBDC rate. But they are imperfect substitutes to households in our model as the elasticity of substitution ε is finite. To this end, we postulate a pricing rule for the debit interest rate proportional – but not necessarily one-to-one – to the CBDC rate. We will be more specific on this issue below.

We closely follow the modern specification of monopolistically competitive banks developed by Ulate (2021) and Gerali et al. (2010). Both consider segmented markets for deposit and loan and introduce a management cost for maintaining the deposit and loan accounts. While these cost structures are important source in their studies, they are not integral parts in our study as we demonstrate.

A banking sector is assumed to be populated by a continuum of banks which are subject to monopolistic competition in the deposit and loan markets. For a bank j, $L_{j,t}$, $RS_{j,t}$, $CH_{j,t}$,$D_{j,t}$, $\Psi_{j,t}$ are respectively loan, reserve, debit account, deposit and the bank capital at time t. These variables in the absence of j represent the aggregate counterparts as the measure of banks are assumed to be 1. The bank j's balance sheet is then given by:

$$L_{j,t} + RS_{j,t} = CH_{j,t} + D_{j,t} + \Psi_{j,t}. \tag{5}$$

Using this balance sheet identity, it can be shown that the bank profit at the beginning of time $t+1$ is given by

$$\begin{aligned} \Pi^B_{j,t+1} &= R^L_{j,t+1} L_{j,t} + RS_{j,t} - R^{CH}_{j,t} CH_{j,t} - R^D_{j,t} D_{j,t} - \Psi_{j,t} \\ &\quad + (R_t - 1)(RS_{j,t} - \theta^{CH} CH_{j,t}) - \Xi_{j,t}, \end{aligned} \tag{6}$$

where $R^L_{j,t+1}$, $R^{CH}_{j,t}$ and $R^D_{j,t}$ are respectively the gross nominal loan, debit and deposit interest rates. θ^{CH} is the required reserve ratio that bank must abide by, and $\Xi_{j,t}$ is the cost function. Notice that the loan rate is stochastic at time t as it will be realized at time $t+1$, which will be explained below. Note also that from Equation (6), it is evident that the bank will have additional revenue as long as it holds more than the required reserve. For ease of exposition, it is assumed that the reserve requirement is imposed only on the debit account, although it is straightforward to extend the requirement to the case of deposit. The bank cost function is given by

$$\Xi_{j,t} = \left(\mu^L L_{j,t} + \mu^D D_{j,t}\right) + \left(g_L\left(\frac{L_{j,t}}{\Psi_{j,t}}\right) + g_D\left(\frac{D_{j,t}}{\Psi_{j,t}}\right)\right)\Psi_{j,t} + \left((1-\varsigma)(1+\pi_{t+1}) - 1\right)\Psi_{j,t} \tag{7}$$

which includes three types of costs. First, it includes fixed costs associated with managing the loan and deposit accounts, denoted by μ^L and μ^D, respectively. Second, variable costs g_L and g_D are associated with loan and deposit are present. The specific functional forms of these costs follow those of Gerali et al. (2010) and will be shown later. Finally, we augment the additional cost of managing the bank capital, following Ulate (2021), which helps simplify the algebra. As mentioned above, the main results of the present paper are almost invariant to this cost function, thereby, a concrete specification of the components of the cost function will be provided later.

A bank capital dynamics is assumed to be exogenous consisting of two parts, and the specification of which follows that of Ulate (2021). First, there exists a fixed fraction of bank capital management cost, ς. Second, a constant fraction ϖ of the bank profit is payed to the households as dividend and the remaining profit belongs to the bank capital. Specifically, the bank capital evolves in the following way.

$$\frac{\Psi_{j,t+1}}{P_{t+1}} = (1-\varsigma)\frac{\Psi_{j,t}}{P_t} + \varpi\frac{\Pi^B_{j,t+1}}{P_{t+1}} \tag{8}$$

Taking as given the total market loan, deposit L_t, D_t, and the bank capital $\Psi_{j,t}$, the central bank interest rate R_t and the reserve requirement for the debit balance θ^{CH}, the representative bank j decides the optimal interest rates for loan, deposit accounts and the level of reserve. Specifically, the bank maximizes the present value of current and future profits

$$\max_{RS_{j,t},R^L_{j,t},R^D_{j,t}} E_t\sum_{s=0}^{\infty}\Lambda_{t,t+s+1}\Pi^B_{j,t+s+1}$$

subject to the balance sheet identity (5), capital dynamics (8) and the demand for loan and deposit given by.

$$\begin{aligned} L_{j,t} &= \left(\frac{R^L_{jt}}{R^L_t}\right)^{-\varepsilon^L} L_t, \quad \varepsilon^L > 1 \\ D_{j,t} &= \left(\frac{R^D_{jt}}{R^D_t}\right)^{-\varepsilon^D} D_t, \quad \varepsilon^D < -1 \end{aligned}$$

where R^L_t and R^D_t are the market loan and deposit rates, $\Lambda_{t,t+j} = \beta^j\frac{U_{C_{t+j}}}{U_{C_t}}$ is the stochastic discount factor between time t and $t+j$, and U_{C_t} is the marginal utility of consumption at time t. ε^L and ε^D are the elasticity of substitution across the banks. Note that the former is positive while the latter is negative. This is because each bank j follows a markup pricing for the loan market and a markdown pricing for the deposit market.

3. Firms

There are four types of firms in addition to the banking sector. In the absence of the banking sector, a canonical New-Keynesian model is sufficiently characterized by two types of firms producing intermediate goods and final goods. When the banking sector is introduced in the model, it is necessary to introduce agents transforming bank loan into physical capital, and supplying capital to intermediate goods producing firms. These two types of agents are referred to as entrepreneurs and capital producing firms, respectively in what follows. The role of these firms are, however, just limited to complete the general equilibrium model for convenience. Many different types of modeling strategy can also be considered, without altering the main finding of this study. To this end, we minimize the description of the firm structure to save space.

3.1. Entrepreneurs

Entrepreneurs (ENT) – assumed to be perfectly competitive – interact with banks, capital goods producers and intermediate goods producers. The main job of entrepreneurs is to transform the bank loan into the physical capital. Specifically, entrepreneurs borrow funds from banks L_{t-1} at the end of $t-1$, and purchase physical capital at the price of Q^K_{t-1} such that:

$$L_{t-1} = Q^K_{t-1} K_t. \tag{9}$$

They rent K_t to intermediate goods producers at the beginning of the period and receive the rental revenue $R^K_t K_t$ as well as the value of effective capital after depreciation at the price of Q^K_t at the end of the period. The total market value of capital at the end of period t for the entrepreneurs is given by $R^K_t K_t + Q^K_t (1-\delta) u_t K_t$, which is sold back to the capital goods producers. Therefore, the total nominal profit for entrepreneurs is given by

$$\Pi^{ENT}_t = R^K_t K_t + Q^K_t (1-\delta) u_t K_t - (1+i^L_t) Q^K_{t-1} K_t.$$

The assumption of perfect competition ensures that

$$1 + i^L_t = \frac{R^K_t + Q^K_t u_t (1-\delta)}{Q^K_{t-1}} \tag{10}$$

This implies that in conjunction with the zero profit assumption for entrepreneurs, the banks bear all of the uncertainty arising from these two factors. This specification is proposed by Gertler and Karadi (2011) and extended by Ulate (2021).

3.2. Capital Goods Producers

Capital goods producers (CGP) decide the level of investment at the end of the period t as follows.

$$K_{t+1} = (1-\delta)u_t K_t + I_t \tag{11}$$

When the level of investment differs from that in the previous period, they need to pay the investment adjustment cost $S_t = S\left(\frac{I_t}{I_{t-1}}\right)$ per unit of investment, which is standard. Since the price of the capital (installed or new) is Q_t^K while the price of investment good is P_t, the total profit for capital goods producers is given by

$$\Pi_t^{CGP} = Q_t^K (K_{t+1} - (1-\delta)u_t K_t) - P_t I_t - P_t S_t I_t.$$

They maximize the present value of current and expected profits

$$E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \Pi_{t+j}^C$$

subject to (11) and the adjustment cost. The equilibrium condition for capital goods producing firms is given by

$$q_t^K = \left(1 + S_t + S_t' \left(\frac{I_t}{I_{t-1}}\right)\right) - E_t \left[\Lambda_{t,t+1} S_{t+1}' \left(\frac{I_{t+1}}{I_t}\right)^2\right] \tag{12}$$

where $q_t^K = Q_t^K / P_t$.

3.3. Intermediate Goods Producer

There exists a unit mass of continuum of intermediate goods producing firms (IGP) indexed by $j \in [0,1]$. Each firm j rent capital $K_t(j)$ from entrepreneurs at the beginning of the period t and pays R_t^K at the end of period, and hire labor

$N_t(j)$ at the nominal wage W_t to produce good $Y_t(j)$ to maximize its profit

$$\Pi_t^{IGP}(j) = P_t(j)\left[u_t K_t(j)\right]^{\alpha}(A_t N_t(j))^{1-\alpha} - (W_t N_t(j) + R_t^K K_t(j))$$

where $P_t(j)$, W_t and R_t^K are the price of good $Y_t(j)$, nominal wage and capital rental rate. A_t is the aggregate labor productivity shock and u_t is the exogenously determined quality of capital. It is assumed that each firm faces perfect competition, thus the profit $\Pi_t^{IGP}(j)$ will be zero ex-post.

3.4. Final Good producers

Final goods producers (FGP) use a variety of intermediate goods and produce differentiated retail goods. The production function is given by:

$$Y_t = \left[\int_0^1 Y(j)^{\frac{\theta-1}{\theta}} dj\right]^{\frac{\theta}{\theta-1}}$$

where the demand for intermediate good j is given by

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta} Y_t$$

θ is the elasticity of substitution across differentiated intermediate goods. It is assumed that FGPs operate under monopolistic competition and face a Calvo problem. Specifically, each FGP has a chance to set its optimal price P_t^* with probability $1-\omega$ to maximize the expected present value of current and future profits $(\Pi_{t+s}^F, s \geq 0)$:

$$E_t \sum_{s=0}^{\infty} (\omega\beta)^s \frac{U_{C_{t+s}}}{U_{C_t}} \frac{P_t}{P_{t+s}} (P_t^* - P_{t+s}((j))\left(\frac{P_{t+s}(j)}{P_{t+s}}\right)^{-\theta} Y_{t+s}.$$

Since every FGP is identical ex-post, the price level is defined as

$$P_t = \left[\int_0^1 P(j)^{1-\theta} dj\right]^{\frac{1}{1-\theta}},$$

where

$$P_t^{1-\theta} = (1-\omega) P_t^{*(1-\theta)} + \omega P_{t-1}^{1-\theta}.$$

4. Central bank, Government and the Resource Constraint

4.1. Monetary Policy

Central bank is assumed to follow a standard monetary policy by setting the target policy rate R_t a la standard Taylor type rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho^R} \left(\frac{1+\pi_t}{1+\pi^*}\right)^{\psi_\pi(1-\rho^R)} \left(\frac{Y_t}{Y}\right)^{\psi_y(1-\rho^R)} \exp(\varepsilon_t^R), \tag{13}$$

where π^* is the target inflation rate, R is the steady state target policy rate and ε_t^R is the monetary policy shock. As usual, ρ^R is the parameter reflecting the interest rate smoothing behavior of the central bank. In the presence of the CBDC, central bank has an additional policy instrument: the CBDC interest rate, R_t^H. There is literally no reference with respect to the "relevant specification" for the CBDC rate. On the one hand, it is possible to set R_t^H in line with, or subordinate to the major policy R_t. On the other hand, it could be a completely independent policy instrument. In order to highlight the role of CBDC rate as a new monetary policy guide, we simply postulate it as an exogenous process as follows:

$$R_t^H = R^H \exp(\eta_t^H), \tag{14}$$

where R^H is the steady state CBDC rate and η_t^H is the CBDC policy shock.

