Household Payment Behavior and the Optimal Quantity of CBDC in Japan*

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Abstract

We analyze Japanese household payment behavior and estimate the welfare-maximizing circulation of a central bank digital currency (CBDC) using a dynamic stochastic general equilibrium (DSGE) model. Based on a nationwide survey of 8,000 individuals conducted by Nomura Research Institute in 2024, we find that households willing to hold CBDC would convert approximately 15.6% of their cash and 12.7% of their deposits into CBDC, suggesting a digital yen would partially substitute for existing means of payment. Calibrating the model with Japanese macroeconomic and financial data and incorporating household liquidity preferences derived from the survey, we find that when the CBDC interest rate is set to zero, the optimal circulation of CBDC amounts to 92% of quarterly GDP, exceeding the euro area benchmark of 64% (Burlon et al., 2024). The larger optimal quantity of CBDC in Japan may reflect not only differences in household liquidity preferences, but also structural characteristics of its financial system, including a larger central bank balance sheet and a higher ratio of corporate lending to GDP.

Keywords: CBDC; Household Survey; Optimal Monetary Policy; Japan.

JEL codes: E23, E42, E58.

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1 Introduction

In recent years, the introduction of central bank digital currencies (CBDCs) as a means of payment for individuals has been discussed around the world. This growing interest reflects the accelerating digitalization of finance, driven by advances in information and communication technology, the spread of mobile payments, and the rise of private cashless payment systems, all accompanying the broader digitalization of the economy. Many central banks view CBDCs as a new public payment infrastructure to partially substitute cash and have been examining their design, advantages, and possible side effects from both theoretical and empirical perspectives.

However, there are relatively few studies which combine behavioral survey data with macroeconomic models to analyze how CBDCs affect social welfare through household payment behavior. Japan provides an interesting case: the use of cash remains high, the expansion of private cashless payments has been gradual by international standards, and the central bank's balance sheet is relatively large. These characteristics make it both a policy-relevant and academically important task to evaluate the welfare implications of introducing CBDC in Japan.

The purpose of this study is to analyze Japanese household payment behavior and their willingness to hold CBDC, and to estimate the welfare-maximizing CBDC circulation using a dynamic stochastic general equilibrium (DSGE) model. Specifically, based on a nationwide survey of 8,000 individuals conducted in March 2024 (Nomura Research Institute, 2024), we first provide descriptive evidence on how Japanese households choose among payment instruments and how they view the potential introduction of CBDC. We then incorporate household liquidity preferences implied from this survey into a DSGE model and compute the welfare-maximizing CBDC circulation under either a quantity or interest-rate-based rule for CBDC issuance. The model builds on the New Keynesian banking framework of Burlon et al. (2024), which analyzes the welfare-maximizing circulation of CBDC in the euro area, and its parameters are calibrated to match Japan's macro-financial data and household survey evidence.

Our main results are as follows. First, the household survey reveals that while cashless payments have become more prevalent—particularly among younger generations—cash usage remains deeply rooted. Only about 12% of respondents expressed a willingness to hold CBDC, and they would convert about 15.6% of their cash and 12.7% of their deposits into CBDC. These findings suggest that CBDC would partially substitute for existing payment methods. Second, the model-based welfare analysis shows that the welfare-maximizing CBDC circulation ranges between 28% and 203% of quarterly GDP, with the corresponding optimal CBDC interest rate between –0.17% and 0.10%.[1] Assuming a zero CBDC interest rate, the optimal quantity of CBDC in Japan is estimated at 92% of quarterly GDP—higher than the 64% benchmark for the euro area.[2]

One reason why the welfare-maximizing level of CBDC circulation is larger in Japan is the stronger household preference for cash. The greater this preference, the higher the overall demand for liquid payment assets—including deposits and CBDC—and thus the larger the implied CBDC demand. That said, these results depend on the specific CBDC issuance rules and the welfare criterion used, and they may vary with changes in other financial conditions. Therefore, they should be interpreted with an appropriate range of uncertainty.

The remainder of this paper is organized as follows. Section 2 describes the design of the household survey and presents the key descriptive results. Section 3 outlines the model structure. Section 4 presents data and calibration procedure. Section 5 conducts the welfare analysis of CBDC introduction, discusses policy implications, and examines robustness to different steady-state inflation targets. Section 6 concludes. The appendix provides details on Japanese macro-financial data sources and the model specification.

2 Household Payment Behavior: Survey Results

This section provides an overview of Japanese households' payment behavior and their willingness to hold CBDC, based on the survey results (Nomura Research Institute, 2024). The analysis does not delve into underlying factors or behavioral mechanisms; instead, these aspects are examined in the next section through the estimation of liquidity demand parameters in the model.

2.1 Overview of the Survey and Sample Characteristics

The outline of the survey is as follows. The survey was conducted on March 25–26, 2024, targeting individuals aged 18 and over across Japan. A total of 8,000 valid responses were collected through an online survey.[3] The survey items are broadly classified into three categories:

[1]The welfare-maximizing circulation of CBDC ranges from 28% to 129% of quarterly GDP under the quantity rule, and from 62% to 203% under the interest rate rule, with the corresponding interest rates ranging between -0.17% and 0.04%, and -0.05% and 0.10%, respectively.

[2]Burlon et al. (2024) show that the optimal quantity of CBDC in the euro area is estimated at 64% of quarterly GDP when the CBDC interest rate is assumed to be zero.

[3]To assess respondents' knowledge and understanding of CBDC, we conducted a quiz and related survey questions. Since public awareness of CBDC remains limited in Japan, a subset of respondents was randomly selected and provided with information about CBDC, allowing us to compare their responses before and after the information provision to evaluate the impact of information disclosure.

(1) current choice of payment methods, their reasons, and associated challenges;

(2) understanding of the differences between existing payment methods and CBDC; and

(3) choice of payment methods and reasons when a CBDC is issued.

Regarding the distribution of sample attributes, gender, age group, occupation, and place of residence (prefecture) are well balanced and broadly consistent with Japan's population structure (Figure 1). The average annual income was 2.85 million yen (3.98 million for men and 1.74 million for women), and the median was 1.53 million yen (2.78 million for men and 0.59 million for women). By age group, the median income was highest for those aged 40–49, followed by those aged 30–39 and 50–59. The average amount of household assets was 20.96 million yen (24.08 million for men and 17.49 million for women), while the median was 2.97 million yen (3.60 million for men and 2.35 million for women). By age group, the median asset holdings were largest for those aged 70–79, followed by 60–69 and 50–59.[4]

In terms of financial literacy, we ask respondents the "Big 3" financial knowledge questions. We find that men tend to score higher, and financial literacy improves with age (Figure 2).[5] We also find that younger male respondents own crypto assets more often. However, among younger generations, there is also a high proportion of individuals who are unaware of cryptocurrencies, indicating a polarization (Figure 3).

2.2 Household Payment Behavior

In Japan, the use of cashless payment methods such as credit cards and QR code payments has been expanding. Nevertheless, only 4.8% of respondents reported that they do not usually carry any cash, indicating that most people still keep some cash on hand. Regarding the amount of cash typically carried (cash on hand), about 30% of respondents reported

[4] Annual income was measured on a gross basis, including bonuses, temporary earnings, and pension benefits, while excluding lump-sum retirement payments. Household assets were aggregated mainly for financial assets, excluding real estate valuations and death insurance benefits. Amounts were reported using predefined brackets. The average was computed as a weighted mean using the midpoint of each bracket, while the median was obtained through linear interpolation based on the two brackets closest to the 50th percentile.

[5] The following three questions—known as the "Big 3"—were asked to assess respondents' financial literacy:

Q1. "Suppose you deposit 1 million yen in a savings account with an annual interest rate of 2%. After five years, how much will be in the account? Please ignore taxes on interest."

Q2. "If the inflation rate is 2% and the interest rate you receive on your savings account is 1%, how much will you be able to buy with the money in this account after one year?"

Q3. "Buying a single company's stock usually provides a safer return than buying a stock mutual fund (a financial product that invests in several companies). Is this statement true or false?"

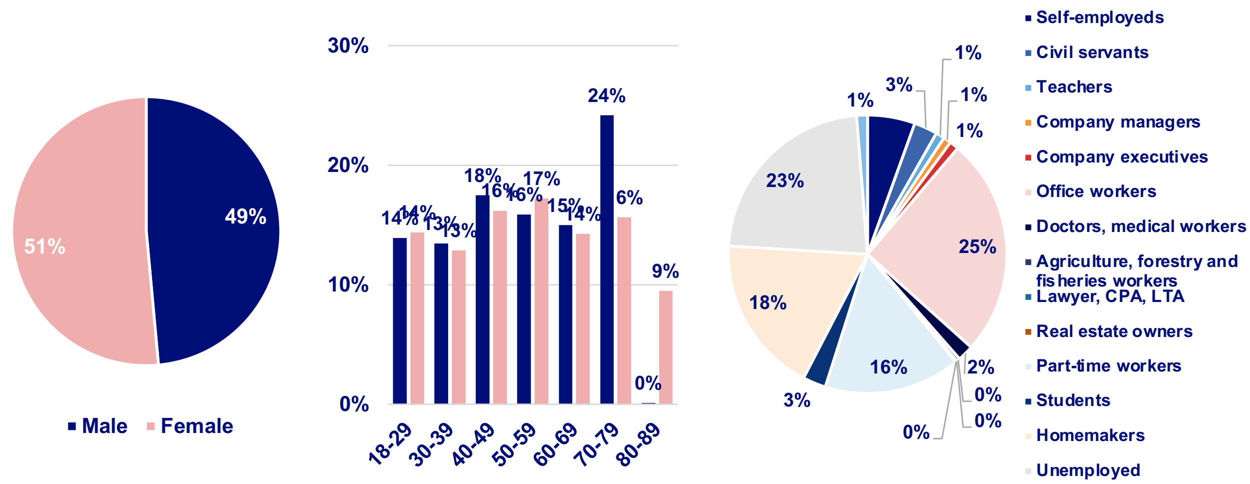

Figure 1. Sample Characteristics: Gender, Age, and Occupation

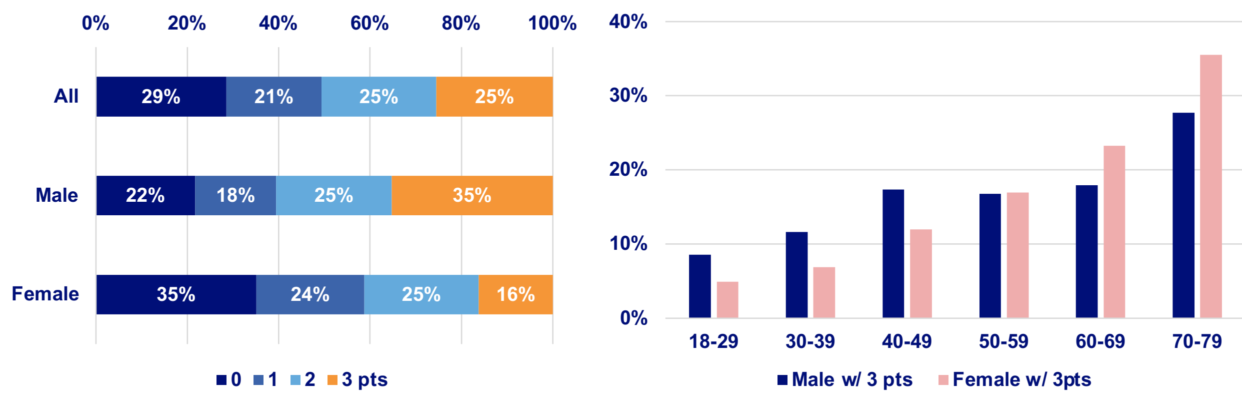

Figure 2. Sample Characteristics: Financial Literacy

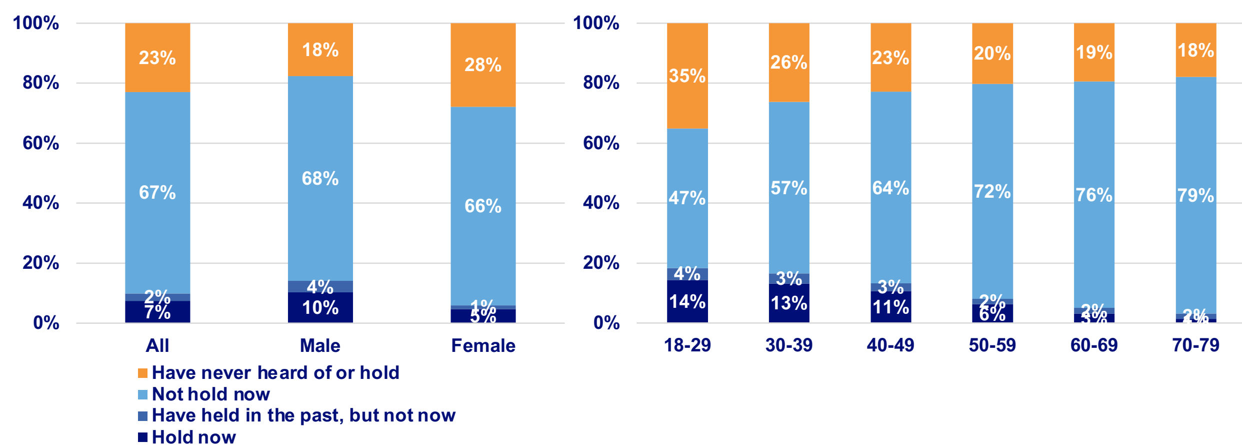

Figure 3. Sample Characteristics: Cryptocurrency Ownership and Awareness

holding between 10,000 and 50,000 yen, followed by slightly more than 20% each who hold between 5,000 and 10,000 yen, and between 1,000 and 5,000 yen. In contrast, when asked whether they keep cash at home, more than 25% answered "no." Only slightly more than 10% reported holding 100,000 yen or more, suggesting that most households keep only the amount necessary for daily life (Figure 4).

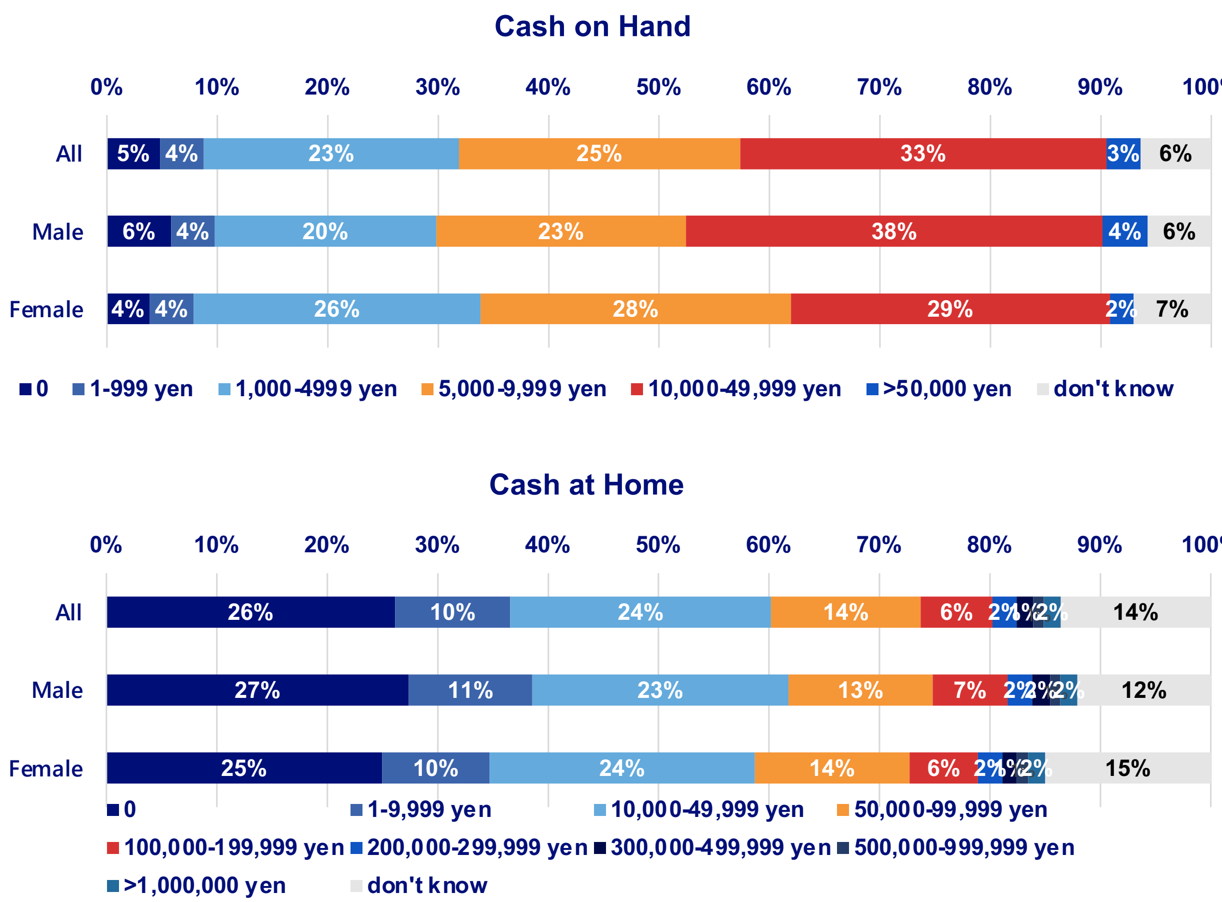

Figure 4. Household Cash on Hand and at Home

Across all generations, cash is the most widely used payment method, with about 90% of respondents reporting that they are using it (Figure 5). Credit cards are the second most common method, used by around 60% of younger respondents and nearly 90% of older respondents. Among other payment methods, older respondents frequently use retail e-money (issued by major distribution companies) and deposit transfer in addition to credit cards, whereas middle-aged respondents tend to use QR code payments, and younger respondents are more likely to use public transportation and deferred payment e-money.