4.2. Fiscal Policy

Two types of fiscal policy have been used in the CBDC-related literature. One strand such as Burlon et al. (2022) considers the seigniorage revenue as an additional source for fiscal policy while the other simply adopts an exogenous and independent fiscal policy. In this article, we consider both and quantify the effects of fiscal policy using both approaches.

In this model with the banking sector and the CBDC, the seigniorage – in nominal term – is given by

$$SN_t = (M_t - M_{t-1}) + (H_t - R^H_{t-1} H_{t-1})$$

In addition to this seigniorage, the reserve banking system implies that there are additional revenue $RS_t - RS_{t-1}$, but there will be a cost R_t per each unit of extra reserve if the private banks hold reserve more than the required level. For simplicity, banks are obliged to hold reserve requirement only for debit account such that $RS_t \geq \theta^{CH} CH_t$ where θ^{CH} is the reserve requirement ratio for the debit account. These revenues – associated with issuing monetary base and the CBDC, and the reserve banking system – are the additional source financing the consolidated government spending in addition to the tax revenue. In real term, the government budget constraint (GBC) can be written as:

$$G_t = T_t + sn_t + rs_t - \frac{rs_{t-1}}{1+\pi_t} - \frac{(R_{t-1} - 1)}{1+\pi_t} (rs_{t-1} - \theta^{CH} ch_{t-1}). \tag{15}$$

First, the fiscal policy is referred to as endogenous when the government expenditure is determined by this GBC for a given tax policy. Second, the fiscal policy is called exogenous if it is conducted irrespective of the GBC. For a clear comparison, the government expenditure is assumed to be a simple exogenous process such that

$$G_t = G_Y Y_t \exp(\eta^G_t) \tag{16}$$

where G_Y is the fraction of the government expenditure relative to the real GDP in steady state, and η^G_t is an exogenous government expenditure process. For the tax policy, we consider two types of policy such that

$$T_t = \tau^w w_t N_t + \tau^P \pi^T_t, \tag{17}$$

$$T_t = T_Y Y_t \exp(\eta^T_t). \tag{18}$$

The first one levies taxes on the labor income and dividend or profit of the monopolistic entities π^T_t – final goods producers and private banks. The respective tax rate is given by τ^w and τ^P. The second policy is simply exogenous, T_Y is the ratio of the total tax revenue relative to the real GDP and η_t^T is the exogenous tax policy shock.

Finally, the resource constraint for this economy contains social costs.

$$P_tY_t = P_tC_t + P_tG_t + P_tI_t + P_tS_tI_t + AdjC_t^B$$

where $AdjC_t^B$ represents the exogenous adjustment cost in the banking sector and S_t is the investment adjustment cost in the capital goods producers. It is shown that the bank adjustment cost is given by:

$$AdjC_t^B = (\mu^L L_{t-1} + \mu^D D_{t-1}) + (\varsigma + g_{L,t-1} + g_{CH,t-1} + g_{D,t-1})\Psi_{t-1}$$

III. The Equilibrium

In this section, we first summarize the set of the equilibrium conditions for the model, followed by the baseline calibration specifications including the steady state values of the variables and the parameter values.

1. The Equilibrium Conditions

For an expositional purpose, we present the equilibrium conditions sector by sector as follows.

A. Households A representative household determines consumption, labor supply, demand for real money, CBDC and debit balances. These optimality conditions are given by:

$$U_{C_t} = (C_t - bC_{t-1})^{-\sigma} \tag{19a}$$

$$U_{C_t} = E_t\left[\beta U_{C_{t+1}} \frac{R_t^D}{1+\pi_{t+1}}\right] \tag{19b}$$

$$w_t = \left(\frac{1}{1-\tau^w}\right)\phi_t N_t^{\eta^N} U_C^{-1} \tag{19c}$$

$$m_t = \xi_t \Phi_t^{-1}\left(\frac{R_t^D - 1}{R_t^D}\right)^{-1} U_{C_t}^{-1} \tag{19d}$$

$$h_t = \left(\frac{a_t^h}{a_t^m}\frac{R_t^D - 1}{(R_t^D - R_t^H)}\right)^{\varepsilon} m_t \tag{19e}$$

$$ch_t = \left(\frac{a_t^{ch}}{a_t^m}\frac{R_t^D - 1}{(R_t^D - R_t^{CH})}\right)^{\varepsilon} m_t, \tag{19f}$$

where U_{C_t} is the marginal utility of consumption and

$$\Phi_t = \left(1 + \left(\frac{a_t^{ch}}{a_t^m}\right)^{\varepsilon}\left(\frac{R_t^D - R_t^{CH}}{R_t^D - 1}\right)^{-(\varepsilon-1)} + \left(\frac{a_t^h}{a_t^m}\right)^{\varepsilon}\left(\frac{R_t^D - R_t^H}{R_t^D - 1}\right)^{-(\varepsilon-1)}\right).$$

Notice that it is the deposit interest rate that governs consumption Euler equation. The demand for CBDC and debit accounts can then be written in terms of the real money demand. However, the real money balance, debit, CBDC and deposit are all mutually dependent of their respective interest rates, and households do hold all three instruments generating liquidity services even when the interest rates are not equal. That is, they are imperfect substitutes.

B. The Banking Sector A monopolistic bank sets the deposit, loan and debit account interest rates as follows

$$R_t^D = \frac{\varepsilon^D}{\varepsilon^D - 1}\left(R_t - \mu^D - g_D'\left(\frac{d_t}{\psi_t}\right)\right) \tag{20}$$

$$E_t R_{t+1}^L = \frac{\varepsilon^L}{\varepsilon^L - 1}\left(R_t + \mu^L + g_L'\left(\frac{l_t}{\psi_t}\right)\right) \tag{21}$$

$$R_t^{CH} = 1 + \lambda^H (R_t^H - 1), \tag{22}$$

where the variable cost functions for deposit and loan management are given by

$$g_i(x) = \kappa^i \nu^i x \left(\ln x - \ln \nu^i - 1\right) + \kappa^i \left(\nu^i\right)^2 \tag{23}$$

where $i = D, L$. This cost function has the following properties. Let ν^D and ν^L be the steady state ratio of deposit and loan to bank capital, d_t/ψ_t and l_t/ψ_t. Then $g_i(x) \approx (x - \nu^i)^2$.

It is important to note that whereas $\varepsilon^L > 0$, $\varepsilon^D < 0$. Therefore, the deposit rate raises less than the policy rate, which can be interpreted as a markdown pricing. In contrast, the coefficient of the policy rate in the loan rate equation is greater than unity. Note also that the bank sets the expected loan rate rather than the current rate. Ulate (2021) justifies this sort of specification.

In the absence of CBDC, the debit interest rate is zero and it would be so even in the presence of the CBDC if the CBDC rate is zero. However, when the central bank pays interest income on holding CBDC account, the private banks need to compete with the CBDC account, regardless of whether the CBDC account is opened at the central bank or the management of which is delegated to the private banks. λ^H measures the sensitivity of the debit rate to the CBDC rate. λ^H will be higher, the more sensitive households are to the CBDC rate. In contrast, if households concern more about privacy, they may well have an incentive not to switch from the private debit account to the CBDC account even when the deposit is fully insured in the CBDC account holding.

The remaining equilibrium conditions are the bank balance sheet identity, exogenous reserve process, bank capital dynamics and the bank profit:

$$
\begin{aligned}
l_t + rs_t &= ch_t + d_t + \psi_t && (24)\\
rs_t &= rs\exp(\eta_t^{rs}) && (25)\\
\psi_t &= (1-\varsigma)\psi_{t-1} + \varpi\pi_t^B && (26)\\
\pi_t^B &= (R_t^L - \mu^L)\frac{l_{t-1}}{1+\pi_t} + R_{t-1}\frac{rs_{t-1}}{1+\pi_t} - (R_{t-1}^{CH} + \mu^{CH} + \theta^{CH}(R_{t-1}-1))\frac{ch_{t-1}}{1+\pi_t} && (27)\\
&\quad -(R_{t-1}^D + \mu^D)\frac{d_{t-1}}{1+\pi_t} - \left(\varsigma + g_L\left(\frac{l_{t-1}}{\psi_{t-1}}\right) + g_D\left(\frac{d_{t-1}}{\psi_{t-1}}\right) + (1-\varsigma)(1+\pi_t)\right)\frac{\psi_{t-1}}{1+\pi_t}
\end{aligned}
$$

C. Firms The equilibrium conditions for entrepreneurs are just (9) and (10) in real terms.

$$
\begin{aligned}
l_t &= q_t^K K_{t+1} && (28)\\
\frac{R_t^L}{1+\pi_t} &= \frac{r_t^K + q_t^K u_t(1-\delta)}{q_{t-1}^K} && (29)
\end{aligned}
$$

where $q_t^K = Q_t^K/P_t$ is the real capital price at time t and $r_t^K = R_t^K/P_t$ is the real capital rental price. The quality of the capital is assumed to be an exogenous persistently evolving process.

$$
u_t = u_{t-1}^{\rho^u}\exp(\varepsilon_t^u) \tag{30}
$$

The investment process and the capital price are given by:

$$
\begin{aligned}
K_{t+1} &= (1-\delta)u_t K_t + I_t && (31)\\
q_t^K &= (1 + S_t + S_t'\left(\frac{I_t}{I_{t-1}}\right)) - E_t\left[\Lambda_{t,t+1}S_{t+1}'\left(\frac{I_{t+1}}{I_t}\right)^2\right] && (32)
\end{aligned}
$$

In the absence of the investment adjustment cost, the capital price collapses to 1.