In terms of the amount of average monthly household payments, credit cards account for the highest share—about 70% of monthly expenditures—followed by cash, QR code payments, and deposit transfer. The amounts paid via QR codes and other methods below that rank are typically less than 10,000 yen per month, indicating that they are mainly used for small-value transactions (Figure 6).

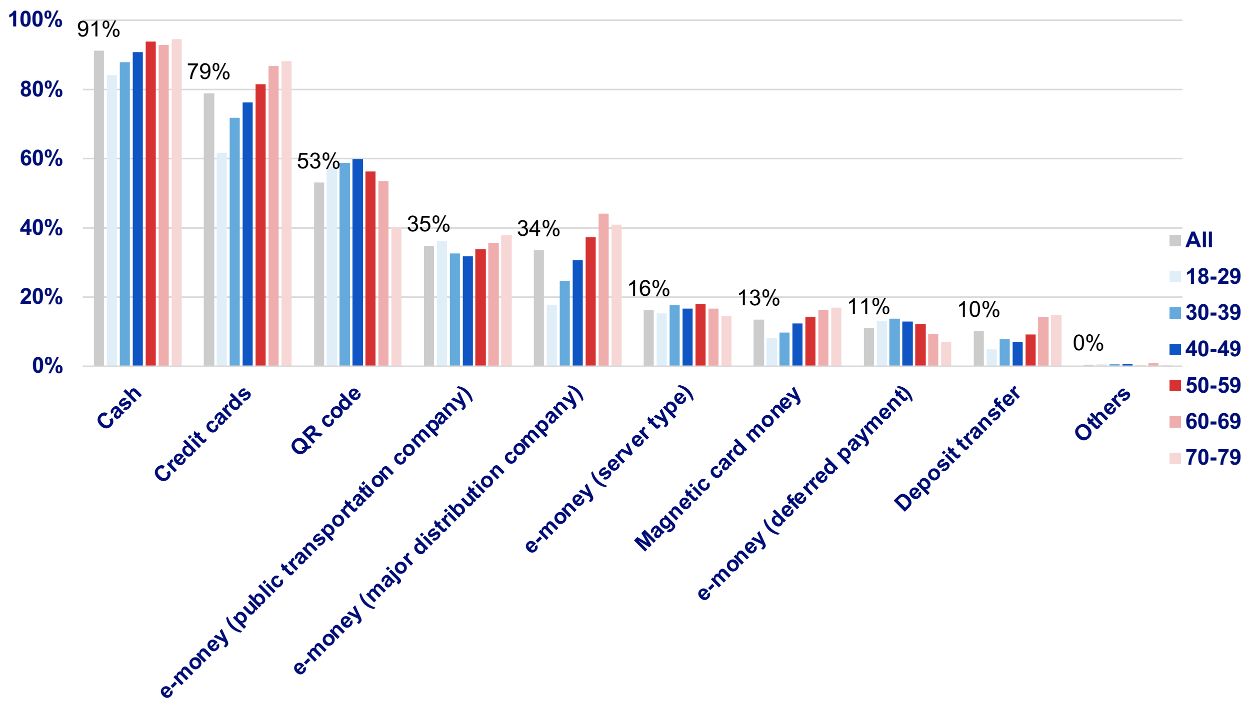

Figure 5. Household Payment Methods

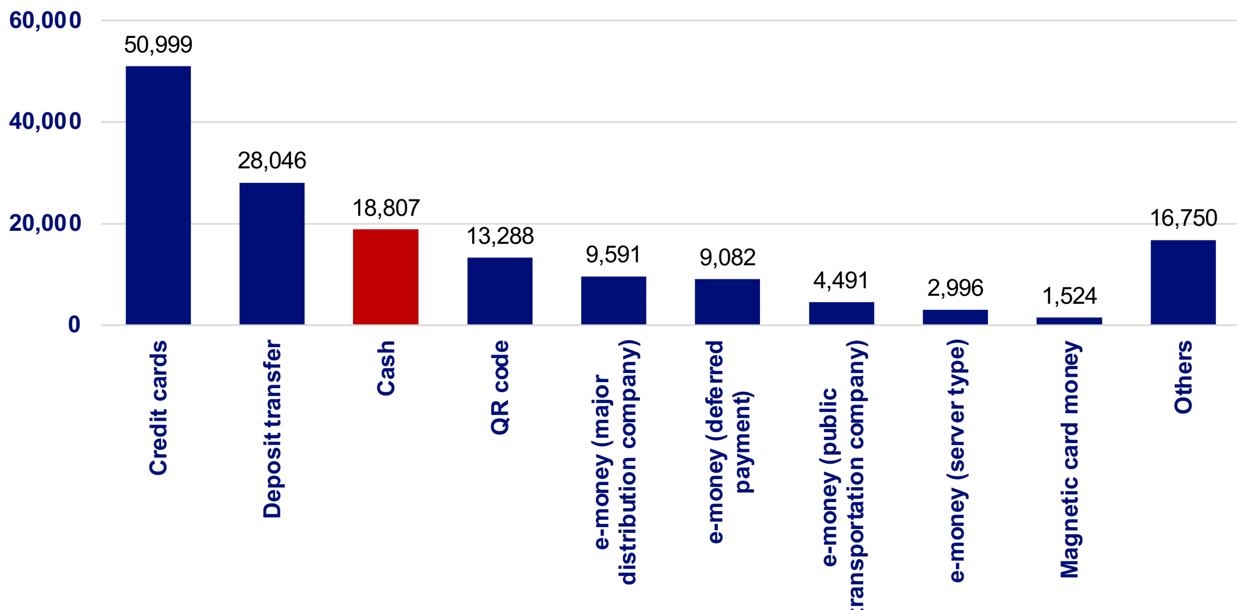

Figure 6. Household Payment Amounts by Payment Methods

When asked about the most frequently used payment method by payment scene, cash remains the most common overall, followed by credit cards, QR code payments, and deposit transfer (Figure 7). Different payment methods are used depending on the context: cash for person-to-person payments, credit cards for irregular or high-value purchases, QR codes for daily shopping, and deposit transfer primarily for local tax payments. Among various payment scenes, the largest average monthly payment amounts are for daily shopping, followed by housing expenses, utilities, local taxes, national taxes, high-value purchases, entertainment, person-to-person transfers, medical and nursing care, and education.

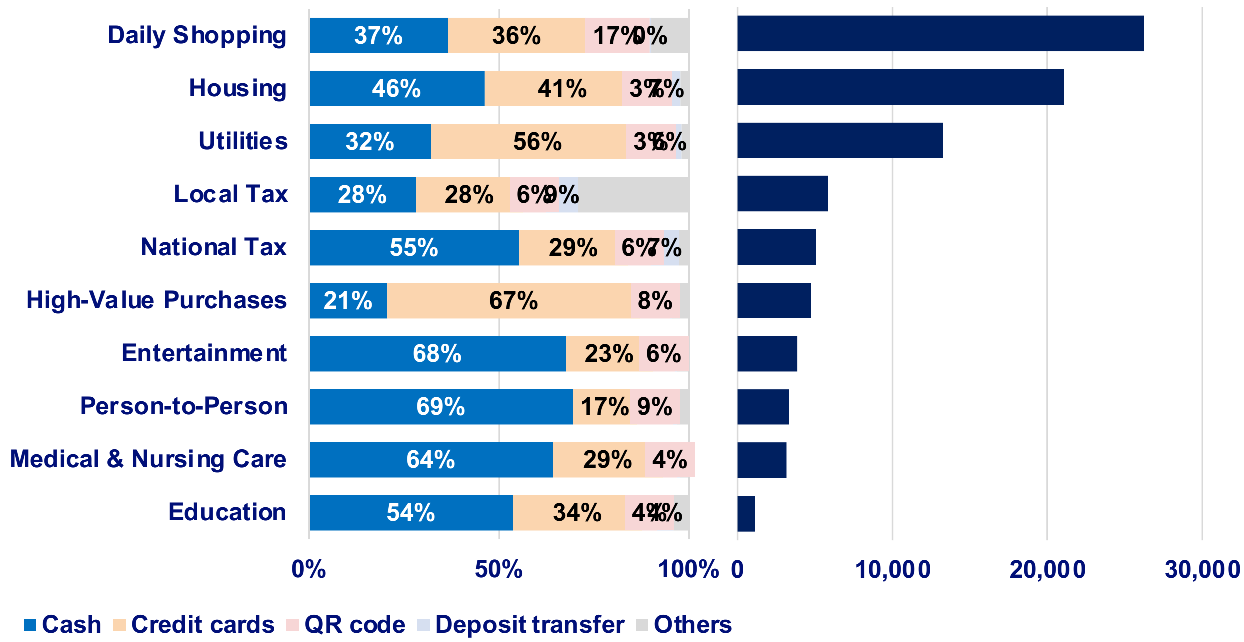

Figure 7. Household Payment Methods and Amounts by Payment Scenes

Note: "Daily shopping" denotes irregular purchases under 10,000 yen, whereas "High-value purchases" denote those over 10,000 yen.

2.3 Household Willingness to Hold CBDC

Among the survey respondents described above, 11.6% of the total sample ($n = 8,000$) answered that they "would like to hold" or "somewhat would like to hold" CBDC (Figure 8).[6]

By gender, men showed a stronger willingness to hold CBDC, with 16.0% responding positively ("would like to hold" or "somewhat would like to hold"). By age group, respondents aged 25–49 were relatively more proactive, with 14–18% in each age group indicating a willingness to hold CBDC. In contrast, among those aged 50 and above, the willingness to

[6]Public awareness of CBDC remains very limited at present in Japan: only 16% of respondents have heard any term related to CBDC, and among them, just 13% actually know what CBDC is. Furthermore, when respondents were given a short quiz about CBDC, many lacked understanding of its basic characteristics—such as its convertibility with cash and its legal tender status. On the other hand, awareness of CBDC is higher among those with greater financial literacy or stronger interest in crypto assets.

hold CBDC declines markedly with age. Moreover, respondents with higher financial literacy scores tend to have a stronger willingness to hold CBDC (Figure 9). Other factors such as place of residence (prefecture), household income, and interest in crypto assets also appear to influence CBDC holding intentions.[7]

Next, among the total sample of 8,000 respondents, we asked the 924 individuals (11.6%) who indicated that they "would like to hold CBDC" or "somewhat would like to hold" how much of their existing assets they would be willing to convert into CBDC.[8] Excluding the top and bottom 5% of responses, the average amount converted from cash was 11,664 yen—equivalent to 15.6% of their current cash holdings—and the average amount converted from ordinary deposits was 120,926 yen—equivalent to 12.7% of their deposit holdings (Table 1).[9][10]

	From cash	From deposits
Amount (yen)	11,664	120,926
% of current assets	15.6%	12.7%

Table 1. Amounts Households Would Transfer from Existing Assets to CBDC

Note: Figures show average amounts converted from cash and deposits, excluding the top and bottom 5 percent of responses.

When respondents were asked in which situations they would like to use CBDC, the most frequently selected options—ranked from most to least common—were: in-store and online daily purchases, monthly fixed payments, taxes and subsidilies, salary receipt, real estate and financial transactions, domestic person-to-person transfers, and cross-border transfers / remittances (Figure 10). By age group, younger respondents expressed a broader range of intended uses—including salary receipt, financial transactions, and real-estate transactions—

[7] Fujiki (2024) shows that there is a significant correlation between knowledge or willingness to hold CBDC and interest in crypto assets. The study also suggests that individuals who hold crypto assets tend to carry significantly less cash on hand and are more likely to rely on cashless payment methods.

[8] In the survey, respondents were asked how much of their existing assets—specifically "cash," "bank deposits (including ordinary, time, and foreign-currency deposits)," and "financial instruments"—they would convert into CBDC. Responses indicating amounts exceeding their current holdings in each asset category were treated as invalid, and the averages were calculated using only the valid responses.

[9] Compared with the average household savings reported in the 2023 Family Income and Expenditure Survey (Savings and Liabilities) for two-or-more-person households—where the average balance of ordinary deposits is approximately 6.6 million yen—the 924 respondents who indicated a willingness to hold CBDC in this study reported a somewhat lower average balance of around 6.12 million yen.

[10] When focusing only on respondents who indicated they would transfer at least one yen from each asset category, the average amount converted is 83,067 yen (48.6%) from cash and 450,374 yen (32.3%) from ordinary deposits. However, when including all respondents—including those who stated they would not hold CBDC—the corresponding averages decline to 7,825 yen (1.9%) from cash and 36,637 yen (1.6%) from ordinary deposits.

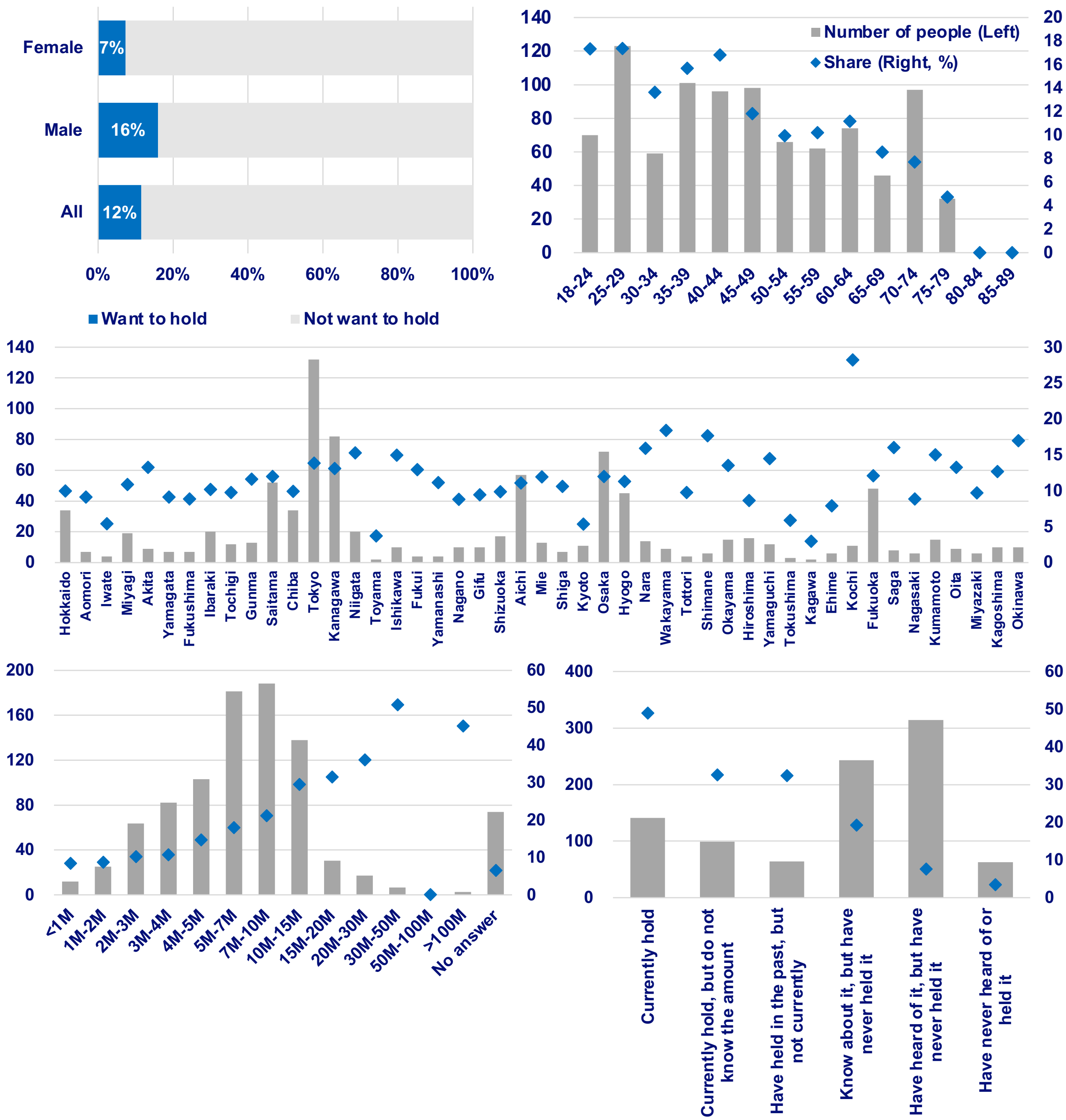

Figure 8. Household Willingness to Hold CBDC: Gender, Age, Place of Residence, Household Income, and Crypto Assets

Note: "Share" refers to the ratio of respondents who answered that they would like to hold CBDC to the total number of survey participants in each category. "Want to hold" includes both "would like to hold" and "somewhat would like to hold," whereas "Not want to hold" includes "unwilling to hold" and "somewhat unwilling to hold."