Intermediate goods, labor demand and the real capital rental rate are given by:

$$
\begin{aligned}
Y_t^m &= \chi (u_t K_t)^{\alpha} (A_t N_t)^{1-\alpha} && (33)\\
w_t &= \frac{P_t^m}{P_t}(1-\alpha)\frac{Y_t^m}{N_t} = p_t^m (1-\alpha)\chi \left(\frac{u_t K_t}{A_t N_t}\right)^{\alpha} A_t && (34)\\
r_t^K &= \frac{P_t^m}{P_t}\alpha \frac{Y_t^m}{K_t} = p_t^m \alpha \chi \left(\frac{u_t K_t}{A_t N_t}\right)^{\alpha-1} u_t && (35)
\end{aligned}
$$

The new Keynesian Phillips curve can be expressed as a set of the optimality condition for the final goods producers as follows:

$$
\begin{aligned}
1 &= (1-\omega)\left(\frac{P_t^*}{P_t}\right)^{1-\theta} + \omega \left(\frac{1}{1+\pi_t}\right)^{1-\theta} && (36a)\\
\theta G_t^1 &= (\theta-1) G_t^2 && (36b)\\
G_t^1 &= U_{C_t}\left(\frac{P_t^m}{P_t}\right) Y_t + \omega\beta E_t \left(\frac{1}{1+\pi_{t+1}}\right)^{-\theta} G_{t+1}^1 && (36c)\\
G_t^2 &= U_{C_t}\left(\frac{P_t^*}{P_t}\right) Y_t + \omega\beta E_t \frac{P_t^*}{P_t}\left(\frac{P_{t+1}^*}{P_{t+1}}\right)^{-1}\left(\frac{1}{1+\pi_{t+1}}\right)^{1-\theta} G_{t+1}^2 && (36d)\\
Y_t^m &= \zeta_t^p Y_t && (36e)\\
\zeta_t^p &= \omega \left(\frac{1}{1+\pi_t}\right)^{-\theta} \zeta_{t-1}^p + (1-\omega)\left(\frac{P_t^*}{P_t}\right)^{-\theta} && (36f)
\end{aligned}
$$

The profit of these final goods producers is given by $\pi_t^F = (1 - p_t^m \zeta_t^p) Y_t$.

D. Monetary and Fiscal Policies For simplicity of exposition, the two monetary policy rules are reiterated as:

$$
\begin{aligned}
\frac{R_t}{R} &= \left(\frac{R_{t-1}}{R}\right)^{\rho^R}\left(\frac{1+\pi_t}{1+\pi^*}\right)^{\psi_\pi(1-\rho^R)}\left(\frac{Y_t}{Y}\right)^{\psi_y(1-\rho^R)} \exp(\varepsilon_t^R) && (37)\\
R_t^H &= R^H \exp(\eta_t^H) && (38)
\end{aligned}
$$

where ε_t^R is independent and identically distributed. The endogenous fiscal policy in real terms is expressed as

$$
\begin{aligned}
G_t &= T_t + sn_t + rs_t - \frac{rs_{t-1}}{1+\pi_t} - \frac{(R_{t-1}-1)}{1+\pi_t}(rs_{t-1} - \theta^{CH} ch_{t-1}) && (39)\\
T_t &= \tau^w w_t N_t + \tau^P \pi_t^T && (40)
\end{aligned}
$$

The exogenous fiscal policy is again repeated for ease of exposition:

$$
\begin{aligned}
G_t &= G_Y Y_t \exp(\eta_t^G) && (41)\\
T_t &= T_Y Y_t \exp(\eta_t^T) && (42)
\end{aligned}
$$

To make the size of government spending and tax revenue equal across the two different fiscal policies, we will calibrate τ^w, τ^P, G_Y and T_Y so that the government expenditure (tax) in the steady state is the same across the two policies. Finally, the resource constraint in real term is written as:

$$
\begin{aligned}
Y_t &= C_t + G_t + I_t + S_t I_t + adj_t && (43)\\
& adj_t = (\mu^L \frac{l_{t-1}}{1+\pi_t} + \mu^D \frac{d_{t-1}}{1+\pi_t}) + (\varsigma + g_{L,t-1} + g_{D,t-1}) \frac{\psi_{t-1}}{1+\pi_t}
\end{aligned}
$$

E. Exogenous Variables and Shock Processes The model is closed by specifying the exogenous variables and the shock processes.

$$
\begin{aligned}
A_t &= A \exp(\eta_t^A) && (44a)\\
\phi_t &= \phi_N \exp(\eta_t^\phi) && (44b)\\
\xi_t &= \xi_X \exp(\eta_t^X) && (44c)\\
a_t^h &= a^h \exp(\eta_t^h) && (44d)\\
a_t^{ch} &= a^{ch} \exp(\eta_t^{ch}) && (44e)\\
a_t^m &= 1 - a_t^h - a_t^{ch} && (44f)
\end{aligned}
$$

The shock processes are all assumed to be autoregressive of order one such that

$$\eta_t^i = \rho^i \eta_{t-1}^i + \varepsilon_t^i \tag{45}$$

where each innovation ε_t^i is assumed to be independent and identically distributed for $i = A, X, h, H, \phi$.

2. Welfare

Another important goal of this study to quantify the potential change in households' welfare when the CBDC is introduced. Central to the analysis is the relevant choice of stochastic discount factor in steady state. To see this, recall that a standard approach of measuring welfare is to evaluate the objective of households in steady state, which is sensitive to the discount factor. Given that our model abstracts from economic growth, the discount factor is simply given be the time discount factor. To correctly measure welfare in reality, the relevant discount factor is $\beta/(1+g)$ where g is the growth rate of consumption, thus output in steady state, as we use the log utility for consumption. If the real natural GDP growth rate is 2%, then the discount factor would be roughly 0.97. In this case the welfare would be about 33 times value of the utility function in steady state. If we stick to the calibration value for the real deposit rate, which is given by 1.5%, then the implied natural growth rate would be only 0.5% and the discount factor be 0.985. But then the value of welfare should be about 66 times the steady state utility level.

Given that the welfare function is sensitive to the choice of the steady state discount factor, we report the result in terms of the level of utility function in steady state. Two potential candidates for gauging welfare are considered, the utility function with and without the liquidity in steady state:

$$U_A(C,N,X \quad : \quad \Theta) = U_B(C,N : \Theta) + \xi \ln X, \tag{46}$$

$$U_B(C,N \quad : \quad \Theta) = (1-b)\ln C - \phi \frac{N^{1+\eta^N}}{1+\eta^N}. \tag{47}$$

where $X = \left(a^m m^{\frac{\varepsilon-1}{\varepsilon}} + a^{ch} ch^{\frac{\varepsilon-1}{\varepsilon}} + a^h h^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$ is the liquidity service in steady state and Θ is a set of parameters or steady states of variables of interest. Note that the consumption elasticity of substitution is unity. For the model to be internally consistent with optimal household decision, U_A is the right one including the liquidity service. However, X may be too much volatile relative to consumption under certain conditions, potentially dominating the welfare effect when the CBDC balance a^h or the CBDC rate changes in steady state. To see this, note that the optimal real money, debit and CBDC holding in steady state are given by:

$$m = \xi \Phi^{-1} \left(\frac{R^D - 1}{R^D}\right)^{-1} U_C^{-1} \tag{48}$$

$$h = \left(\frac{a^h}{a^m} \frac{R^D - 1}{(R^D - R^H)}\right)^{\varepsilon} m \tag{49}$$

$$ch = \left(\frac{a^{ch}}{a^m} \frac{R^D - 1}{(R^D - R^{CH})}\right)^{\varepsilon} \tag{50}$$

where

$$\Phi = \left(1 + \left(\frac{a^{ch}}{a^m}\right)^{\varepsilon} \left(\frac{R^D - 1}{R^D - R^{CH}}\right)^{\varepsilon-1} + \left(\frac{a^h}{a^m}\right)^{\varepsilon} \left(\frac{R^D - 1}{R^D - R^H}\right)^{\varepsilon-1}\right) \tag{51}$$

Then it is straightforward to compute X as follows:

$$X = \xi \left(a^m\right)^{\frac{\varepsilon}{\varepsilon-1}} \Phi^{\frac{1}{\varepsilon-1}} \left(\frac{R^D - 1}{R^D}\right)^{-1} U_C^{-1},$$

which can be affected heavily by the change in the CBDC holding, the CBDC rate and the elasticity of substitution across real money, debit and CBDC. When R^H is sufficiently large and close to the deposit interest rate R^D, it is easy to see that the liquidity service can increase rapidly absorbing not just real money balance but also debit account, potentially dominating change in the utility. Therefore, although U_B is less preferable to U_A from a theoretical point of view, it is also of interest how sensitive U_B would be to change induced by the introduction of CBDC.

In this study, we quantify the change in welfare in terms of consumption unit as usual. Specifically, suppose that a parameter or steady state is changed and let it be denoted by $\hat{\Theta}$. Let $\hat{x}$ be the steady state of a variable x associated with $\hat{\Theta}$. This change can be expressed as:$U_A(\hat{C},\hat{N},\hat{X}:\hat{\Theta}) = U_B(\hat{C},\hat{N}:\hat{\Theta}) + \xi \ln \hat{X}$. Then we measure Δ such that

$$U_A(C(1+\Delta),N,X \quad : \quad \Theta) = U_A(\hat{C},\hat{N},\hat{X}:\hat{\Theta}) \tag{52}$$

$$U_B(C(1+\Delta),N \quad : \quad \Theta) = U_B(\hat{C},\hat{N}:\hat{\Theta}). \tag{53}$$

That is, Δ measures the welfare gain in terms of percentage change in consumption unit when Θ is changed to $\hat{\Theta}$ in U_A and U_B. For the purpose of this study, we change the CBDC weight a^h or CBDC rate R^H and assess the quantitative implication for welfare.

IV. Calibration

Using the Korean data (from the Bank of Korea) and following literature, we calibrate the model such that parameter values and the steady state of the variables are consistent with the equilibrium conditions described above. The annual target inflation is set to be 2%, the official target rate of the Bank of Korea. For the past two decades, the nominal deposit and loan rates as well as the Base Rate have been overall decreasing, especially marking the lowest rate, 0.5% in history during the COVID-19 period. Since then the Base Rate gradually moves upward and now is believed to be higher than what is referred to as a neutral nominal rate. Therefore, the steady state values may be sensitive to the sample period. For this reason, we calibrate these interest rates at different level and inspect how sensitive the results are. Fortunately, the main finding is not very sensitive to the choice. As a basic calibration, we set the Base Rate, deposit and loan rates respectively at 3%, 3.5% and 5.5%, reflecting the fact that the spread between the deposit and loan rates is quite stable around 2% since 2001 as shown by Cho and Hwang (2022). Since the CBDC rate is unknown, we first assume the steady state CBDC rate and the debit interest rate to be zero.

Then we vary the CBDC interest rate from 0% up to the half of a deposit rate, $((R^D-1)/2)\%$. The debit rate is then set $R^{CH}=1+\lambda^H(R^H-1)$ with a benchmark value $\lambda=1$. Then we also examine the case of $\lambda^H \in [0,2]$.