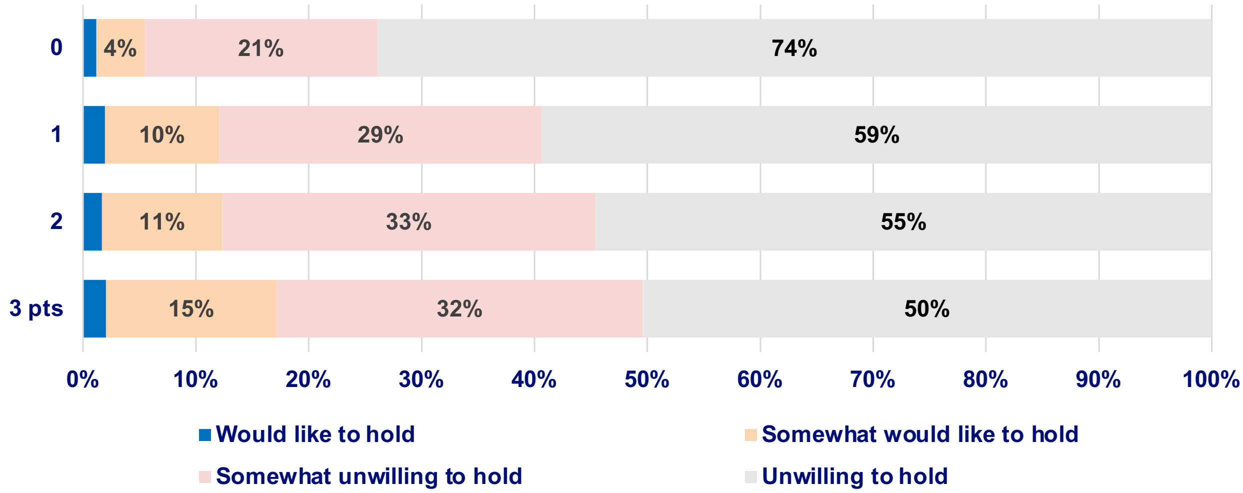

Figure 9. Household Willingness to Hold CBDC: Financial Literacy

while across all generations, strong demand was observed for tax payments and receiving subsidies.

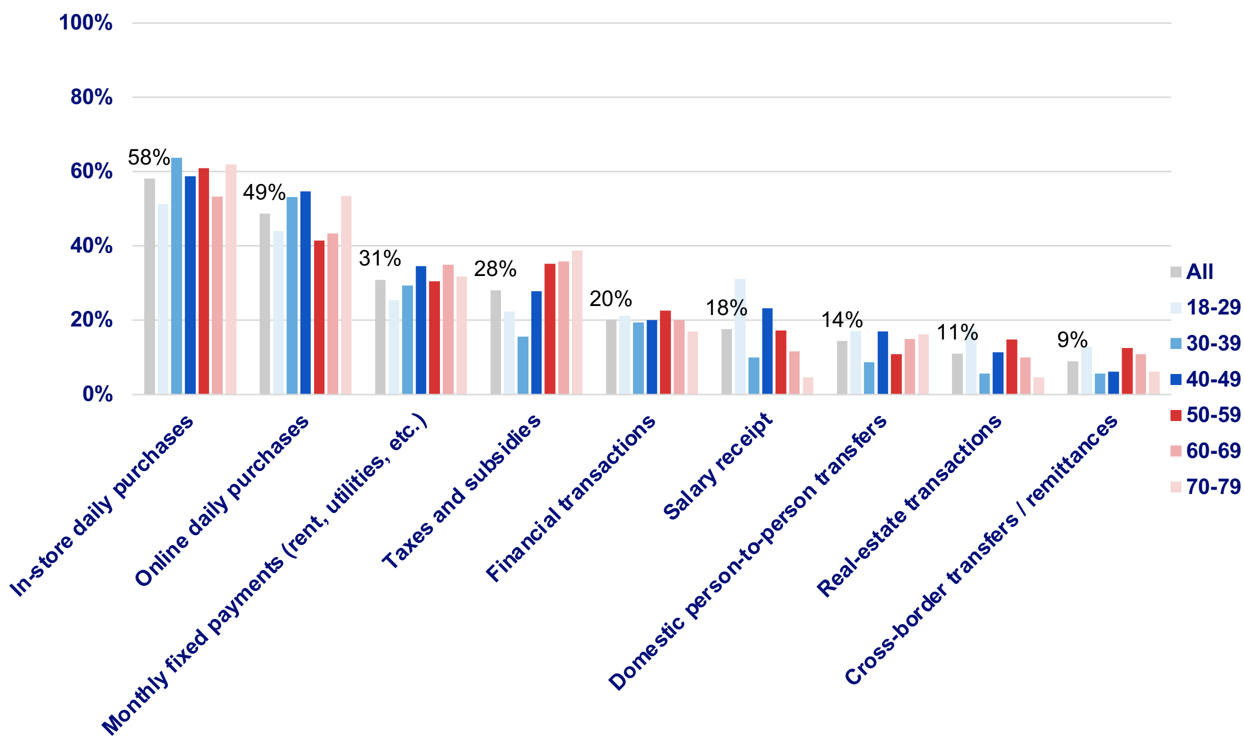

Figure 10. Household Usages of CBDC by Payment Scenes

In summary, the survey of Japanese households shows that while the use of cash remains deeply rooted, cashless payments are expanding, particularly among younger generations. Male, younger, and higher-income respondents, as well as those who own crypto assets tend to be more willing to hold CBDC, with an average intention to shift 15.6% of their cash holdings and 12.7% of their deposits into CBDC. The introduction of CBDC could therefore provide households with a new payment option within their diverse payment behaviors and potentially influence their liquidity preferences and payment choices.[11]

3 Model

The model employed in this section is based on Burlon et al. (2024). We provide a brief overview of the model structure and the transmission channels through which CBDC influences the economy. For further details, readers are referred to Appendix C of this paper or to Burlon et al. (2024).

3.1 Related Literature

Since no advanced economy has yet introduced a central bank digital currency (CBDC), theoretical models are used to examine its potential effects on the economy. Existing studies can be broadly classified into the following three categories:

1. New Monetarist (Search) Models (Lagos and Wright, 2005): These studies explore the design of CBDC as a means of payment, including Williamson (2022) and Keister and Sanches (2023).

2. Banking Models (Diamond and Dybvig, 1983): These examine the potential implications of CBDC for financial instability, such as the risk of bank runs, and for banks' market power in the deposit market, including Andolfatto (2021), Fernández-Villaverde et al. (2021), and Chiu et al. (2023).

3. Quantitative Dynamic Stochastic General Equilibrium (DSGE) Models: These assess the quantitative macroeconomic effects of CBDC issuance, including Barrdear and Kumhof (2022), Burlon et al. (2024), Bidder et al. (2024), and Abad et al. (2025).

[11] CBDC adoption may do more than simply diversify payment options; it could stimulate household spending and potentially reveal latent consumption demand. Prior studies can be reviewed from two perspectives: (i) the effect of CBDC substituting for cash payments, and (ii) the effect of adding CBDC as a public digital payment instrument alongside existing private cashless methods. The key findings are summarized below. For (i), empirical evidence shows that the shift to cashless payments reduces the psychological "pain of paying" and increases spending (Feinberg, 1986; Runnemark et al., 2015; Falk et al., 2016; Fujiwara, 2023). For (ii), Nocciola and Zamora-Pérez (2024) show, using EU data, that the diffusion of mobile payments may facilitate CBDC adoption. In Japan, Wakamori and You (2025) find that cashless payments have continued to expand even after the end of the government's point-rebate program. Therefore, CBDC adoption could help broaden consumer markets by enhancing the diversity and complementarity of payment instruments.

In addition, a growing strand of the literature analyzes CBDC in heterogeneous-agent economies, examining financial inclusion and distributional effects (Banet and Lebeau, 2022).

This study falls into the third category. It constructs a quantitative DSGE model incorporating the banking sector under certain assumptions about CBDC design, and calibrates the model parameters using macro-financial data. The model is then used to estimate the optimal quantity of CBDC that maximizes social welfare, defined as the aggregate utility of households. In the quantitative DSGE model employed in this study, the welfare costs and benefits of CBDC are derived from the following three components:

1. Liquidity Service Effect: The issuance of CBDC improves depositor welfare by enhancing liquidity provision. In the household utility function, cash, deposits, and CBDC are assumed to be imperfect substitutes.

2. Bank Intermediation Effect: The issuance of CBDC reduces bank deposits and tightens lending conditions, thereby lowering borrower welfare.

3. Stabilization Effect: The issuance of CBDC stabilizes fluctuations in deposits and lending over the business cycle, improving borrower welfare.

Social welfare is defined as the sum of the benefits from (1) and (3) minus the cost from (2).

3.2 Setup

The model consists of households (net savers and net borrowers), firms, banks, the government, and the central bank (Figure 11).

There are two types of households: patient net savers and impatient net borrowers.[12] Net savers hold cash, bank deposits, and CBDC, as well as government bonds.[13] The holdings of cash, deposits, and CBDC provide positive utility to households through improved liquidity services.[14] We assume that cash, deposits, and CBDC are imperfect substitutes in the household utility function. Net savers consume goods and housing services, supply labor to

[12]The "patience" of households is determined by their discount factor for future utility: a higher discount factor indicates greater patience, as households allocate more resources to future consumption rather than current spending.

[13]While deposits, CBDC, and government bonds generate income through interest payments, holding cash involves a holding cost.

[14]This corresponds to the so-called money-in-the-utility assumption, under which the model does not endogenously explain the reason households choose to hold cash, deposits, or CBDC.

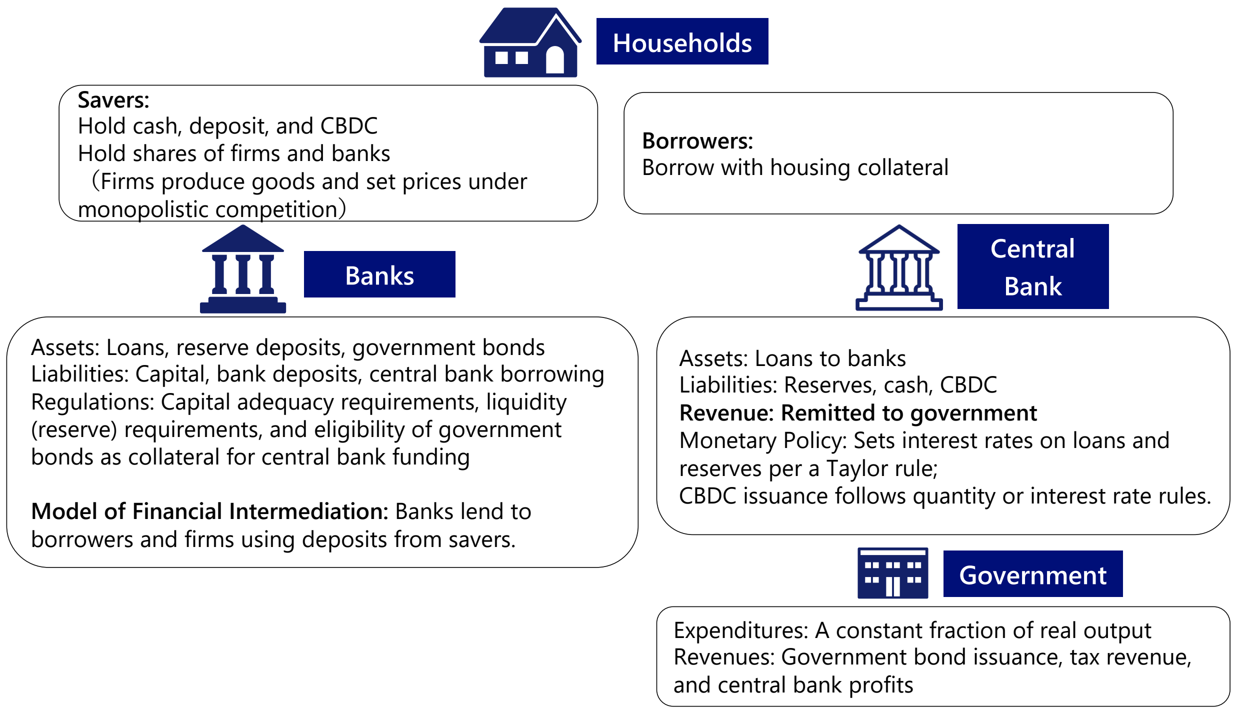

Figure 11. Agents in the model and their behavior

firms, and earn income from wages and financial assets.[15] Net borrowers, by contrast, borrow from banks using existing housing as collateral and use the borrowed funds to purchase consumption goods and housing services. Like net savers, they supply labor to firms and earn wage income.

Private banks hold government bonds, reserves, and loans as assets, and central bank borrowing, equity, and deposits as liabilities (Figure 12). We impose a capital adequacy constraint requiring equity to exceed a fixed share of total loans, defined as the risk-weighted average of household and corporate lending.[16] We also incorporate a liquidity requirement that sets a lower bound on reserves as a fraction of deposits, while we assume that central bank borrowing is subject to an upper limit determined by the collateral value of government bonds.[17]

[15]The model includes four types of firms: intermediate goods producers, final goods producers, capital goods producers, and entrepreneurs, who own the intermediate goods firms. Intermediate goods producers combine capital, housing services, and labor to produce differentiated intermediate goods and set prices under monopolistic competition. Final goods producers aggregate these intermediate goods and sell the resulting composite good to households. Capital goods producers manufacture the capital required for production and sell it to entrepreneurs. Entrepreneurs borrow from banks using existing capital as collateral and purchase capital and housing services with the borrowed funds. The capital and housing services owned by entrepreneurs, together with labor supplied by households, are used as inputs in the production of intermediate goods.

[16]We assume that the risk weights assigned to government bonds and reserve holdings are zero.