The steady state relation for the bank balance sheet can be written in terms of the ratio of each element to the bank capital such that

$$\nu^L+\nu^{RS}=\nu^{CH}+\nu^D+1 \tag{54}$$

The loan to bank capital ratio $\nu_t^L=l_t/\psi_t$ has been quite stable for the period of 2007-2021, and this is consistent with the model as well: the steady state of capital stock and thereby the loan amount is determined by the real side of the economy. Therefore, we set the sample mean as $\nu^L=8.26$. The official bank reserve holding ratio has increased from 3.49% to 4.16% for the same period. But in our model counterpart is the reserve to total deposit ratio, which corresponds to 2.76% to 3.28%. As mentioned above, we assume that the reserve requirement is in force for the debit account. Hence we set the sample mean of this ratio as $\theta^{CH}=0.0291$. Then $\nu^{RS}=\theta^{CH}\nu^{CH}$. The remaining ratios ν^{CH} and ν^D are to be determined endogenously in equilibrium, particularly by the households. However, it is easy to identify ν^{CH}/ν^D from data. The ratio of a debit account to the bank deposit had been around 10% for 2007-2012 but since then, it has been increasing, marking 18.7% in 2022. To this end, we set the sample average of this ratio as its initial steady state, which is equivalent to $\nu^{CH}/\nu^D=0.124$. Then using (54) and the optimal choice of debit account holding (54), the parameter ξ_X is set to ensure $\nu^{CH}/\nu^D=CH/D$. In the absence of debit account, the case we will analyze for comparison, the weight on the liquidity is set as $\xi_X=0.0541$ following Burlon et al. (2022). ν^D can then be computed using (54), which is $\nu^D=6.48$. As we will demonstrate in the sensitivity analysis, introduction of CBDC alter the optimal debit and deposit level. Therefore, this ratio will be updated whenever the steady state of CH/D changes.

The fixed management costs for loan and deposit can be easily computed by the steady state relation of (20) and (21): $\mu^L=\frac{\varepsilon^L-1}{\varepsilon^L}R^L-R$, $\mu^D=R-\frac{\varepsilon^D-1}{\varepsilon^D}R^D$. The parameter ε^L can be computed by the estimate of $\frac{\varepsilon^L}{\varepsilon^L-1}$ in (21). While it is difficult to estimate this parameter in the context of monopolistically competitive bank industry using the Korean data, Cho and Hwang (2022) computed the parameter estimate of $\frac{\varepsilon^L}{\varepsilon^L-1} = 1.0893$. On a quarterly basis, this implies that $\varepsilon^L = 45.8$. Similarly, we also compute ε^L, which is -407.1. The estimates of these two parameters in Ulate (2021) ($\varepsilon^L = 203$ and $\varepsilon^D = -268$ for the U.S. economy) imply that, if they are reliable, the Korean banking industry is relatively less competitive in the loan market and more competitive in the deposit market. Since we do not have the estimate for the other parameter κ^L in the variable cost function, we adopt the (quarterly) estimate of Ulate (2021): $\kappa^L = 0.0012$. But we compute κ^D using the presumption that the coefficient of $\kappa^i \nu^i$ must be equivalent for $i = D$ and L from Equation (23). The remaining parameters for the banking sector are ϖ and ς. These parameter values need to be set to satisfy the equilibrium conditions for the bank capital dynamics. The case in which the steady state inflation rate is zero is shown by in Ulate (2021). We extend this computation procedure to our case in which inflation rate is set at 2%.

For the households, the time discount factor can be computed from the steady state relation of the consumption Euler equation as $\beta = (1+\pi^*)/R^D$. σ, the inverse of the elasticity of substitution for consumption is 1 and the consumption habit parameter b is 0.8150. ϕ_N, the relative weight on the leisure choice in the utility function is set to be 3.409. The inverse of Frisch elasticity of labor supply $\eta^N = 1$. The relative weights on the CBDC, debit account and the real cash balance for the liquidity have no historical data, we initially set $a^h = 0.3$ with CBDC and 0 otherwise.

The weights of debit and cash out of liquidity instruments are calibrated to match the sample mean of the debit and cash for 2007-2022 period, which are $a^{ch} = 0.7(1-a^h)$ and $a^m = 0.3(1-a^h)$ as a benchmark. This implies that the relative weight of debit over the traditional money – sum of cash and debit – is 70%. The elasticity of substitution among real money, debit and CBDC accounts are set to be $\varepsilon = 2$.

The parameters associated with the production side are specified as follows. The weight on the capital in the production function is $\alpha = 1/3$ and the capital depreciation rate is $\delta = 0.08$. The parameters in final good sector associated with the Calvo pricing are $\theta = 6$ and $\omega = 0.75$, which are standard. The steady state of the productivity shock A is normalized to be 1 and the persistence of the quality of capital ρ^u is chosen to be 0.9.

For the monetary policy, the response of the Base Rate to inflation and the output gap are respectively, $\psi_\pi = 1.5$ and $\psi_y = 0.2$, and the interest rate smoothing parameter $\rho^R = 0.7$. The weight of the government spending relative to GDP is higher than 0.2 in recent years, but historically, the average weight is about 0.2 for the Korean economy. To this end, we set $G_Y = 0.2$. The tax rate are set so that it is consistent with the government budget constraint.

V. Results

This section presents the main results of this study through the lens of a standard DSGE model in which the CBDC is explicitly introduced. The main research questions are whether the CBDC would affect the real economy in a significant way in the long run, how sizable its effect on the welfare of the households would be. Our main finding is that 1) the CBDC would not have a quantitatively sizable real effect, 2) the effect on households' welfare is not directional and it is dominated by changes in the liquidity service induced by variations of the CBDC holding and the CBDC interest rates, and 3) introduction of CBDC does not necessarily promote competition in the banking industry. We first present the results of the baseline specification, followed by a robustness study with alternative specifications such as the absence of debit account or different types of fiscal policy.

1. Results from the Baseline Model

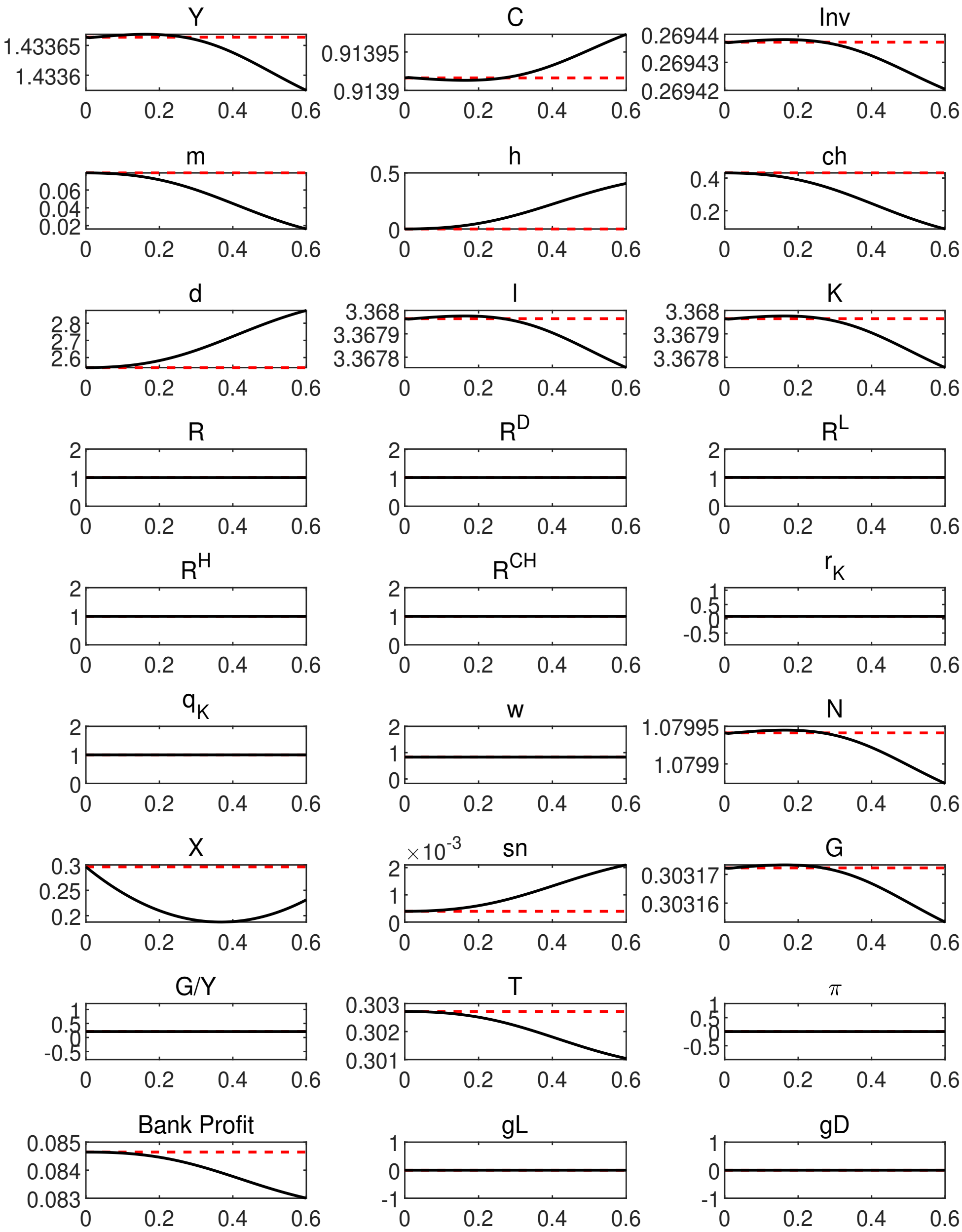
As a benchmark case, we postulate the exogenous fiscal policy. And the debit account, a natural substitute for the CBDC account is present in the model. Then, we vary the willingness to hold the CBDC, a^h and the CBDC rate R^H, a potentially new and independent monetary policy.

CBDC Weight and the Long-run Equilibrium We first examine the effect of introducing CBDC with respect to the weight of CBDC holding in the liquidity service on the steady state of the economy. Figure 1 displays the change in the endogenous variables as the CBDC holding increases from zero to 60% out of total liquidity X. The red dashed line indicates the steady state of each variable when the CBDC weight is zero, i.e., the steady state in the absence of the CBDC. Then we increase the weight from 0 to 0.6.

A number of important observations are noteworthy. First, the initial steady state remains virtually constant as the CBDC weight increases up to 0.3 and begins to fall, reaching the lowest value when a^h rises to 60%. However, the annual percentage decrease of the steady state of output is just 0.025% at $a^h = 0.6$. This is quite small relative to the changes in output reported in the literature. Such a small variation in output can be inferred as follows. The increase in the CBDC weight significantly substitutes out the traditional money: debit account and real cash balance. However, this is compensated by almost an equal size of increase in deposit, hence the amount of the loanable funds is almost intact.

Second, while the change in the steady state of the output is small quantitatively, it is important to understand why it actually falls. To understand this, notice that households do not need to hold liquidity as much as before because the CBDC provides an additional source of liquidity service. This change in turn induces households to increase consumption and leisure. Consequently, labor supply falls resulting in a reduction of equilibrium labor, lowering output. Nevertheless, it is important to acknowledge that the changes in consumption and labor are as marginal as output.

Figure 1. Effect of Changes in CBDC weight on Steady State



This figure plots the change of the variable in steady state as the CBDC weight a^h increases from zero to 0.6.