[17]Banks choose the composition of their balance sheets to maximize the discounted present value of future

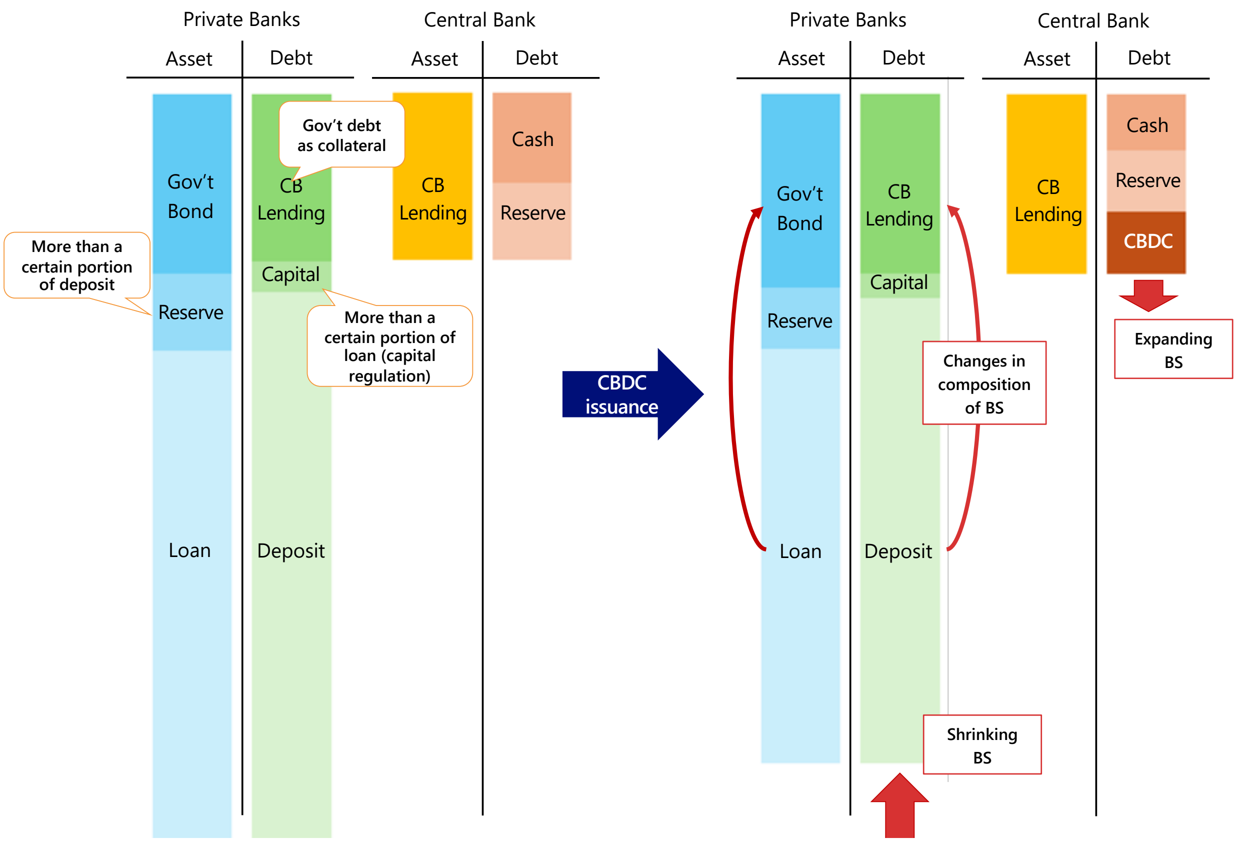

Figure 12. Private and Central Bank Balance Sheets

The government levies lump-sum taxes on net savers and banks and spends a fixed share of GDP. Expenditures and interest payments on existing government bonds are financed by taxes, central bank profits, and new bond issuance. The central bank sets the lending rate and the interest rate on reserves: the lending rate follows a Taylor-type policy rule based on inflation and GDP growth, while the reserve rate is maintained at a fixed margin below the lending rate (the interest rate corridor).

When the central bank issues a CBDC, its supply or interest rate is determined by a policy rule. The central bank holds central bank lending as assets, and cash, reserves, and CBDC as liabilities.[18] All assets and liabilities, except for cash, bear interest. The resulting net profit is transferred to the government when positive, whereas losses are covered by the government when negative.

dividends.

[18]In reality, the Bank of Japan holds a large amount of government bonds on the asset side of its balance sheet. Following Burlon et al. (2024), we assume that the central bank's asset-side counterpart to CBDC issuance is lending to private banks rather than purchases of government bonds. Under this assumption, the central bank lends an equivalent amount back to private banks against government-bond collateral; this allows us to isolate the deposit-substitution channel and its effects on banks' funding costs. See Section 5 for the implications of CBDC issuance for government-bond demand.

Let us now examine how the issuance of CBDC affects GDP through changes in the balance sheets of private banks and the central bank (Figure 13). Whether CBDC issuance reduces GDP depends on the relative magnitudes of its positive and negative effects, which are determined by the model's parameter values.

Under the assumption that CBDC is an imperfect substitute for other liquid assets held by households—namely, cash and deposits—the issuance of CBDC increases the total liquidity in the economy (cash + deposits + CBDC), thereby expanding household liquidity. This expansion leads to an enlargement of the central bank's balance sheet and an increase in its profit through seigniorage (monetary issuance gains).[19] The resulting profits are transferred to the government, strengthening its fiscal space and contributing positively to GDP.

At the same time, although household liquidity increases, the share of bank deposits in household liquidity declines depending on the degree of imperfect substitutability between deposits and CBDC. This results in a contraction of private banks' balance sheets. In terms of composition, on the liability side, part of the reduced deposits is replaced by borrowing from the central bank, which in turn increases the amount of government bonds held as collateral on the asset side, while reducing the share of loans in total assets. These balance-sheet adjustments—from relatively low-cost funding (deposits) to higher-cost funding (central bank borrowing) on the liability side, and from higher-yield assets (loans) to lower-yield assets (government bonds) on the asset side—compress banks' profitability.[20] Thus, the decline in financial intermediation, accompanied by reduced lending, exerts downward pressure on GDP.

4 Data and Calibration

Calibration involves adjusting model parameters so that model-generated variables align with observed data. Using quarterly macroeconomic time series from 2000Q1 to 2023Q4, we target the sample means and the standard deviations of detrended series. Specifically, we set parameters so that the steady-state values of the model variables closely correspond to the empirical data averages. Furthermore, we calibrate some parameters related to household demand for cash and deposits based on household survey results, reflecting potential CBDC demand in Japan.

Also, we choose the volatilities of exogenous shocks such that the standard deviations of the model variables closely align with those of the corresponding data series, measured as the

[19] A decline in deposits also reduces reserve holdings, but to a lesser extent, owing to the lower bound imposed by the liquidity requirement. Since CBDC pays less interest than reserves, the shift from reserves to CBDC on the liability side of the balance sheet improves the central bank's profitability.

[20] Consequently, banks' equity capital decreases, and their holdings of risky assets—loans—decline further.

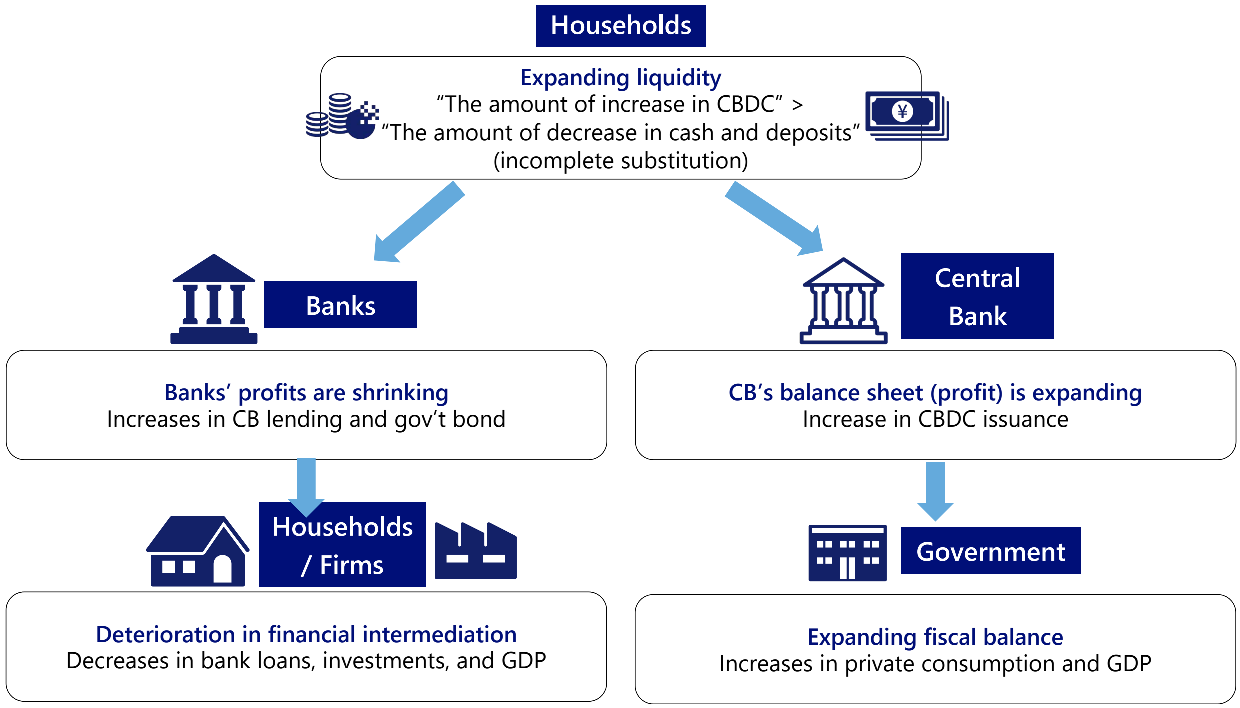

Figure 13. The Impact of CBDC Issuance on GDP

standard deviations of deviations from linear trends over the sample period.[21] Appendix A provides details on the data sources. Also, Appendix B compares the model-implied moments with the corresponding data moments.

4.1 Data

This section provides a detailed account of the macroeconomic time-series data used for calibration, emphasizing a comparison between Japan and the euro area. For comparison, we also report the euro area data employed in Burlon et al. (2024).

The ratio of household bank loans to GDP (L_i/Y) has remained around 2 in the euro area since the 2000s (sample-period average: 1.9824), whereas it is approximately 1 in Japan (1.0097). In contrast, the ratio of corporate bank loans to GDP (L_e/Y) exceeds 1 in both economies but is substantially higher in Japan (4.2673) than in the euro area (1.6820).

[21] As some of the data series exhibit growth trends, we use the standard deviations of detrended series—that is, deviations from linear trends—in the analysis. The trends are estimated separately for each series; we do not assume a common or co-trended linear trend across the series. We deliberately keep this choice, rather than switching to log-differences, for comparability. Our benchmark, Burlon et al. (2024), calibrates the euro-area model to standard deviations of deviations from linear trends. Since the main exercise of our paper is the comparison of the optimal quantity of CBDC between Japan and the euro area under a common framework, applying a different filter to the Japanese data would confound cross-country differences with differences arising from the filtering choice.

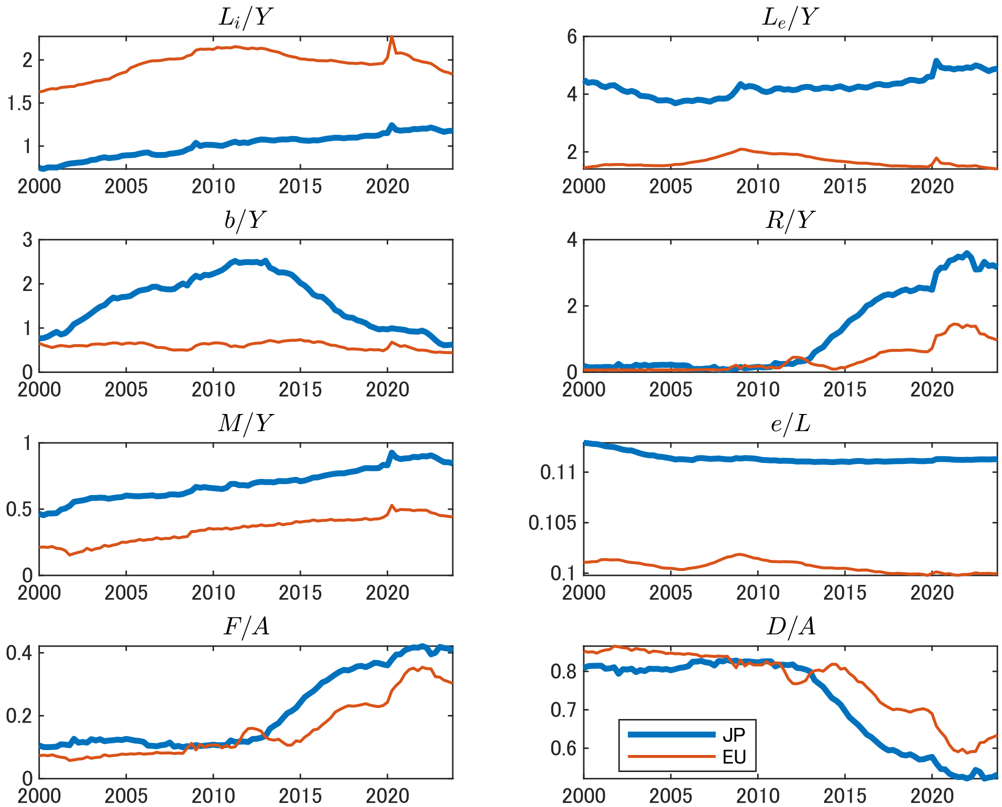

Figure 14. Data Used for Calibration

The ratio of reserves to GDP (R/Y) in Japan has trended upward, especially since the launch of large-scale monetary easing in 2013 (1.1596). In the euro area, it rose during the 2011 sovereign debt crisis, declined thereafter, increased again following the introduction of negative interest rates in 2014, and surged during the COVID-19 pandemic, but has recently been declining (0.3326). The ratio of government bonds held by domestic banks to GDP (b/Y) rose in Japan until 2012 but declined after 2013 as the Bank of Japan's purchases reduced market holdings (1.5824). In the euro area, it has been on a downward trend since 2014, despite a temporary rise during the pandemic (0.6099). Overall, the central bank balance sheet has expanded more markedly in Japan.

The ratio of currency in circulation (banknotes + coins) to GDP (M/Y) has continued to rise in the euro area, exceeding 30% despite a slight decline following a temporary increase during the COVID-19 pandemic (0.3326). In Japan, the ratio has increased from about 50% in the early 2000s to nearly 70% in recent years (0.6929). The bank capital-to-loan ratio (e/L)—where capital is defined by the model's capital adequacy constraint as $e = (1-\gamma_i)L_i + (1-\gamma_e)L_e$ and total loans as $L = L_i + L_e$—has remained broadly stable in both the euro area (0.1060) and Japan (0.1114).[22]

[22]In this analysis, we compute the risk weights for household and corporate loans, $(1-\gamma_i, 1-\gamma_e)$, from

In the model, central bank lending (F) is defined as the sum of cash (M) and reserves (R), such that $F = M + R$. From private banks' balance sheets, total assets are given by $A = L_i + L_e + R + b$, while total liabilities consist of deposits (D), equity (e), and central bank borrowing (F).[23] Because total assets equal total liabilities, deposits are obtained as $D = A - e - F$.[24] Using these definitions, the ratio of central bank lending to total assets (F/A) has increased in both the euro area (0.0892) and Japan (0.2118), whereas the ratio of deposits to total assets (D/A) has declined in both economies (0.8047 and 0.7210, respectively).

The deposit rate (r_d) has remained extremely low in Japan but was somewhat higher in the early part of the sample in the euro area. The corporate lending rate (r_e) declined in both regions, though it has recently risen in the euro area with monetary tightening. The average spread ($r_e - r_d$) is 1.18% in Japan and 3.05% in the euro area (annualized).

The central bank lending rate (r_f) exceeds the interest rate on reserves (r_R), with an average spread ($r_f - r_R$) of 0.24% in Japan and 1.39% in the euro area. In the model, the central bank lending rate is determined by a Taylor-type rule, and the spread between the lending rate and the reserve rate is kept constant.

Early in the sample, the reserve rate was above the deposit rate, but under the negative interest rate policy it fell below it; the average spread ($r_R - r_d$) is 0.03% in Japan and 0.27% in the euro area. Consumption and investment have been relatively stable, at about 60% and 20% of GDP, respectively, in both economies.

4.2 Calibration

The model parameters can be broadly classified into three categories: (1) parameters that are predetermined; (2) parameters calibrated such that the steady-state values of model variables match the corresponding sample means in the data; and (3) parameters related to households' potential demand for CBDC, which are derived from household survey results.

In this study, we basically follow the procedure of Burlon et al. (2024), with some modifications to incorporate the survey results described in Section 2.3. Specifically, we follow a two-step procedure:

In the first step, taking the set of fixed parameters (1) as given, we calibrate the parameters (2) so that the model's steady-state values match the empirical data moments. In

the calibration results, whereas we assume that the risk weights for reserves and government bonds are zero.

[23] See also Figure 12 for the balance sheets of private banks and the central bank.

[24] While we can obtain deposit data can in principle directly from the balance sheets of private banks, many balance sheet items of both private and central banks are abstracted from the model. Therefore, in this paper, we compute deposits as a residual derived from the balance sheet identity.