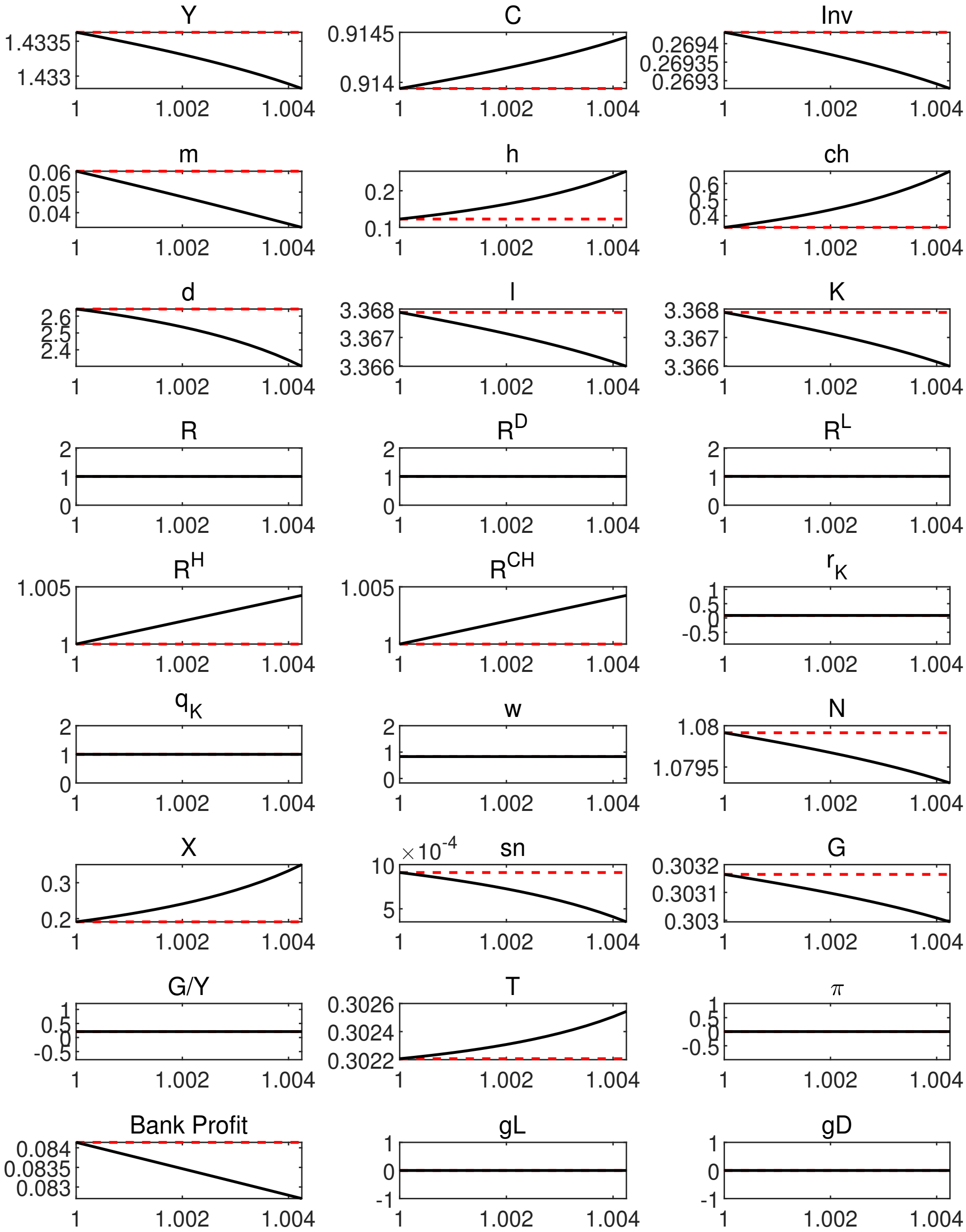
Third, all of the real prices such as capital rental price, wage, all of the nominal and real interest rates remain unchanged. This arises because banks have no incentive to reset the optimal deposit and loan rates. Therefore, capital, labor and the output do change, but the changes are quantitatively of a similar size to output.

Finally, one interesting observation is that bank profit falls because banks need to compete with the central bank in the debit market. As a consequence, banks' interest payment increase as deposit increases while debit account shrinks. In this model, this does not imply that the banking industry becomes more competitive, thus the inefficiency induced by the monopolistic banking industry does not disappear. That is, introduction of CBDC simply shrinks bank profit, and does not help the banking market be more competitive.

CBDC Interest Rate and the Long-run Equilibrium Next, the central bank may well adopt the CBDC interest rate as a second and independent policy instrument. Figure 2 depicts the change in steady state when the central bank varies this new policy rate.

The effect on the steady state output is again very marginal: When the CBDC rate increases from 0% to 1.75% year on year (0% to 0.425% quarterly), the output falls marking a decrease of 0.225% on an annual percentage. As the CBDC rate increases, consumption actually increases as in the case of an increase in the CBDC holding weight. An increase in CBDC rate induces households to hold more CBDC balance and banks need to raise the debit interest rate to compete with the CBDC. Consequently, households reduce real cash balance and more importantly, deposit as well. Banks need to hold more reserves, reducing the total loan amount. Consequently, the physical capital has to fall. Households also increase the total liquidity and increase consumption while reducing leisure. Therefore, the equilibrium labor also falls, resulting in a decrease in output in steady state. Since there is no reference on the CBDC rate pass-through coefficient λ^H in the debit interest equation (22), we vary the value from zero to 1 and confirm that alternative pass-through does not alter the results. This implies that

Figure 2. Effect of Changes in CBDC Interest Rate on Steady State



This figure plots the change of the variable in steady state as the CBDC interest rate R^H increases from 1.000 to 1.00425 on a quarterly basis.

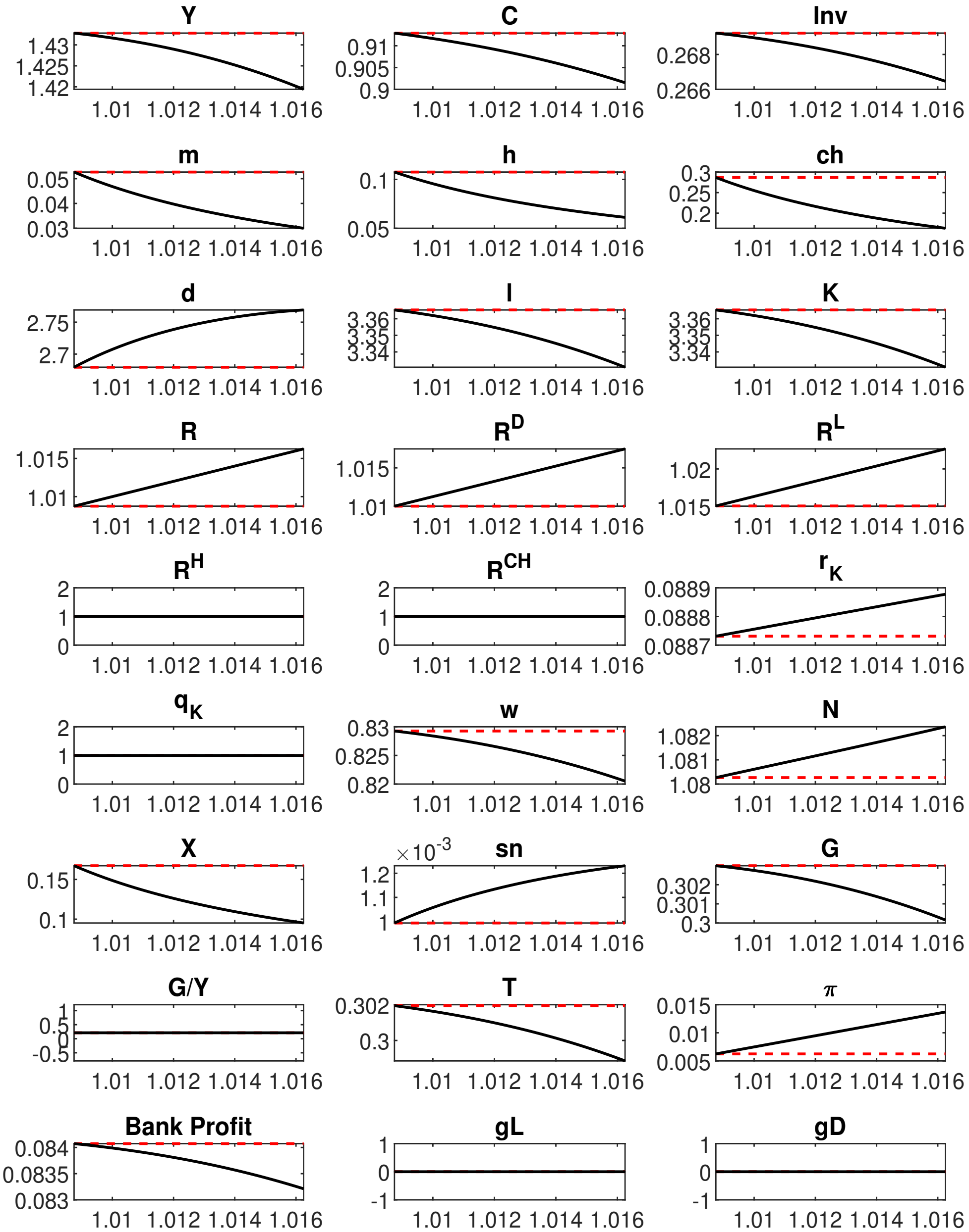
a decrease in labor is mainly responsible for reducing the steady state output. As mentioned earlier, a reduction of output is not quantitatively large, thus it would be even smaller for a model in the absence of labor market.

Notice that the deposit and loan interest rates do not change as they are responsive only to the main monetary policy rate $\boldsymbol{R}$. If one considers a model of banking in which the debit and deposit market are integrated so that banks respond to the CBDC rate as well, increase in the deposit and loan rates would exacerbate the output in steady state. Or the same conclusion can be obtained simply when the central bank raises the primary policy rate in line with the CBDC rate. For instance, Figure 3 shows the change in steady state when the central bank raises the primary interest rate. As expected, the output falls. To see this, notice first that the long run real deposit interest rate is invariant to change in the policy rate while the long run real loan rate rises, which can be seen from the consumption Euler equation in steady state, $\beta(R^D) = 1 + \pi^*$. Therefore, the Fisher effect holds for the deposit rate. From Equations (20,21), the nominal deposit rate rises by $\frac{\varepsilon^D}{\varepsilon^D - 1}$ to a rise in the policy rate, which is smaller than unity as $\varepsilon^D < 0$ while the loan rate rises more than unity as $\frac{\varepsilon^L}{\varepsilon^L - 1} > 1$. This observation is pointed out by Cho and Hwang (2022).

1.1. Welfare Implications

To evaluate the change in welfare when CBDC is introduced in otherwise a standard model, we change the CBDC weight and the CBDC interest rate separately as we did for the steady state analysis. As mentioned earlier, what we found in this study is that the amount of liquidity service can be extremely large, dominating the welfare effect. For this reason, we report two different measures of the welfare: the one with the liquidity service and the other ignoring the liquidity. Figure 4 depicts the results as the CBDC weight (a^h) increases from 0% to 60%. The the top left and bottom left panels show the change in the value of the utility function with and without the liquidity services in steady state, respectively. The top right and bottom right panels depict the corresponding percentage change in consumption explained in Equations (52,53).