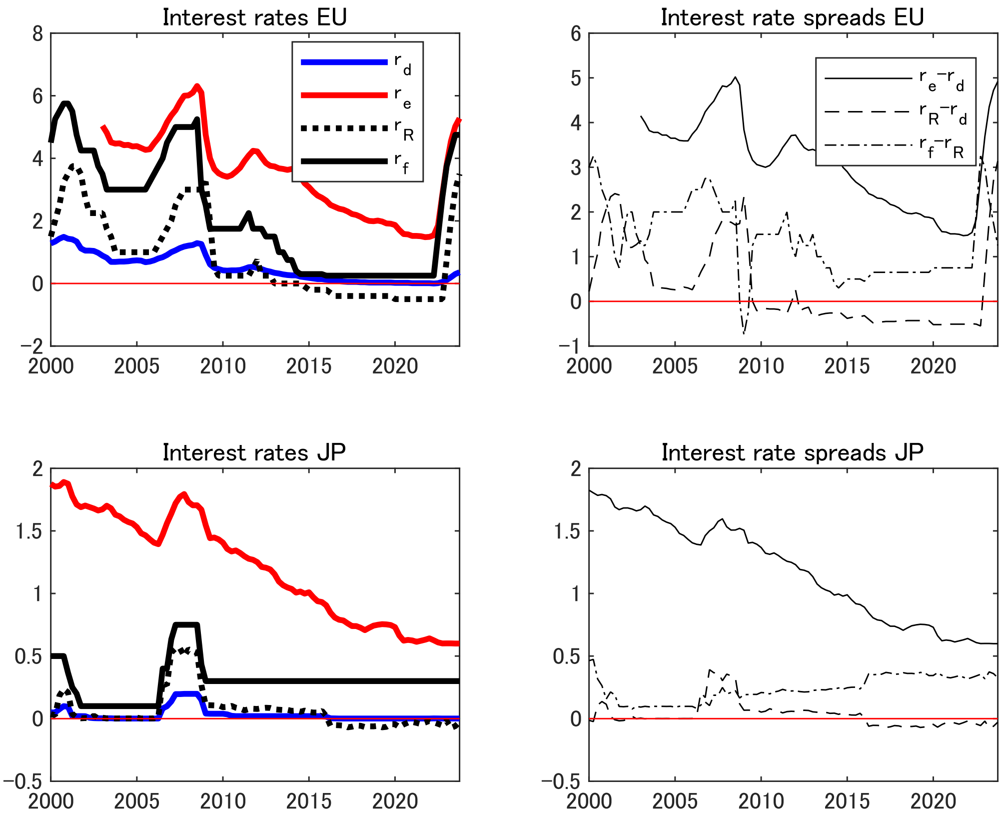

Figure 15. Data Used for Calibration: Interest Rates

the second step, we re-estimate the household money-demand parameters (3) by solving the household utility maximization problem with respect to liquidity services.

Table 2 summarizes the parameters that are predetermined. For reference, it reports both the parameter values calibrated for Japan (JP) and those for the euro area (EU) from Burlon et al. (2024). In Japan, the prolonged period of near-zero interest rates has led to an overall lower level of interest rates. Reflecting this, the discount factors of patient and impatient households (β_p, β_i) are set at relatively high values. The parameters of the shares of capital and housing (α, ν), the collateral requirement on central bank lending (θ_b^{ss}), and the intertemporal elasticity of substitution in dividends (σ) are set equal to those used for the euro area.

Given that inflation in Japan has been persistently low, the steady-state net inflation rate in the model ($\pi^{ss} - 1$) is set to zero. Since CBDC has not yet been issued in Japan, the parameter representing the CBDC-to-GDP ratio (ϕ_y) is set to zero when we calibrate the model.

Parameter	Description	JP	EU
β_p	Saver's discount factor	0.9990	0.9930
β_i	Borrowers' discount factor	0.9950	0.9800
α	Capital share in production	0.3300	0.3300
ν	Real estate share in production	0.0100	0.0100
θ_b^{ss}	Central bank funding collateral requirement	0.9950	0.9950
π^{ss}	Gross inflation target	1.0000	1.0050
σ	EIS dividends	2.0000	6.4000
ϕ_y	CBDC quantity rule	0.0000	0.0000

Table 2. Fixed Parameters

Next, taking these fixed parameters as given, we calibrate the remaining parameters so that the steady-state values of the model variables match, as closely as possible, the sample means of the corresponding data series. The results of this calibration are summarized in Table 3.

For the household and corporate sector parameters, the utility weight on housing services for borrowers (j_i^{ss}) is smaller in Japan than in the euro area, reflecting the lower ratio of household loans to GDP (L_i/Y) observed in the Japanese data. Similarly, the utility weight on liquidity services for savers (χ_i^{ss}) is also smaller in Japan. In contrast, the loan-to-collateral (LTC) ratio on productive capital for corporate borrowing (m_K^{ss}) is larger in Japan, consistent with the higher ratio of corporate loans to GDP (L_e/Y) relative to the euro area.

For the banking sector parameters, the calibrated risk weights on household and corporate loans ($1-\gamma_i, 1-\gamma_e$) indicate that the weight for corporate loans is smaller than that for household loans in Japan. This reflects the fact that Japanese banks extend a larger volume of loans to corporations than to households and tend to be more cautious toward the relatively riskier household lending. The reserve requirement ratio (θ_R^{ss}), which specifies the required reserves as a fraction of deposits, is higher in Japan. In addition, the spread between the central bank lending rate and the reserve rate (μ) is smaller in Japan, consistent with observed data.

	Parameter			Target		
	Description	JP	EU		JP	EU
j_p^{ss}	Savers' housing services weight	0.0089	0.0100	$(1+r_d)^4$	1.0003	1.0230
j_i^{ss}	Borrowers' housing services weight	0.4245	8.7902	$400(r_e - r_d)$	1.1752	3.0474
χ_z^{ss}	Savers' liquidity services weight	0.0146	0.0541	$400(r_R - r_d)$	0.0334	0.2650
ω_d	Deposits weight in liquidity services	0.4003	0.7100	$400(r_f - r_R)$	0.2394	1.3860
η_z^{ss}	Elast. of subst. liquidity services	3.9366	3.5800	L_i/Y	1.0097	1.9824
ψ_m	Cash storage cost parameter	0.0004	0.0020	L_e/Y	4.2673	1.6820
m_K^{ss}	LTC ratio on NFC physical capital	0.4255	0.2140	R/Y	1.1596	0.3326
γ_e	Debt-to-assets, NFC risk-adjusted	0.9588	0.8950	M/Y	0.6929	0.3326
γ_i	Debt-to-assets, HH risk-adjusted	0.9450	0.9200	b/Y	1.5824	0.6099
δ_e	Erosion rate of bank capital	0.0709	0.0710	F/A	0.2118	0.0892
θ_R^{ss}	Bank's liquidity (reserves) requirement	0.1739	0.0874	L_i/A	0.1268	0.4303
ϕ_p	Fiscal rule: HH gov. bonds response	0.4029	0.4010	D/A	0.7211	0.8047
ϕ_b	Fiscal rule: Banks' gov. bonds response	0.2281	0.2300	C/Y	0.5542	0.5479
ρ	Public consumption-to-GDP ratio	0.1912	0.2070	I/Y	0.2533	0.2124
μ	Lending-deposit facility corridor parameter	0.0007	0.0059	G/Y	0.1912	0.2070

Table 3. Calibration: Steady State

Note: In the model, the following represent steady-state values: Y: GDP; C: consumption; I: investment; M: cash; R: reserves; F: central bank lending; L: private bank lending (to households and firms); e: bank equity; D: deposits; L_i: household loans; L_e: corporate loans; A: total bank assets; b: bank holdings of government bonds; G: public consumption; π: gross inflation rate; r_d: deposit rate; r_e: corporate lending rate; r_f: central bank lending rate; r_R: interest rate on reserves.

Finally, taking the previously calibrated parameters as given, we re-estimate a subset of parameters related to household money demand using the results of the household survey. In this analysis, we assume imperfect substitutability among the three components of household liquidity services—cash, deposits, and CBDC. Under this assumption, when a CBDC is introduced, households shift part of their holdings from cash and deposits into CBDC. To quantify this degree of substitutability, we consider the following utility maximization problem for household liquidity services:

$$\max_{(m,\, cbdc,\, d)} \left[m^{\frac{\eta-1}{\eta}} + \omega_d \, d^{\frac{\eta-1}{\eta}} + I_{cbdc} \, cbdc^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

$$\text{subject to} \quad m + q_{cbdc} \, cbdc + q_d \, d + \frac{\psi_m}{2} m^2 \leq w,$$

where, m, d, and $cbdc$ denote household holdings of cash, deposits, and CBDC, respectively. q_{cbdc} and q_d represent the prices of CBDC and deposits, which are the inverses of their respective gross interest rates (cash, by contrast, bears no interest). I_{cbdc} is an indicator variable that takes a value of 0 or 1, where $I_{cbdc} = 0$ indicates the pre-CBDC period and

$I_{cbdc} = 1$ indicates the post-CBDC period. η is the elasticity of substitution parameter among liquidity instruments.[25] ω_d represents the preference weight for deposits, while ψ_m is a parameter associated with the holding cost of cash. Finally, w denotes household income, which is treated here as an exogenous variable.[26]

By solving this utility-maximization problem, the household's desired holdings of cash, deposits, and CBDC can be expressed as functions of the parameters $\theta = (\eta, \omega_d, \psi_m, w, q_{cbdc}, q_d)$ and the indicator I_{cbdc}. That is, after the introduction of CBDC, the fractions shifted from cash and from deposits into CBDC are given by:

$$\frac{cbdc(\theta; I_{cbdc} = 1)}{m(\theta; I_{cbdc} = 0)}, \quad \frac{cbdc(\theta; I_{cbdc} = 1)}{d(\theta; I_{cbdc} = 0)}.$$

Using the parameter values set to match macro data $(\eta, \omega_d, \psi_m) = (3.9366, 0.4003, 0.0004)$, the implied substitution shares—i.e., the fractions shifted into CBDC from cash and from deposits—are 3.982 and 1.362, respectively.[27] By contrast, the household survey yields much smaller values, 0.156 (from cash) and 0.127 (from deposits), suggesting that the macro-data calibration may overstate households' preference for CBDC.[28] Accordingly, we recalibrate the preference/holding-cost parameters (ω_d, ψ_m) so that the model-implied substitution shares align as closely as possible with the survey evidence, which yields $(\omega_d, \psi_m) = (1.5352, 0.000008)$ (Table 4). In other words, relative to the macro-calibrated values, households exhibit a stronger preference for deposits and a much lower holding cost of cash.

[25] That is,

$$\eta = \frac{\partial \log(\mathrm{cbdc}/m)}{\partial \log(q_{\mathrm{cbdc}})} = \frac{\partial \log(d/m)}{\partial \log(q_d)}$$

(when $I_{\mathrm{cbdc}} = \omega_d = 1$), which represents the price elasticity of the relative holdings of CBDC and deposits with respect to cash.

[26] In the model presented in Section 2, household income is determined endogenously by factors such as wages, interest rates, labor supply, and the amount of capital owned.

[27] The value of w is calibrated so that the model-implied ratio $m(I_{\mathrm{cbdc}} = 0)/d(I_{\mathrm{cbdc}} = 0)$ matches the data value of 0.1664. The values of (q_{cbdc}, q_d) are taken from the steady-state values of the model described in Section 2.

[28] The mean ratio—calculated for respondents who answered "I would like to hold CBDC" ($n = 924$)—of the amount of CBDC they wish to hold (numerator) to their existing holdings of cash and bank deposits (ordinary deposits) (denominator), respectively.

	Description	JP
ω_d	Deposits weight in liquidity services	1.5352 (0.4003)
ψ_m	Cash storage cost parameter	0.000008 (0.0004)

Table 4. Parameters Recalibrated Using Survey Results

Note: Figures in parentheses indicate the values before recalibration (i.e., those obtained from the initial calibration).

When setting the parameters for the standard deviations of exogenous shocks in the model—each assumed to follow a normal distribution—we target, on the data side, the standard deviations of deviations from linear trends.[29] The parameters are chosen such that the standard deviations of the model variables match as closely as possible the standard deviations of deviations from linear trends in the corresponding data over the sample period.[30]

Figure 16 displays these detrended series—i.e., deviations from linear trends—for each variable (GDP, consumption, fixed investment, currency in circulation, reserves, central bank lending, private bank lending (to households and to firms), bank equity capital, deposit volume, and the deposit interest rate). All variables except the deposit rate are expressed in real terms using the GDP deflator.

Comparing these movements between Japan and the euro area, GDP, consumption, and investment are broadly positively correlated across the two economies, whereas financial variables such as currency and reserves exhibit markedly different dynamics around their trends. Moreover, examining the standard deviations reveals notable cross-regional differences. In Japan, the volatility of variables such as cash, loans, and bank equity is smaller than in the euro area, whereas reserves and central bank lending exhibit greater volatility. The deposit interest rate shows extremely low variability in the Japanese data.

Table 5 summarizes the calibration results for the standard deviations of shocks. The standard deviation of productivity shocks (σ_A) is lower for Japan than for the euro area. Consistent with the smaller overall volatility of lending, the standard deviation of the collateral constraint shock for nonfinancial firms (σ_{m_K}) is also lower. Conversely, the relatively

[29] It is assumed that the trends differ across macroeconomic variables. That is, the trends are estimated separately for each series, and we do not impose a common or co-trended linear trend across the series; the calibration targets are the standard deviations of the deviations of each individual series from its own linear trend. We use deviations from linear trends rather than log-differences for comparability with Burlon et al. (2024), which applies the same filtering approach to the euro-area data, as discussed at the beginning of this section. Therefore, the balanced growth path (BGP) assumption is not satisfied in this analysis.

[30] In a real business cycle (RBC) model, the standard deviation of exogenous productivity shocks is set so that the standard deviation of GDP in the model matches the standard deviation of the cyclical component of GDP in the data—that is, the deviation of GDP from its trend.

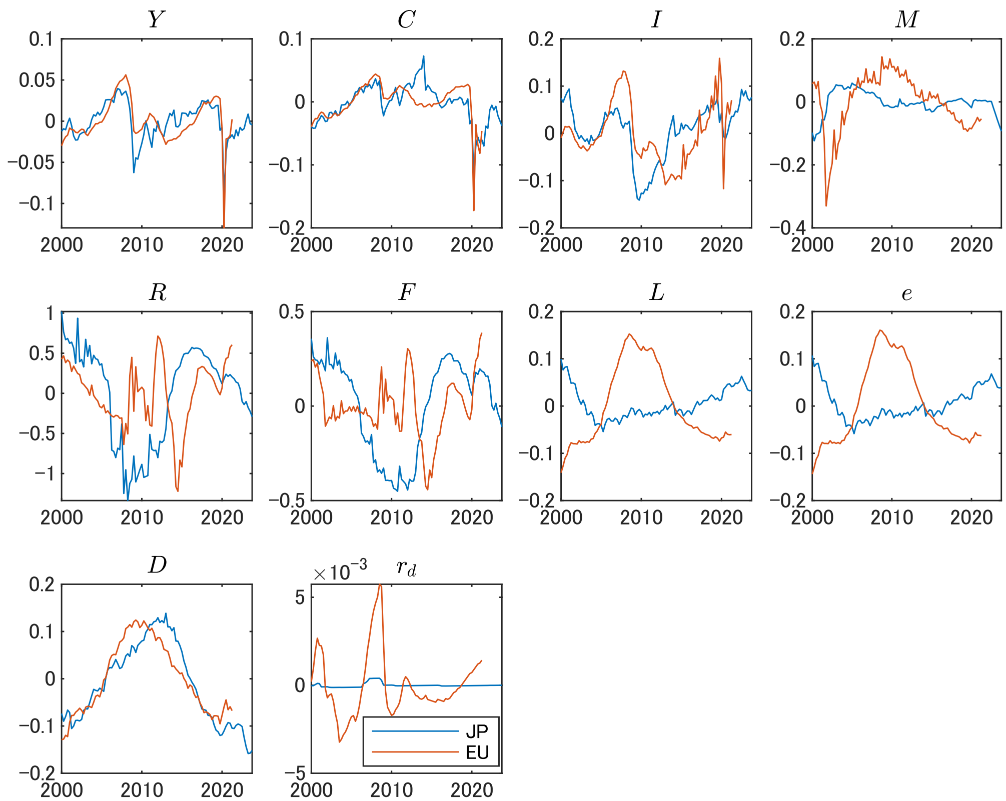

Figure 16. Data Used for Calibration: Deviations from Linear Trends

large volatility of reserves and central bank lending translates into a higher standard deviation of the liquidity requirement shock (σ_{θ_R}). Finally, the standard deviation of the interest rate shock (σ_r) is smaller in Japan, reflecting its prolonged period of low interest rates.

	Parameter				Target	
	Description	JP	EU		JP	EU
ψ_I	Investment adj. cost parameter	0.0112	0.0920	σ_I/σ_Y	2.611	3.137
σ_A	Std. productivity shock	0.0007	0.0023	$100\sigma_Y$	2.199	2.631
σ_h	Std. housing pref. shock	0.0020	0.0090	σ_C/σ_Y	1.366	1.169
σ_η	Std. elast. of subst. liquidity services shock	0.0037	0.0012	σ_D/σ_Y	3.815	3.123
σ_z	Std. liquidity pref. shock	0.0057	0.0043	σ_M/σ_Y	1.700	3.408
σ_{mh}	Std. HH collateral shock	0.0003	0.0076	σ_L/σ_Y	1.467	3.138
σ_{mk}	Std. NFC collateral shock	0.0005	0.0237	σ_e/σ_Y	1.606	3.656
σ_{θ_R}	Std. reserves requirement shock	0.1911	0.1540	σ_R/σ_Y	26.910	15.011
σ_{θ_b}	Std. central bank funding collateral shock	0.0032	0.0015	σ_F/σ_Y	11.221	6.375
σ_r	Std. interest rate shock	0.0004	0.0006	σ_{r_d}/σ_Y	0.006	0.043

Table 5. Calibration: Standard Deviations of Shocks

Note: σ_x, $x \in \{Y, C, I, M, R, F, L, e, D, r_d, \Omega\}$ denotes the standard deviation of deviations from linear trends for GDP, consumption, investment, cash, reserves, central bank lending, private bank lending (to households and firms), bank equity, deposits, the deposit rate, and bank profits, respectively.

5 Numerical Results

Using the calibrated parameters from the previous section, we analyze the macroeconomic effects of CBDC introduction in Japan. We first examine the steady-state responses of macro variables to changes in CBDC circulation. In evaluating alternative policy rules within the quantitative DSGE framework, we assess how effectively each rule stabilizes variables such as consumption, GDP, and inflation in response to exogenous shocks. Social welfare is then derived from the utility functions of net savers and net borrowers.[31]

Steady State Figure 17 presents the steady-state ratios of total liquidity services and their components—cash, deposits, and CBDC—to GDP. We examine how variations in the CBDC-to-GDP ratio (ϕ_Y = CBDC$/Y$) affect these steady-state values. As the share of CBDC rises, the ratios of cash and deposits to GDP decline. Given that cash, deposits, and CBDC are imperfect substitutes, total liquidity services increase with CBDC introduction, while the share of deposits in total liquidity services declines.

Figure 18 presents the steady-state ratios to GDP of the central bank and private banks' balance-sheet items——central bank lending, reserves, central bank profits, government bond

[31]Specifically, when we compute a second-order approximation of household utility around the steady state, the approximated utility becomes a function of the squared terms (variances) of consumption and inflation (Schmitt-Grohe and Uribe, 2007).

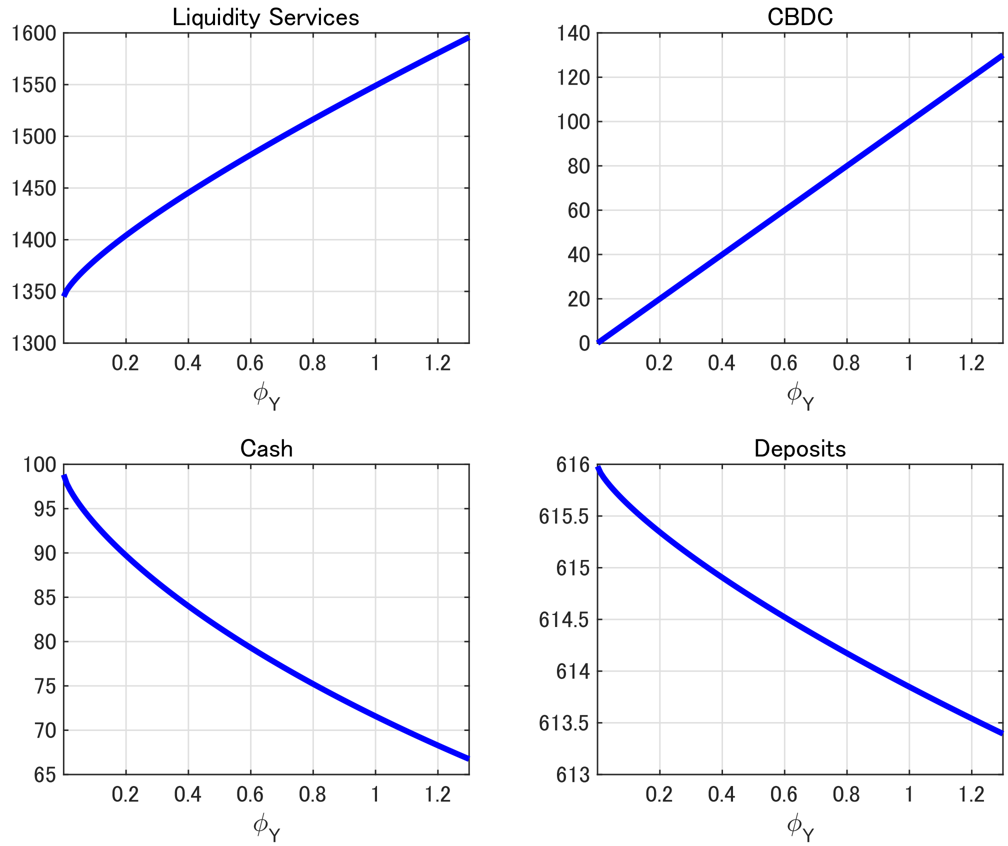

Figure 17. Steady State: Liquidity Services (Cash, Deposits, and CBDC)

holdings, equity capital, and bank loans.

As CBDC circulation increases, the central bank's balance sheet expands; since its only asset in the model is lending to banks, both central bank lending and profits (seigniorage) rise accordingly, while required reserves decline with lower household deposit demand.

For private banks, a shift on the liability side from deposits to central bank borrowing raises government bond holdings on the asset side and reduces loans to households and firms. That is, private banks replace low-cost deposit funding with more expensive collateralized borrowing from the central bank, which lowers bank profitability and erodes equity capital. The resulting tightening of the capital-adequacy constraint further reduces bank lending and raises lending spreads, with the largest burden falling on bank-dependent borrowers.

Private banks hold more government bonds as collateral for their increased central-bank borrowing; the demand for government bonds thus rises with CBDC issuance. Recall that we follow Burlon et al. (2024) in assuming that the central bank's asset-side counterpart to CBDC issuance is lending to private banks rather than purchases of government bonds. Under this assumption, the central bank lends an equivalent amount back to private banks against government-bond collateral; this allows us to isolate the deposit-substitution channel and its effects on banks' funding costs. The key difference from the current situation in Japan is *who* holds the bonds: private banks hold them as collateral in the model, whereas the Bank of Japan holds them in reality. Modeling JGB purchases as the asset-side counterpart to CBDC issuance would require an explicit specification of the government-bond market, including the determination of bond yields, which is beyond the scope of this paper. Our objective is not to replicate the current composition of the BOJ's balance sheet, but to isolate the deposit-substitution channel through which CBDC affects banks' funding costs.

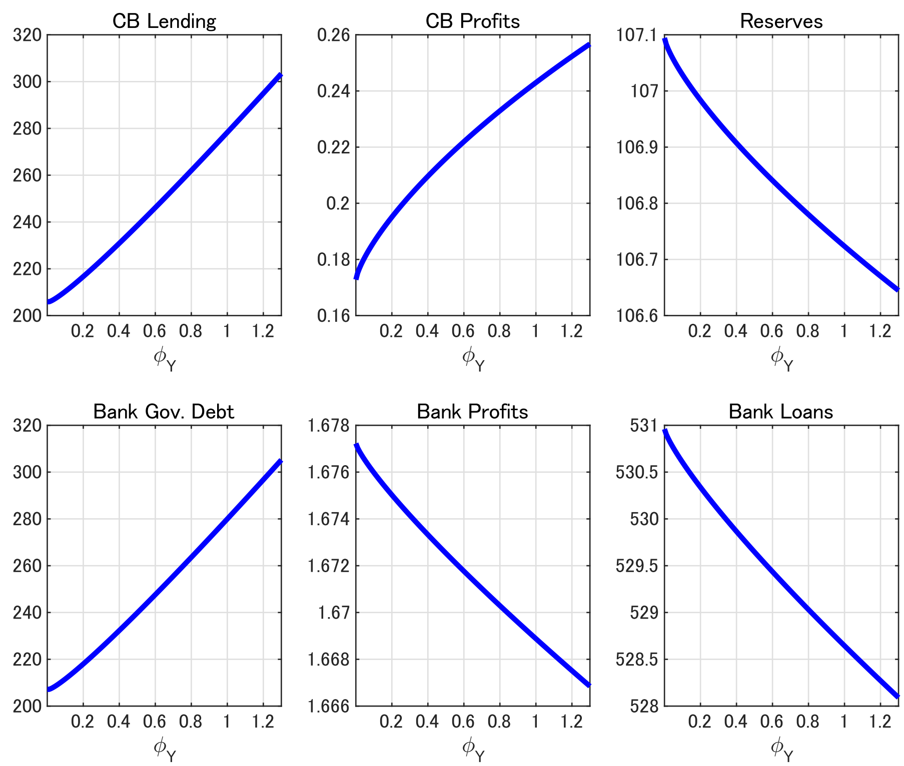

Figure 18. Steady State: Balance Sheets of the Central Bank and Private Banks

Figure 19 shows the steady-state ratios of investment, tax revenue, and consumption to GDP, as well as the steady-state level of GDP, where the value of GDP is normalized to 100 when $\phi_Y = 0$. A decline in corporate lending suppresses investment. At the same time, an increase in seigniorage income due to the expansion of the central bank's balance sheet and a rise in demand for government bonds as eligible collateral by private banks strengthen the government's fiscal capacity. This, in turn, boosts consumption and GDP through tax reductions. Overall, however, as the circulation of CBDC increases, GDP gradually declines.

Given household demand for CBDC, when the central bank sets its supply, the market determines the corresponding interest rate. The CBDC circulation level consistent with a zero interest rate equals 92% of quarterly GDP, substantially higher than the 64% estimated for the euro area.

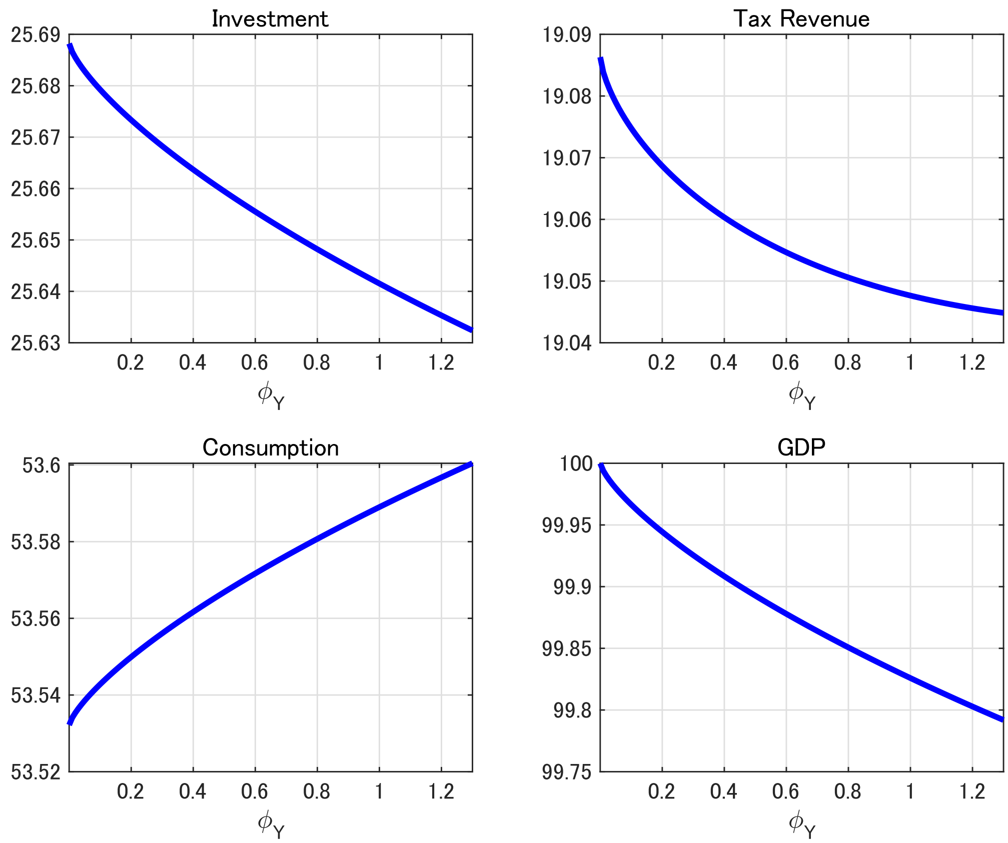

Figure 19. Steady State: Real Economy

Social Welfare under Shocks Figure 20 compares the utilities of net savers and net borrowers, and their weighted average (social welfare), when the model is exposed to shocks under different CBDC issuance rules. Three types of quantity rules are considered:

(i) issuance linked to real GDP: $CBDC_t = \phi_Y Y_t$,

(ii) a fixed ratio to steady-state real GDP: $CBDC_t = \phi_Y Y$, and

(iii) issuance linked to past CBDC circulation, the steady-state level of real GDP, and deviations from the steady-state real GDP: $CBDC_t = \rho CBDC_{t-1} + (1-\rho)(\phi_Y Y + \phi_X \log(Y_t/Y))$.

The utility of net savers increases with CBDC circulation due to its liquidity service effect, while that of net borrowers follows an inverted U-shaped relationship, reflecting the trade-off between stabilization gains and reduced bank intermediation. As circulation rises, the welfare gains from liquidity and stabilization effects outweigh the costs from weaker intermediation.

Social welfare is evaluated under two weighting schemes. The first approach (Case A) assigns equal weights to the utilities of net savers and net borrowers, whereas the second approach (Case B) assigns a lower (higher) weight for net savers (borrowers) according to their high (low) discount factors. Under Case A, the welfare-maximizing CBDC circulation is about 129% of GDP across all issuance rules (i)–(iii). Under Case B, it is 28% of GDP. Given household demand, the corresponding market-determined CBDC interest rates are 0.04% (Case A) and –0.17% (Case B).

Figure 21 compares different issuance rules regarding the CBDC interest rate. We consider three rules:[32]

(i) a zero interest rate: $r_{cbdc,t} = 0$,

(ii) a fixed rate proportional to the steady-state interest rate on reserves: $r_{cbdc,t} = \phi_r r_R$, and

(iii) a rate linked to the current interest rate on reserves: $r_{cbdc,t} = \phi_r r_{R,t}$.

In rules (ii) and (iii), it is optimal for savers that the CBDC interest rate moves more strongly in the same direction as the reserve rate ($\phi_r > 1$), whereas for borrowers, it is optimal that the CBDC rate moves in the opposite direction ($\phi_r < 0$). This is because savers directly benefit from a positive CBDC rate, while borrowers prefer a lower CBDC rate, which encourages the central bank to reduce CBDC issuance, increase private bank lending, and thereby enable greater borrowing.

In rule (i), the CBDC circulation is 92% of GDP, and the CBDC interest rate is 0%. In rule (ii), under the optimal interest rate rule, the market-determined CBDC circulation equals 203% of GDP under Case A and 65% under Case B, with corresponding CBDC interest rates of 0.10% and –0.05%, respectively. In rule (iii), under the optimal interest rate rule, the market-determined CBDC circulation equals 172% of GDP under Case A and 62% under Case B, with corresponding interest rates of 0.08% and –0.05%, respectively.

Figure 22 plots the optimal interest rate (x-axis) and optimal circulation (y-axis) under different quantity and interest rate rules. Depending on the weighting scheme of household utility, the welfare-maximizing CBDC circulation ranges between 28% and 203% of quarterly GDP, while the optimal CBDC interest rate lies between –0.17% and 0.10%.

5.1 Sensitivity to the Inflation Target

Our baseline calibration for Japan sets the steady-state inflation rate to zero, reflecting Japan's prolonged low-inflation environment. Since the attractiveness of cash relative to

[32] Rule (i) can be regarded as a special case of rules (ii) and (iii) when $\phi_r = 0$.