Figure 3. Effect of Changes in Primary Policy Rate on Steady State



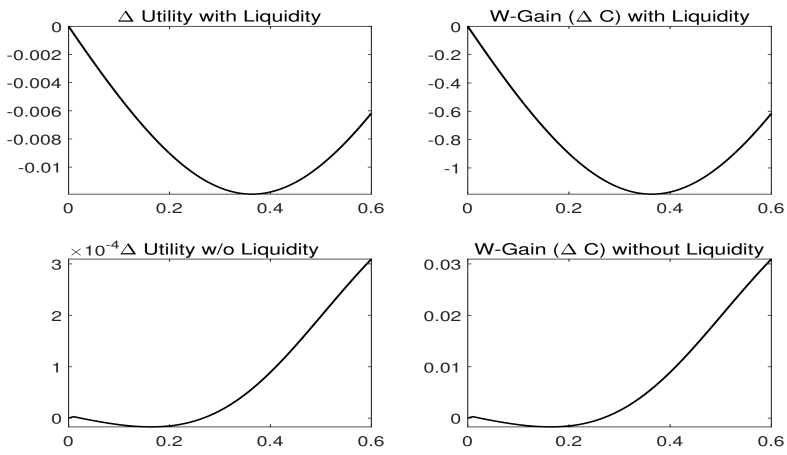
This figure plots the change of the variable in steady state as the gross primary policy interest rate R increases from 1.0075 to 1.015 on a quarterly basis (net policy rate increases from 3% to 6% in annual terms).

Recall from Figure 1 that consumption and leisure increase, which would improve the welfare of households from a traditional point of view. In contrast, the total amount of liquidity falls, implying the utility loss from the liquidity services. Therefore, the welfare will be determined by the relative size of these two factors. It turns out that utility increases with respect to consumption and leisure $U_B(\hat{C},\hat{N} : a^h) > U_B(C,N : a^h = 0)$ where hatted variable is the optimal values associated with a^h but $U_A(\hat{C},\hat{N},\hat{X} : a^h) < U_A(C,N,X : a^h = 0)$. This implies that the change in liquidity service is decisive in evaluating welfare: in the utility measure U_B i.e., in the absence of liquidity services, welfare gain the percentage change in consumption unit is 0.03% when $a^h = 0.6$. In stark contrast, the welfare loss is lower than −1% in the case of utility U_A with liquidity service X. This is enormous as the welfare measure should be at least 33 times higher than the level of liquidity.

Similar results are also obtained with the CBDC rate. Figure 5 depicts the change in the utility and percentage change in consumption as the CBDC rate increases from 0% to 1.75%, analogous to Figure 4. In this case, all of consumption, leisure and the amount of liquidity service increase with the CBDC rate. Therefore, a positive CBDC interest rate is welfare-improving although output still falls in steady state. But again the contribution of liquidity services is 8 times bigger than that of consumption and leisure crease in improving welfare.

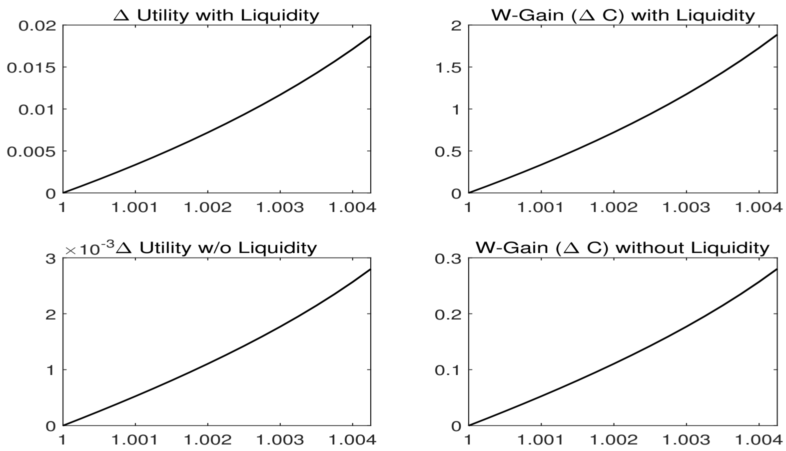
To summarize, the pros and cons of both measures of welfare are clear. When we measure the welfare without consideration of the change in the liquidity service, the quantitative implication for change in welfare level appears reasonable: assuming that the steady state welfare function is around 33 times higher than the utility level, the percentage change in consumption for the welfare function is around 1% in the case of $a^h = 0.6$ and 3% when the CBDC interest rate is 1.75% per annum, However, this measure is inconsistent with the model because the optimal decision of households are based on the liquidity services. The second measure with liquidity services is internally consistent with the model, but the quantitatively, the size of the change in welfare appears too large relative to the

Figure 4. Effect of Changes in CBDC weight on Welfare



This figure plots the change of utility function and the welfare gain in terms of percentage change in consumption as the CBDC weight a^h increases from zero to 0.6.

Figure 5. Effect of Changes in CBDC Interest Rate on Welfare



This figure plots the change of utility function and the welfare gain in terms of percentage change in consumption as the CBDC interest rate R^H increases from 1.000 to 1.00425 on a quarterly basis.

findings in the literature.[4)]

1.2. Discussions

Our main results and their implications shed light on several important issues pertaining to the efficacy of CBDC. First, CBDC would have been completely neutral in the absence of any kind of deposit (interest-bearing or not) account because it just completely substitutes out physical real cash. Therefore, the existence of bank deposits is a key factor in the study of CBDC. Moreover, we have shown that it is important to distinguish debit – as liquid as cash – to compete with CBDC from deposit like an asset.

Second, it is then important to understand the consequence of interest-bearing (savings) deposit as an alternative liquidity service provider. Indeed, some studies such as Burlon et al. (2022) do consider a "deposit-in-the-utility (DIU)" specification. While this is similar to ours, a single deposit contains both characteristics: liquidity and asset. account. This sort of specification would have a much larger impact on output and welfare in steady state. One the one hand, the size of deposit has been traditionally much bigger relative to that of debit account. Any change in CBDC – weight or interest rate – leading to an increase in deposit would amplify the effect on output as the loan and capital shock will be larger as well, provided that the parameter measuring liquidity service ξ is the same.[5)] On

4) One avenue to alter the specification of our model would be to set the lower value for the steady state of ξ for calibration, but then the bank intermediation channel through which CBDC affects the economy becomes negligible. We leave this issue as a future research topic.

5) Demand deposit has been expanding rapidly in U.S. since 2020 as the Fed lifts the regulation on limits on the number of transactions or withdrawals permitted on savings deposit accounts. According to the FRED data, demand deposit as of Oct 2, 2023 was 5036 billion dollars, almost three times larger than that of December 30, 2019 (1810 billion dollars). Deposits (all commercial banks) are 13190 billion dollars as of December 25, 2019 and 17364 billion dollars as of October 11, 2023. Therefore, if our measure debit to interest-bearing deposit ratio is proxied by the ratio of demand deposit to all deposit less demand deposit jumps from around 0.16 to 0.41. Therefore, our analysis may not be consistent with the U.S. data. However, demand deposit still contains some interest-bearing deposits, thus it may not be as liquid as cash or CBDC. Moreover, our robustness analysis indicates that the main result does not change even if the initial debit/deposit ratio is calibrated at the level higher than our benchmark. We thank Oik Kwan for advising us the changes in the Policy in U.S.

the other hand, the optimal bank decision is to raise the deposit interest rate in order to compete with CBDC in the case of DIU model. If deposit does increase, the amount of bank loan will also expands, inducing an increase in capital and output. For welfare, this change obviously raises the amount of liquidity service, raising welfare, presumably at a much bigger rate than our benchmark counterpart. This is in contrast to our model: an increase in CBDC holding would substitute out debit account while the sum of debit and deposit account barely changes, so do the deposit and loan rates.

Third, our finding is in line with other studies in that bank profit falls as a consequence of introduction of CBDC. But our study indicates that this does not automatically promote competitiveness of the banking industry. This is natural because in our model, there is no model for entry and exit in the banking industry. Therefore, it can be an important extension of our model to allow the exit of existing banks and entry of new banks. Even if this is allowed, however, the improvement in efficiency by eliminating some monopolistic power in banks would not be sizable regardless of the size of CBDC, if the strong offsetting movements of debit and deposit remain valid.

Fourth, the alternative endogenous fiscal policy utilizing the seigniorage revenue does not alter the main result of ours. This is also in contrast to the findings of Burlon et al. (2022) who demonstrate that the optimal level of CBDC under various circumstances lie between 15% to 45% relative to the output when cash to output ratio is calibrated to be 34.4%. It seems that the relative preference parameter on CBDC and deposit in their study are fixed and not clearly reported, whereas it is the key preference parameter we vary and analyze. When we vary the preference parameter, the relative weight of CBDC, a^h (their ϑ in steady state) from 0% to 60%, the optimal CBDC-output ratio rises from 0% to 25%. This also implies that the optimal cash to output ratio falls by a substitution effect. It is not possible to directly compare their results with ours because deposit is absent in the liquidity service in our model. Nevertheless, it is easy to see that the seigniorage revenue should be much smaller than that of Burlon et al. (2022). Therefore, even if we adopts an alternative fiscal policy such that the seigniorage revenue is used to finance the government expenditure, the results on the output and welfare would be negligible. When the central bank raises the CBDC rate, the seigniorage revenue is actually decreases, but the size of government expenditure under this alternative fiscal policy is almost the same as that of the exogenous fiscal policy. Indeed, the results for the steady state analysis and welfare analysis are indiscernible with the benchmark results, Figures 1, 2 and 5, thus we do not report them here.

To summarize, what matters for the steady state real effect and welfare implication is how one interprets and defines liquidity service. This study adopts the traditional notion of liquidity, excluding deposit as a source of liquidity, and treats deposit as an interest-bearing asset. If interest-bearing savings account constitutes the liquidity service, the real effect of CBDC and the impact on welfare may be too large to be consistent with reality.

2. Robustness

We have tested many alternative specifications including alternative endogenous fiscal policy in which seigniorage revenue can be used as an additional source for fiscal policy. Recall that from Figures (1, 2), the seigniorage revenue rises only very marginally when the CBDC weight increases and it actually falls as the CBDC interest rate goes up. In any case, the change in the seigniorage revenue is negligible, thus, alternative fiscal policy does not change the main results. For this reason, we do not report the result based on the alternative fiscal policy to save space. This is in stark contrast to the finding in Burlon et al. (2022) which emphasizes the seigniorage channel of fiscal policy and other fiscal policy devices in Barrdear and Kumhof (2021).

Most of parameters in our model are not related to the composition of debit and deposit, thus one can expect that no noticeable change would emerge when evaluating the model with other parameter values. Indeed, we have verified this conjecture by performing a number of exercises. This is so even when the elasticity of substitution across the three types of money is large. Our benchmark value for the elasticity is 2, but it can be much larger. For instance, in a New-Monetarist framework in which CBDC, debit and cash are perfect substitutes, Chiu et al. (2023) and Williamson (2022) demonstrate that introduction of CBDC can be welfare-improving. In our framework, however, even if this effect exists, it should be only marginal. Figures 6 and 7 verify this conjecture in which the elasticity is set at 5. As the households' CBDC holding weight increases from 20% to 40%, loan (thus capital) and labor in equilibrium increase and push up the output, but they fall if the CBDC weight is over 40%. Moreover, the change in output is quite small quantitatively. In the case of an increase in CBDC rate, the result is qualitatively similar to the benchmark case, but the fall in output is slightly larger than the benchmark counterpart. We also find that the change in consumption, labor/leisure and liquidity does not alter the welfare implication from the benchmark case, we do not report the results.