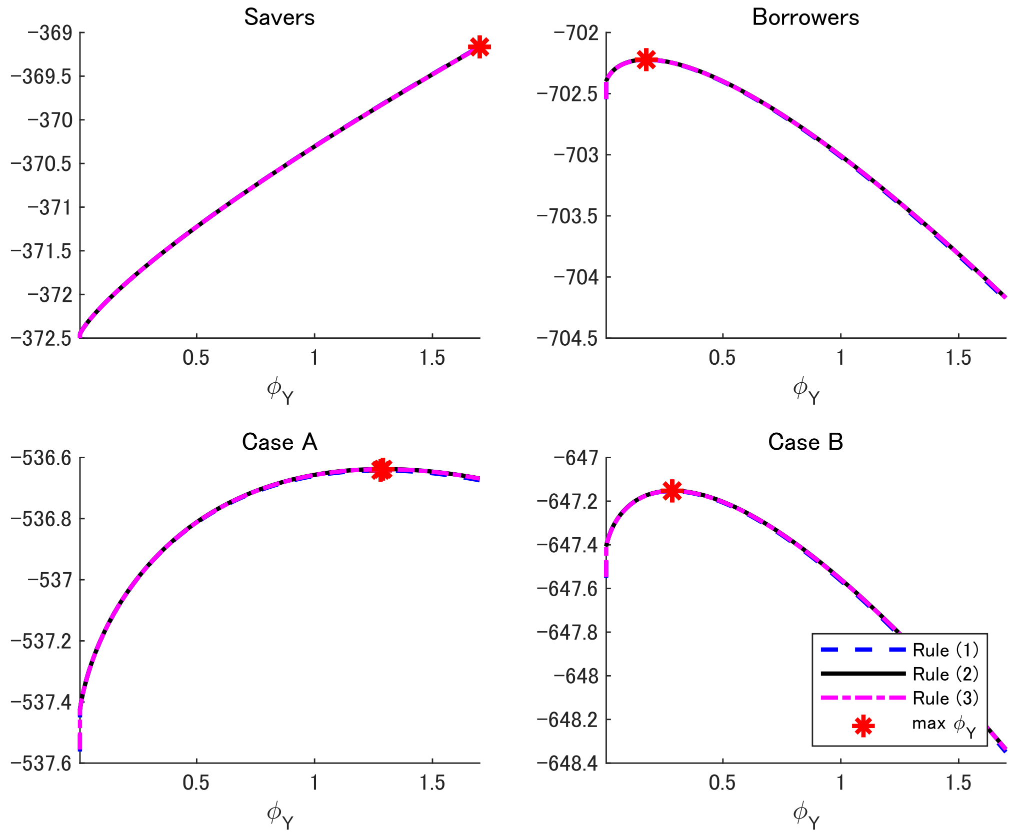

Figure 20. Social Welfare under Shocks: Quantity Rules

CBDC depends on trend inflation, we examine how the optimal quantity of CBDC varies with the steady-state inflation target. Table 6 presents the results under the quantity-based issuance rule for annual inflation targets of $\{0.0, 0.5, 1.0, 2.0\}$ percent.

	Case A		Case B	
π^{ss} (ann.)	$CBDC/Y$	r_{cbdc}	$CBDC/Y$	r_{cbdc}
0.0%	128%	0.04%	28%	−0.17%
0.5%	168%	0.55%	29%	0.27%
1.0%	170%	1.05%	37%	0.81%
2.0%	170%	2.05%	39%	1.81%

Table 6. Sensitivity to the Inflation Target: Optimal CBDC Circulation and Interest Rate

Note: The quantity of CBDC is set by rule (i), $CBDC_t = \phi_Y Y_t$. For each inflation target, the table reports the level of CBDC circulation (relative to quarterly GDP) that maximizes social welfare, and the market-determined annualized CBDC interest rate at that level of circulation. Cases A and B refer to the two welfare weighting schemes defined above.

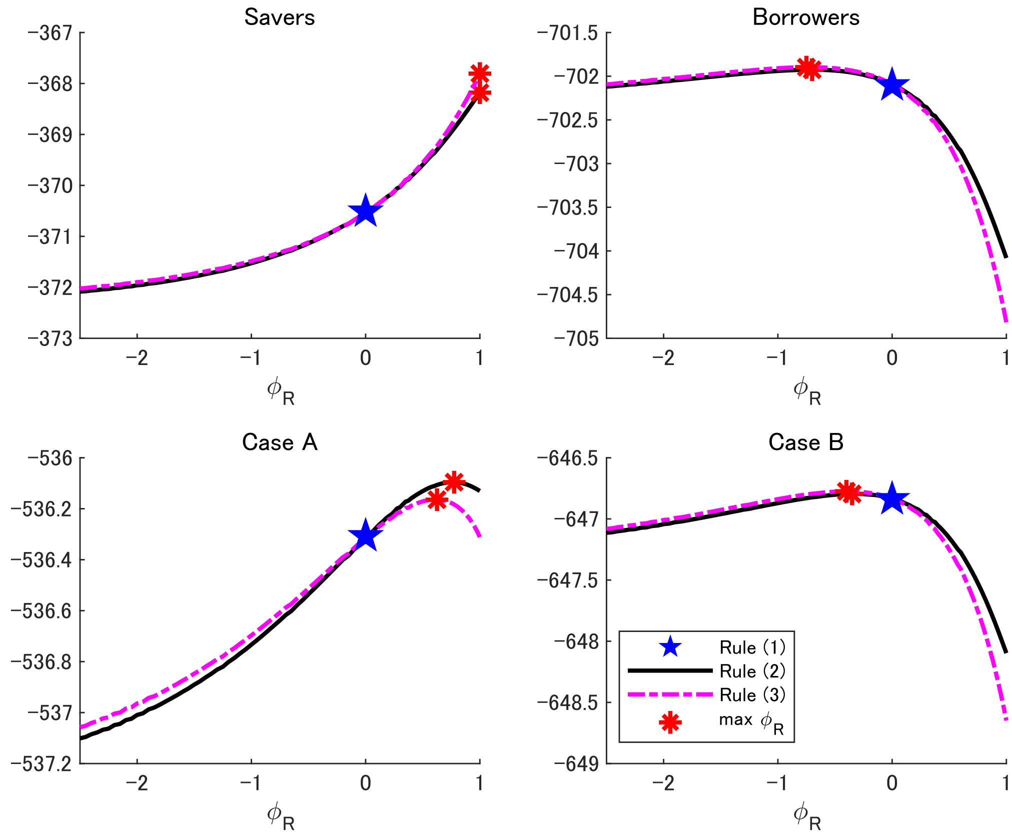

Figure 21. Social Welfare under Shocks: Interest Rate Rules

There are two main findings. First, the optimal *nominal* CBDC rate rises approximately one-for-one with the inflation target, so that the optimal *real* CBDC rate remains roughly invariant (around 0.0 percent under Case A and -0.2 percent under Case B). Second, the optimal quantity of CBDC increases mildly with the inflation target: higher trend inflation raises the implicit tax on cash, shifting household liquidity demand toward CBDC and thereby increasing its welfare-maximizing quantity in circulation.

Finally, these results speak to the relationship between CBDC and the effective lower bound (ELB) on nominal interest rates. Cash coexists with CBDC in our framework, so the introduction of CBDC does not by itself eliminate the ELB. However, because holding cash is costly due to quadratic holding costs, mildly negative rates are feasible. Indeed, our baseline results already feature optimal CBDC rates (i.e., the remuneration rate paid on CBDC, which is distinct from the policy rate) as low as -0.17%.[33] Thus, our framework allows CBDC to facilitate mildly negative nominal interest rates, but it should not be interpreted as a full quantitative assessment of the ELB-elimination benefit of CBDC.

[33] Burlon et al. (2024) also find that the optimal CBDC interest rate is as low as about -3% in the euro area.

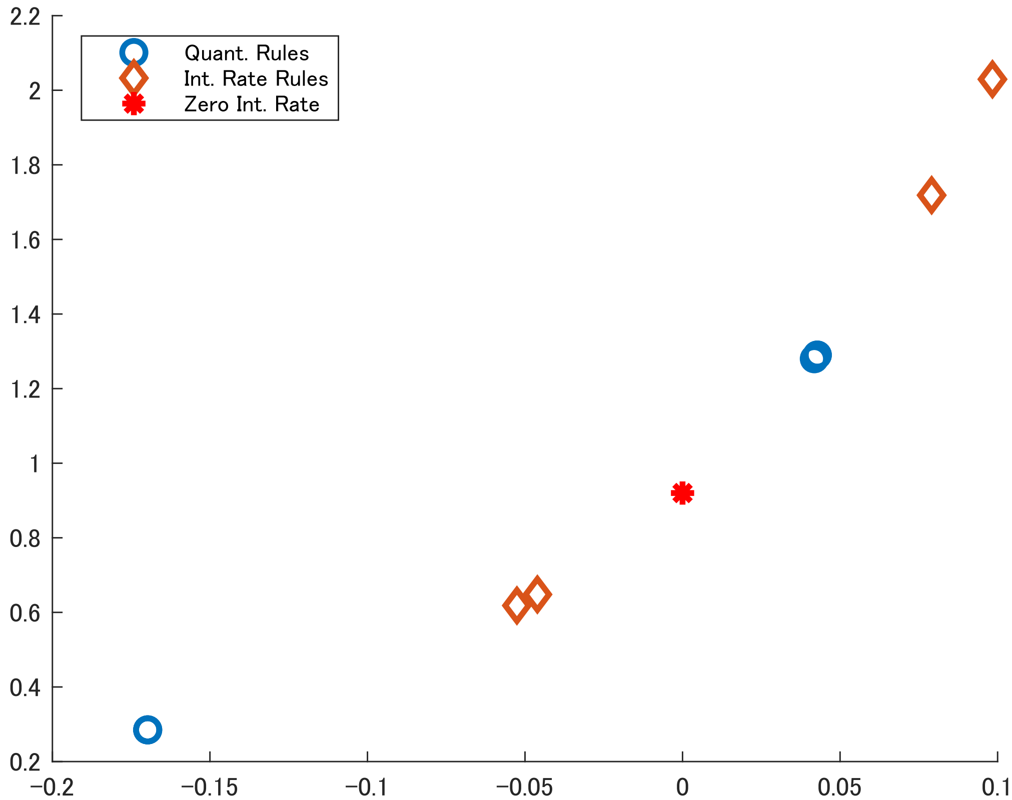

Figure 22. Social Welfare under Shocks: Quantity vs. Interest Rate Rules

6 Concluding Remarks

This paper examined Japanese households' payment behavior and estimated the welfare-maximizing circulation of a central bank digital currency (CBDC) using a dynamic stochastic general equilibrium (DSGE) model. Based on a nationwide household survey conducted in 2024, we found that cashless payments have become more prevalent—particularly among younger generations—while cash usage remains deeply rooted. Only about 12 percent of respondents expressed a willingness to hold CBDC, indicating that they would convert approximately 15.6 percent of their cash and 12.7 percent of their deposits into CBDC. Incorporating the liquidity preferences derived from the survey into a calibrated DSGE model, we found that the welfare-maximizing CBDC circulation in Japan ranges between 28 and 203 percent of quarterly GDP, with the corresponding optimal CBDC interest rate between –0.17 and 0.10 percent. Assuming a zero CBDC interest rate, the optimal circulation is 92 percent of quarterly GDP—higher than the 64 percent benchmark for the euro area.

These results are likely influenced, among other factors, by the strong household preference for cash in Japan. However, these results depend on the specific CBDC issuance rules and the welfare criterion used, and they may vary with changes in other financial conditions.

Therefore, they should be interpreted with an appropriate range of uncertainty.

There are three important avenues for future research: how CBDC would affect the transmission of balance-sheet policies such as quantitative easing, how richer household heterogeneity would alter the welfare evaluation of CBDC, and how CBDC interacts with the effective lower bound on nominal interest rates.

Two further caveats concern the banking sector. First, the model abstracts from heterogeneity in firms' access to market finance: since large firms can substitute toward bond and equity markets while small and medium-sized enterprises (SMEs) may not be able to, the aggregate lending decline in the model likely understates the distributional burden on SMEs. Second, our framework is one of interest-rate policy; it does not explicitly model monetary aggregates, the money multiplier, or quantitative easing, and these issues therefore lie outside its scope. Nevertheless, the decline in inside money (deposits) is partly offset by the increase in outside money (CBDC), so that total household liquidity rises and the central bank's balance sheet expands with CBDC issuance. Thus, a decline in bank deposits should not be interpreted as an equivalent decline in the overall money supply in our framework. What the model cannot speak to is how CBDC would affect the transmission of balance-sheet policies such as quantitative easing; this remains an important open question for future research.

The household survey results presented in this paper show clear differences in payment behavior and willingness to hold CBDC across household characteristics such as gender, age, place of residence, and financial literacy. Moreover, the liquidity service effect, banking intermediation effect, and stabilization effect—which are all important for evaluating household welfare in the model—may vary not only between savers and borrowers but also across other household attributes. Therefore, using a model that incorporates a broader range of household heterogeneity is crucial for analyzing the welfare-maximizing level of CBDC circulation. A full heterogeneous-agent treatment with a three-asset liquid portfolio (cash, deposits, and CBDC)—as in the recent work on CBDC in heterogeneous-agent economies (Banet and Lebeau, 2022)—would be computationally demanding and would raise the additional question of how social welfare should be aggregated across heterogeneous households. Thus, the choice of a social welfare criterion—e.g., how to assign welfare weights across households—is itself an important normative assumption. Incorporating richer household heterogeneity and an explicit welfare-weighting scheme would be an important direction for future research.

Another important avenue for future research concerns the effective lower bound (ELB) on nominal interest rates. While mildly negative CBDC rates are feasible in our framework owing to the cost of holding cash, we cannot address cases in which the ELB binds. A full comparison of economies with and without an occasionally binding ELB constraint would require nonlinear solution methods, and we leave this for future research.

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Appendix A Data Sources

Household loans (L_i): The sum of bank loans (to households) and shinkin bank loans (to households). Bank loans (to households) are taken from the Bank of Japan, "Loans by Industry", defined as the sum of: (1) Housing funds / Balance / Loans to individuals / Total of banking accounts, trust accounts, and overseas branches / Domestic banks (LA01'DLHLLKG71_DLHL2DSSL); (2) Consumer goods and services purchase funds / Balance / Loans to individuals / Total of banking accounts, trust accounts, and overseas branches / Domestic banks (LA01'DLCLLKG71_DLCL2DSTSL).

Shinkin bank loans (to households) are obtained from Shinkin Central Bank, "Loans by Industry", under the item "Individuals."

Loans to non-financial corporations (L_e): The sum of bank loans (to firms) and shinkin bank loans (to firms). Bank loans (to firms) are taken from the Bank of Japan, "Loans by Industry", Total loans / Balance / Banking accounts, trust accounts, and overseas branches / Domestic banks (LA01'DLLILKG90_DLLI5DS2T). Shinkin bank loans (to firms) are from Shinkin Central Bank, "Loans by Industry", Total loans / Balance / Banking accounts / Shinkin banks (LA01'DLLILKG90_DLLI5KB2T).

Bank holdings of government bonds (b): From the Bank of Japan, "Flow of Funds Accounts", the sum of two items under "Government bonds and FILP bonds (banks + postal savings)": (1) Assets – Government and FILP bonds / Banks / Stock (FF'FOF_FFAS121A311); (2) Assets – Government and FILP bonds / Postal savings / Stock (FF'FOF_FFAS126A311).

Currency in circulation (M): From the Bank of Japan, "Currency in Circulation" (MD05'MACCV1). Monthly data are converted to quarterly data using end-of-quarter values and seasonally adjusted by X13.

Reserves (R): From the Bank of Japan, "Assets and Liabilities of Domestic Banks (Banking Accounts)", item "Deposits with the Bank of Japan / Assets" (BS02'FAABK_FAAB2DBEA06). Data prior to September 2007 include deposits of Japan Post and Japan Post Bank.

Total bank assets (A): Calculated as the sum of household loans, corporate loans, government bond holdings, and reserves based on the model's private bank balance sheet: $A = L_i + L_e + b + R$.

Central bank lending (F): Calculated as the sum of currency in circulation and reserves, based on the central bank balance sheet: $F = M + R$.

GDP (Y), **consumption** (C), **investment** (I), and **government spending** (G): From the National Accounts of Japan. We use nominal, seasonally adjusted series for GDP (expenditure side), private final consumption, gross fixed capital formation, and government final consumption expenditure. Real values are obtained using the GDP deflator.

Deposit rate (r_d): From the Bank of Japan, "Average Interest Rates on Deposits by Type", ordinary deposit rate (IR02'DLDR120). Monthly data are averaged and converted to quarterly frequency.

Corporate loan rate (r_e): From the Bank of Japan, "Average Contract Interest Rates on Loans", computed as a weighted average of: (1) Stock / Short-term / Domestic banks (IR04'DLLR2CIDBST2), (2) Stock / Short-term / Shinkin banks (IR04'DLLR2CICR31).

Monthly data are averaged and converted to quarterly frequency. The weights are based on outstanding loan amounts from Shinkin Central Bank, "Loans by Industry".