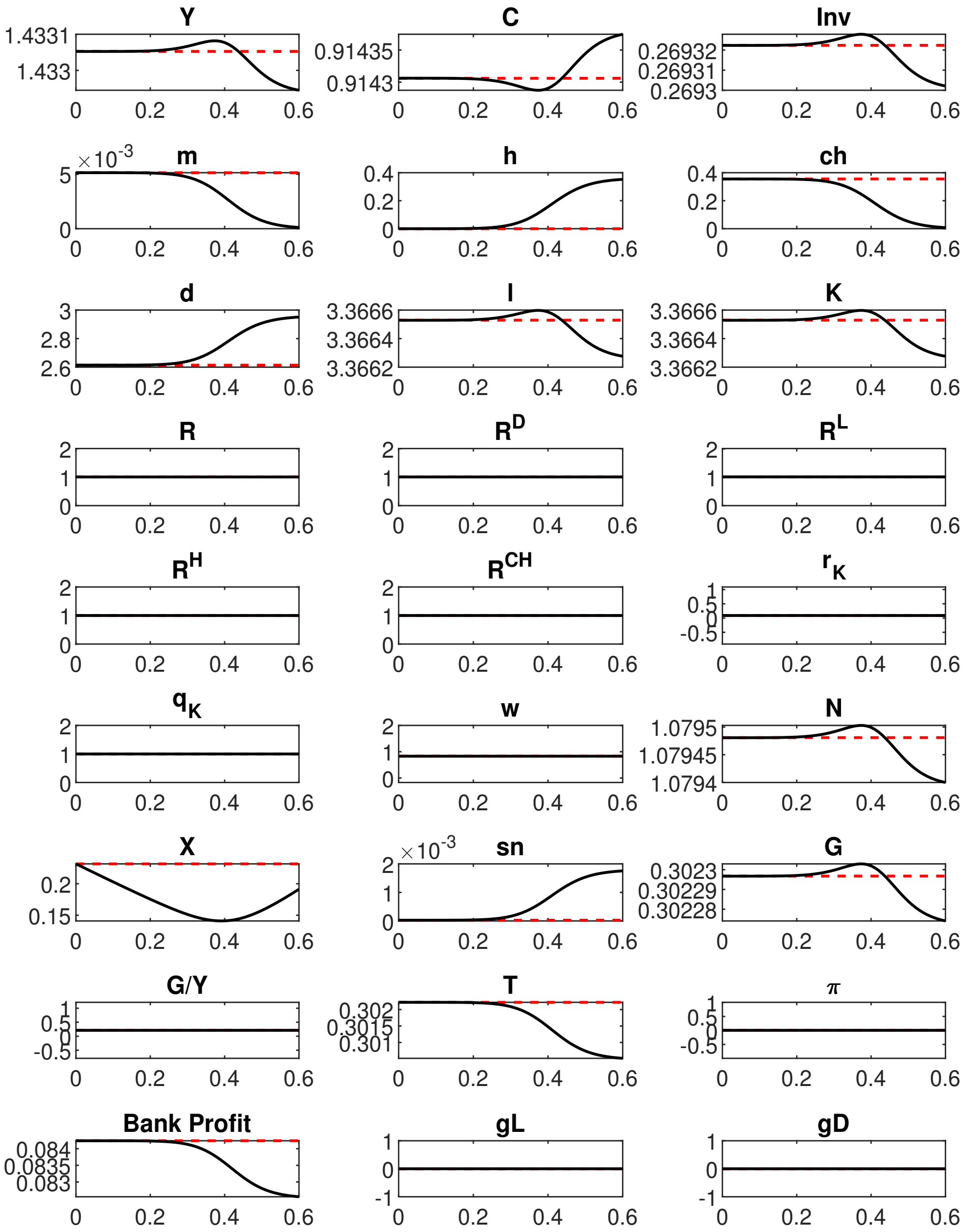
3. Short-run Analysis

Now we move on to the short-run analysis using impulse responses to the monetary policy. We first presents the impulse response analysis when the central bank conducts a contractionary monetary policy by raising the primary interest rate.

As expected, the result is consistent with a typical New-Keynesian macroeconomic model: Output, consumption and inflation falls as the primary interest rate rises. In our model with a banking sector, all of the interest rates (deposit and loan rates) increase, but asymmetrically – loan rate rises more than the deposit rate. Consequently, the equilibrium deposit rises, but because debit account holding falls more than an increase in deposit, the total loan and the resulting capital falls.

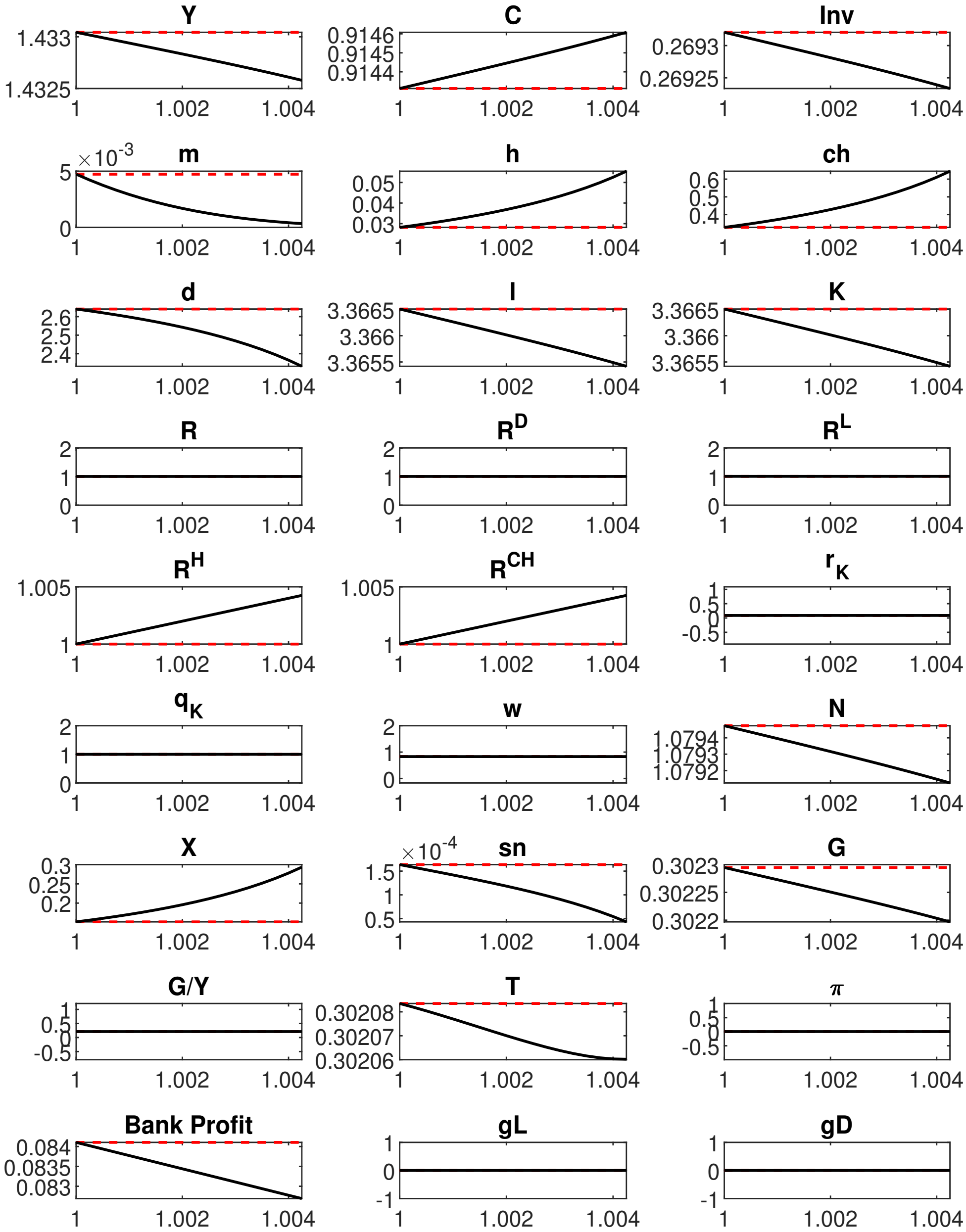
Given that our model matches the standard impulse-responses to a contractionary monetary policy shock, we assess the impact of an increase in the CBDC interest rate in Figure 9. As Figure 9 illustrates, output increases in contrast to the case of a contractionary monetary policy shock. This result can be understood

Figure 6. Effect of Changes in CBDC weight on Steady State When $\varepsilon = 5$.



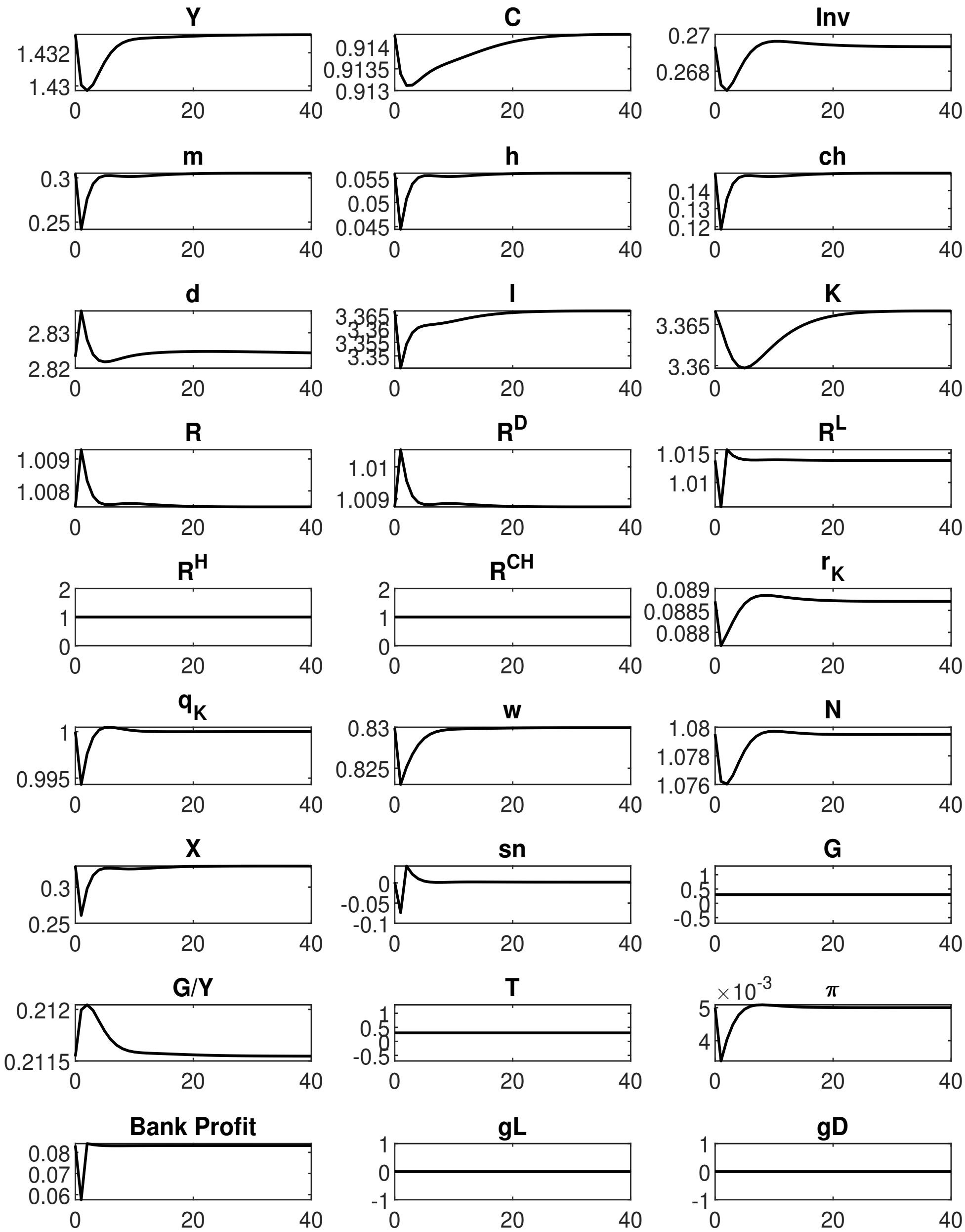
This figure plots the change of the variable in steady state as the CBDC weight a^h increases from zero to 0.6.

Figure 7. Effect of Changes in CBDC Interest Rate on Steady State When $\varepsilon = 5$



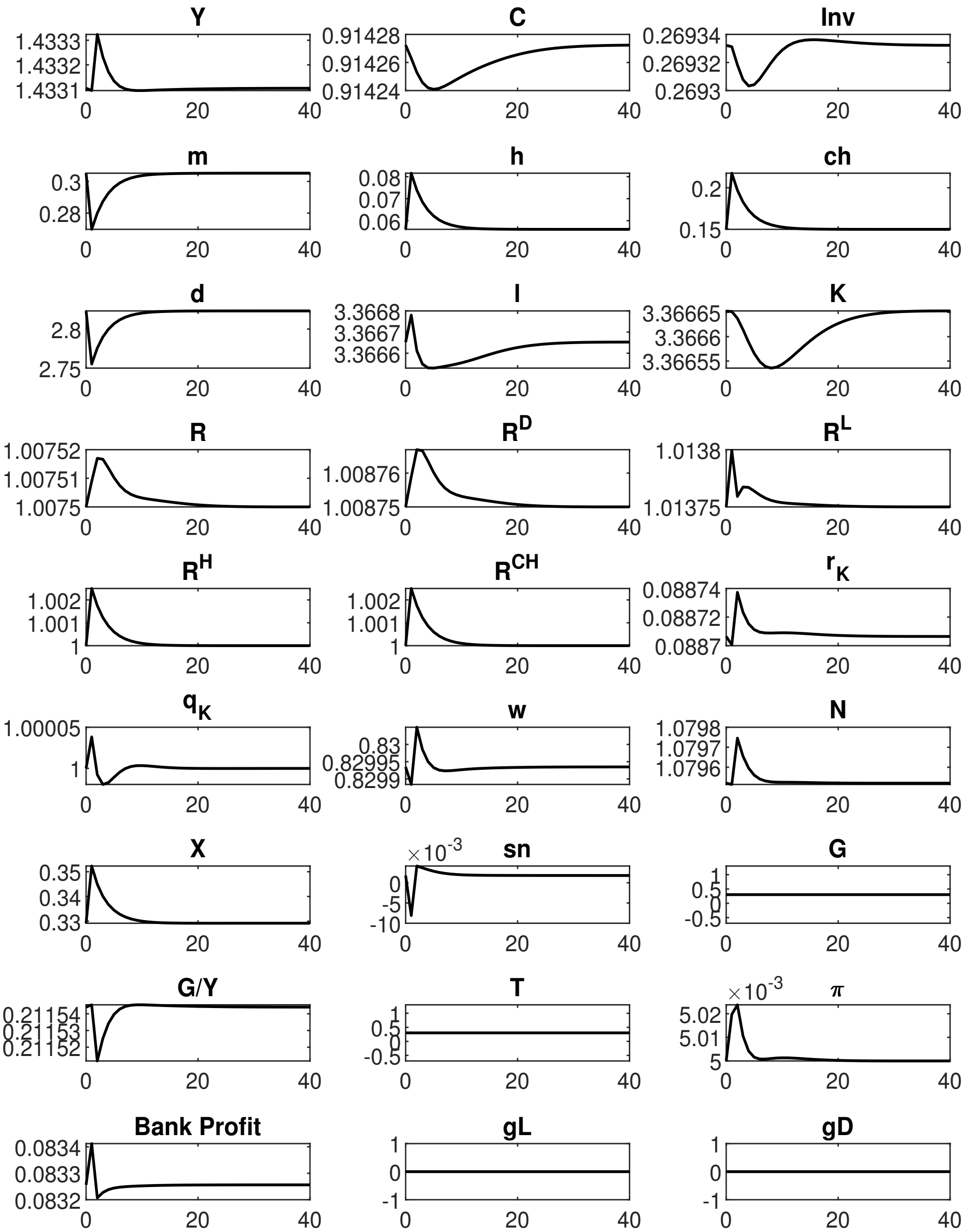
This figure plots the change of the variable in steady state as the CBDC interest rate R^H increases from 1.000 to 1.00425 on a quarterly basis.

Figure 8. Effect of an Exogenous Increase in the Primary Interest Rate



This figure plots the impulse-responses of each variable to a 0.25% increase in the primary interest rate on an annual basis.

Figure 9. Effect of an Exogenous Increase in the CBDC Interest rate Rate



This figure plots the impulse-responses of each variable to a 0.25% increase in the CBDC interest rate on an annual basis.

in the following way. Facing a sudden increase in the CBDC rate, households decrease consumption and increase labor supply. Recall that in the steady state analysis, the long-run equilibrium labor actually falls. As a consequence, the total amount of the three liquidity instruments and deposit rises. Moreover, while the deposit rate does not increase in the steady state analysis, banks do increase both debit and deposit rates not to lose debit and deposit. Therefore, the total loan amount actually increases. Summing the effect of increases in labor and loan contribute to the rise of output. Although the effect of the CBDC interest rate on output and consumption is still marginal quantitatively, an alternative and independent CBDC interest rate policy clearly has a qualitatively different impact on output and consumption from the standard primary policy instrument. To summarize, the introduction of CBDC has some mixed long-run effect on output and welfare in steady state and in the short-run, and the CBDC interest rate policy provides the central bank a fresh, novel and potentially powerful policy instrument to achieve possibly multiple policy goals, if appropriately mixed with a primary interest rate policy.

VI. Conclusion

In this study, we extend a standard DSGE model with a solid microfoundation for a banking sector based on Ulate (2021) in which CBDC competes directly with traditional money providing liquidity services – physical cash and non-interest-bearing debit – and indirectly with the interest-bearing deposit, which is a standard asset for households. What is novel in this approach is that the distinction between these two types of bank liabilities other than bank capital provides a fresh interpretation for the efficacy of CBDC on the real economy and welfare. All of our results lie in the following observation. Any change in debit caused by CBDC – such as changes in the preference of holding CBDC or changes in CBDC interest rate – is mostly offset by the change in households' demand for deposit, rather than consumption and labor in the long-run. Therefore, the banks' balance sheet is barely affected. Consequently, the effect of CBDC on the real economy is found to be marginal quantitatively. Our classification of the two types of deposit is not of course innocuous because there exists a variety of deposits differing in liquidity and interest rates in reality. Also, the banking sector abstracting from exit and entry decisions is a clear shortfall in our model, therefore our model cannot explain the potential benefit of CBDC enhancing competitiveness in the banking industry. However, our results can be interpreted as an extension of the traditional lesson about neutrality of money: Change in money demand or money supply – regardless of whether the central bank changes the target monetary aggregate or target interest rate, the real value of deposit, loans, capital thereby output are all invariant to this monetary adjustment. In our setup, there are only composition effect in banks' liabilities, but since the banking industry is relatively competitive, particularly in deposit market, such a composition effect barely affects the total real value of deposit, leading to near-neutrality of money and CBDC.

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⟨Abstract in Korean⟩

중앙은행 디지털화폐, 실물효과와 국민후생*

조성훈 **

본 연구는 표준적인 뉴케인지안 동태 확률 일반균형(DSGE) 모형의 틀에서 중앙은행 디지털화폐(CBDC) 도입이 실물경제와 후생에 미치는 장단기 영향을 분석한다. 기존 모형들과 가장 큰 차이점은 민간은행이 요구불예금과 저축성 예금이라는 두 가지 유형의 예금을 발행하고 이 두 금융상품은 각각 가계의 유동성과 자산으로서의 성격을 지닌다는 것이다. 따라서 본 모형에서 CBDC는 실제 현금 및 요구불 예금 등 전통적인 화폐와 직접적으로 경쟁하지만 저축성예금과 간접적으로 경쟁한다. CBDC의 도입은 균형에서 요구불예금 최적보유량에 중요한 영향을 미칠 수 있는데 그 크기와 방향은 CBDC 보유 선호도, 현금, 요구불예금 CBDC간 대체탄력성 그리고 CBDC 이자율에 달려있다. 그러나 저축성 예금은 요구불 예금과 반대방향으로 움직여 요구불예금 변화분을 상쇄하게 되고 따라서 전체 은행의 부채 및 자산은 CBDC가 도입되더라도 크게 영향을 받지 않는다. 이러한 결과는 CBDC 도입이 국민소득과 후생에 미치는 영향이 정량적으로 크지 않음을 의미하고 한 가지 유형의 예금만을 대상으로 한 이전 연구의 결과와 차별화된다.

핵심 주제어: 중앙은행 디지털화폐, 국민후생

JEL Classification: C32; E43; E52

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** 본 연구에 중요하고 유익한 논평을 해주신 권오익 박사님과 현정환 교수님, 그리고 한국은행 세미나 참석자분들께 깊이 감사드린다. 또한 연구진행과정에서 큰 도움을 주신 강환구 박사님과 황인도 박사님께도 깊은 감사를 드리며 세세하고 건설적인 논명을 해주신 익명의 심사자분들께 도감사드린다. 본 연구는 한국은행의 재정지원을 받아 진행되었음을 밝힌다.

BOK 경제연구 발간목록

한국은행 경제연구원에서는 Working Paper인 『BOK 경제연구』를 수시로 발간하고 있습니다.
『BOK 경제연구』는 주요 경제 현상 및 정책 효과에 대한 직관적 설명 뿐 아니라 깊이 있는 이론 또는 실증 분석을 제공함으로써 엄밀한 논증에 초점을 두는 학술논문 형태의 연구이며 한국은행 직원 및 한국은행 연구용역사업의 연구 결과물이 수록되고 있습니다.
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