Central bank lending rate (r_f): From the Bank of Japan, "Basic Discount Rate and Basic Loan Rate (formerly Official Discount Rate)" (IR01'MADR1M). Monthly averages are converted to quarterly data.

Interest rate on reserves (r_R): From the Bank of Japan, "Call Market Statistics (Daily)", uncollateralized overnight call rate / average daily rate (FM01'STRDCLUCON). Daily data are averaged to monthly and then converted to quarterly frequency.

Appendix B Calibration Fit

Table B1 reports the calibration targets alongside the corresponding model-implied moments: Panel A shows the steady-state ratios and Panel B the standard deviations. The model matches the steady-state targets closely. Among the volatility targets, the relative volatility of cash is substantially overstated, reflecting the high elasticity of household cash demand in the model; the fit for the remaining variables is reasonably close.

		Model	Data
Panel A: Steady-state ratios (data: sample means, 2000Q1–2023Q4)			
$400\,r_d$	Deposit rate (ann., %)	−0.017	0.030
$400(r_e - r_d)$	Corporate lending spread (ann., %)	1.155	1.175
$400(r_R - r_d)$	Reserve rate spread (ann., %)	0.147	0.034
$400(r_f - r_R)$	Interest rate corridor (ann., %)	0.273	0.239
L_i/Y	Household loans / GDP	1.059	1.010
L_e/Y	Corporate loans / GDP	4.251	4.267
R/Y	Reserves / GDP	1.071	1.160
M/Y	Cash / GDP	0.988	0.693
b/Y	Bank gov. bond holdings / GDP	2.072	1.582
F/A	Central bank lending / bank assets	0.244	0.212
L_i/A	Household loans / bank assets	0.125	0.127
D/A	Deposits / bank assets	0.729	0.721
C/Y	Consumption / GDP	0.535	0.554
I/Y	Investment / GDP	0.257	0.253
G/Y	Gov. consumption / GDP	0.191	0.191
Panel B: Standard deviations (data: deviations from linear trends)			
σ_I/σ_Y	Investment	2.148	2.611
$100\,\sigma_Y$	GDP	2.513	2.199
σ_C/σ_Y	Consumption	0.830	1.366
σ_D/σ_Y	Deposits	4.584	3.815
σ_M/σ_Y	Cash	14.866	1.700
σ_L/σ_Y	Bank lending	1.269	1.467
σ_e/σ_Y	Bank equity	1.569	1.606
σ_R/σ_Y	Reserves	21.946	26.910
σ_F/σ_Y	Central bank lending	8.113	11.221
σ_{r_d}/σ_Y	Deposit rate	0.006	0.006

Table B1. Calibration Fit: Data vs. Model Moments

Note: GDP denotes quarterly GDP. All ratios follow the definitions in the data section. Panels A and B follow the order of the calibration targets in Tables 3 and 5, respectively. The standard deviations reported in Panel B are calculated from deviations from series-specific linear trends in the data, and are the corresponding theoretical moments of the model.

Appendix C Model Appendix

This appendix summarizes the optimization problems and the corresponding first-order conditions (FOCs) in the model.

C.1 Patient Households

Patient households maximize expected utility and solve the following optimization problem:

$$\max_{c_{p,t},h_{p,t},d_{p,t},m_t,cbdc_t,b_{p,t},n_{p,t}} \quad E_0 \sum_{t=0}^{\infty} \beta_p^t \left\{ \frac{1}{1-\sigma_h} \left(c_{p,t} - \frac{n_{p,t}^{1+\phi}}{1+\phi} \right)^{(1-\sigma_h)} + j_{p,t} \log h_{p,t} + \chi_{z,t} \log z_t \right\}$$

$$\text{s.t.} \quad c_{p,t} + q_t(h_{p,t} - h_{p,t-1}) + m_t + f(m_t) + cbdc_t + d_t + b_{p,t} + \omega_T T_t$$

$$= \frac{m_{t-1}}{\pi_t} + R_{cbdc,t-1} \frac{cbdc_{t-1}}{\pi_t} + R_{d,t-1} \frac{d_{t-1}}{\pi_t} + R_{g,t-1} \frac{b_{p,t-1}}{\pi_t} + w_t n_{p,t} + \Omega_t \tag{C1}$$

where the liquidity aggregator $z_t(m_t, cbdc_t, d_t)$ is given by

$$z_t(m_t, cbdc_t, d_t) = \left[m_t^{(\eta_{z,t}-1)/\eta_{z,t}} + cbdc_t^{(\eta_{z,t}-1)/\eta_{z,t}} + \omega_d d_t^{(\eta_{z,t}-1)/\eta_{z,t}} \right]^{\eta_{z,t}/(\eta_{z,t}-1)} \tag{C2}$$

and total profits from the ownership of entrepreneurial firms and banks are given by

$$\Omega_t \equiv \Omega_{b,t} + \Omega_{e,t} \tag{C3}$$

Accordingly, the Lagrangian for this optimization problem is:

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta_p^t \Bigg\{ \frac{1}{1-\sigma_h} \left(c_{p,t} - \frac{n_{p,t}^{1+\phi}}{1+\phi} \right)^{(1-\sigma_h)} + j_{p,t} \log h_{p,t} + \chi_{z,t} \log z_t$$
$$- \lambda_t^p \Bigg[c_{p,t} + q_t(h_{p,t} - h_{p,t-1}) + m_t + f(m_t) + cbdc_t + d_t + b_{p,t} + \omega_T T_t$$
$$- \frac{m_{t-1}}{\pi_t} - R_{cbdc,t-1} \frac{cbdc_{t-1}}{\pi_t} - R_{d,t-1} \frac{d_{t-1}}{\pi_t} - R_{g,t-1} \frac{b_{p,t-1}}{\pi_t} - w_t n_{p,t} - \Omega_t \Bigg] \Bigg\}$$

The resulting first-order optimality conditions are:

- FOC w.r.t. $c_{p,t}$:

$$\lambda_t^p = \left(c_{p,t} - \frac{n_{p,t}^{1+\phi}}{(1+\phi)} \right)^{-\sigma_h} \tag{C4}$$

- FOC w.r.t. $n_{p,t}$:

$$w_t = n_{p,t}^{\phi} \tag{C5}$$

- FOC w.r.t. $h_{p,t}$:

$$\frac{j_{p,t}}{h_{p,t}} + \beta_p E_t \left(\lambda_{t+1}^p q_{t+1} \right) = \lambda_t^p q_t \tag{C6}$$

- FOC w.r.t. m_t:

$$\lambda_t^p(1+\psi_m m_t) = \beta_p E_t\left(\frac{\lambda_{t+1}^p}{\pi_{t+1}}\right) + \frac{\chi_{z,t}}{z_t}\left(\frac{z_t}{m_t}\right)^{1/\eta_{z,t}} \tag{C7}$$

- FOC w.r.t. $cbdc_t$:

$$\frac{\chi_{z,t}}{z_t}\left(\frac{z_t}{cbdc_t}\right)^{1/\eta_{z,t}} + \beta_p E_t\left(\frac{\lambda_{t+1}^p R_{cbdc,t}}{\pi_{t+1}}\right) = \lambda_t^p \tag{C8}$$

- FOC w.r.t. d_t:

$$\frac{\chi_{z,t}}{z_t}\omega_d\left(\frac{z_t}{d_t}\right)^{1/\eta_{z,t}} + \beta_p E_t\left(\frac{\lambda_{t+1}^p R_{d,t}}{\pi_{t+1}}\right) = \lambda_t^p \tag{C9}$$

- FOC w.r.t. $b_{p,t}$:

$$\lambda_t^p = \beta_p E_t\left(\frac{\lambda_{t+1}^p R_{g,t}}{\pi_{t+1}}\right) \tag{C10}$$

- FOC w.r.t. λ_t^p: the patient household's budget constraint at period t.

C.2 Impatient Households

Impatient households maximize expected utility and solve the following optimization problem:

$$\max_{c_{i,t},h_{i,t},n_{i,t},l_{i,t}} \quad E_0\sum_{t=0}^{\infty}\beta_i^t\left\{\frac{1}{1-\sigma_h}\left(c_{i,t}-\frac{n_{i,t}^{1+\phi}}{(1+\phi)}\right)^{1-\sigma_h} + j_{i,t}\log h_{i,t}\right\}$$

$$\text{s.t.} \quad c_{i,t} + q_t(h_{i,t}-h_{i,t-1}) + R_{i,t-1}\frac{l_{i,t-1}}{\pi_t} + (1-\omega_T)T_t = l_{i,t} + w_t n_{i,t} \tag{C11}$$

$$\text{and} \quad l_{i,t} \leq m_{H,t}E_t\left(\frac{q_{t+1}}{R_{i,t}}h_{i,t}\pi_{t+1}\right) \tag{C12}$$

Assuming that the borrowing constraint binds in the neighborhood of the steady state, we can substitute it into the budget constraint. Consequently, the Lagrangian is given by:

$$\begin{aligned}\mathcal{L} = E_0\sum_{t=0}^{\infty}\beta_i^t\Bigg\{&\frac{1}{1-\sigma_h}\left(c_{i,t}-\frac{n_{i,t}^{1+\phi}}{(1+\phi)}\right)^{1-\sigma_h} + j_{i,t}\log h_{i,t}\\ &-\lambda_t^i\Bigg[c_{i,t}+q_t(h_{i,t}-h_{i,t-1})+R_{i,t-1}\frac{m_{H,t-1}E_{t-1}\left(\frac{q_t}{R_{i,t-1}}h_{i,t-1}\pi_t\right)}{\pi_t}+\\ &(1-\omega_T)T_t - m_{H,t}E_t\left(\frac{q_{t+1}}{R_{i,t}}h_{i,t}\pi_{t+1}\right) - w_t n_{i,t}\Bigg]\Bigg\}\end{aligned}$$

After algebraic simplification, the Lagrangian can be written as:

$$
\begin{aligned}
\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta_i^t \Bigg\{ & \frac{1}{1-\sigma_h} \left(c_{i,t} - \frac{n_{i,t}^{1+\phi}}{(1+\phi)} \right)^{1-\sigma_h} + j_{i,t} \log h_{i,t} \\
& - \lambda_t^i \Big[c_{i,t} + q_t(h_{i,t} - h_{i,t-1}) + (m_{H,t-1} q_t h_{i,t-1}) + \\
& (1-\omega_T) T_t - m_{H,t} E_t \left(\frac{q_{t+1}}{R_{i,t}} h_{i,t} \pi_{t+1} \right) - w_t n_{i,t} \Big] \Bigg\}
\end{aligned}
$$

The resulting first-order optimality conditions are:

- FOC w.r.t. $c_{i,t}$:

$$
\lambda_t^i = \left(c_{i,t} - \frac{n_{i,t}^{1+\phi}}{(1+\phi)} \right)^{-\sigma_h} \tag{C13}
$$

- FOC w.r.t. $n_{i,t}$:

$$
w_t = n_{i,t}^{\phi} \tag{C14}
$$

- FOC w.r.t $h_{i,t}$:

$$
\frac{j_{i,t}}{h_{i,t}} - \lambda_t^i \left(q_t - E_t \left[\frac{m_{H,t} q_{t+1} \pi_{t+1}}{R_{i,t}} \right] \right) + \beta_i E_t \left[\lambda_{t+1}^i q_{t+1} (1 - m_{H,t}) \right] = 0 \tag{C15}
$$

- FOC w.r.t. λ_t^i: the impatient household's budget constraint at period t.

C.3 Banks

Banks maximize the present value of dividends transferred to patient households and solve the following optimization problem:

$$
\begin{aligned}
\max_{\Omega_{b,t}, L_{i,t}, L_{e,t}, b_{b,t}, \tilde{R}_{b,t}, D_t, f_t} \quad & E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} f(\Omega_{b,t}) \\
\text{s.t.} \quad & L_{i,t} + L_{e,t} + b_{b,t} + \tilde{R}_{b,t} = e_t + D_t + f_t \\
& \Omega_{b,t} + e_t - (1-\delta^e)\frac{e_{t-1}}{\pi_t} \\
& = \frac{\left(r_{i,t-1}L_{i,t-1} + r_{e,t-1}L_{e,t-1} + r_{g,t-1}b_{b,t-1} + r_{\tilde{R},t-1}\tilde{R}_{b,t-1} - r_{d,t-1}D_{t-1} - r_{f,t-1}f_{t-1}\right)}{\pi_t} \\
& D_t + f_t \leq \gamma_i L_{i,t} + \gamma_e L_{e,t} + \gamma_b b_{b,t} + \gamma_{\tilde{R}} \tilde{R}_{b,t} \\
& \theta_{R,t} D_t \leq \tilde{R}_{b,t} \\
& f_t \leq \theta_{b,t} E_t \left(\frac{b_{b,t}}{R_{f,t}} \pi_{t+1} \right)
\end{aligned}
$$

where $\Lambda_{0,t} = \beta_p^t \, (\lambda_t^p / \lambda_0^p)$, and from the bank's balance sheet identity we can express equity as

$$
e_t = L_{i,t} + L_{e,t} + b_{b,t} + \tilde{R}_{b,t} - D_t - f_t \tag{C16}
$$

Plugging this into the bank's cash-flow constraint yields:

$$
\begin{aligned}
\Omega_{b,t} = & -\left(L_{i,t} + L_{e,t} + b_{b,t} + \tilde{R}_{b,t} - D_t - f_t\right) + (1-\delta^e)\frac{\left(L_{i,t-1} + L_{e,t-1} + b_{b,t-1} + \tilde{R}_{b,t-1} - D_{t-1} - f_{t-1}\right)}{\pi_t} \\
& + \frac{\left(r_{i,t-1}L_{i,t-1} + r_{e,t-1}L_{e,t-1} + r_{g,t-1}b_{b,t-1} + r_{\tilde{R},t-1}\tilde{R}_{b,t-1} - r_{d,t-1}D_{t-1} - r_{f,t-1}f_{t-1}\right)}{\pi_t}
\end{aligned} \tag{C17}
$$

Given that $f(\Omega_{b,t}) \equiv \frac{\Omega_{b,t}^{1-1/\sigma}}{1-1/\sigma}$, we can rewrite the optimization problem as follows:

$$
\begin{aligned}
\max_{L_{i,t}, L_{e,t}, b_{b,t}, \tilde{R}_{b,t}, D_t, f_t} \quad & E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \frac{\Omega_{b,t}^{1-1/\sigma}}{1-1/\sigma} \\
\text{s.t.} \quad & D_t + f_t \leq \gamma_i L_{i,t} + \gamma_e L_{e,t} + \gamma_b b_{b,t} + \gamma_{\tilde{R}} \tilde{R}_{b,t} \\
& \theta_{R,t} D_t \leq \tilde{R}_{b,t} \\
& f_t \leq \theta_{b,t} E_t \left(\frac{b_{b,t}}{R_{f,t}} \pi_{t+1} \right)
\end{aligned}
$$

Accordingly, the Lagrangian for the bank's problem is:

$$\begin{aligned}\mathcal{L} = E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \Bigg\{ & \frac{\Omega_{b,t}^{1-1/\sigma}}{1-1/\sigma} \\ & - \mu_{e,t}\left[D_t + f_t - \gamma_i L_{i,t} - \gamma_e L_{e,t} - \gamma_b b_{b,t} - \gamma_{\tilde{R}} \tilde{R}_{b,t}\right] \\ & - \mu_{\tilde{R},t}\left[\theta_{R,t} D_t - \tilde{R}_{b,t}\right] \\ & - \mu_{f,t}\left[f_t - \theta_{b,t} E_t\left(\frac{b_{b,t}}{R_{f,t}}\pi_{t+1}\right)\right]\Bigg\}\end{aligned}$$

The resulting first-order optimality conditions are:

- FOC w.r.t. $L_{i,t}$:

$$\Omega_{b,t}^{-1/\sigma} - \mu_{e,t}\gamma_i = E_t\left\{\Lambda_{t,t+1}\Omega_{b,t+1}^{-1/\sigma}\left[\frac{r_{i,t} + 1 - \delta^e}{\pi_{t+1}}\right]\right\} \tag{C18}$$

- FOC w.r.t. $L_{e,t}$:

$$\Omega_{b,t}^{-1/\sigma} - \mu_{e,t}\gamma_e = E_t\left\{\Lambda_{t,t+1}\Omega_{b,t+1}^{-1/\sigma}\left[\frac{r_{e,t+1} + 1 - \delta^e}{\pi_{t+1}}\right]\right\} \tag{C19}$$

- FOC w.r.t. $b_{b,t}$:

$$\Omega_{b,t}^{-1/\sigma} - \mu_{e,t}\gamma_b - \mu_{f,t}\theta_{b,t}E_t\left(\frac{\pi_{t+1}}{R_{f,t}}\right) = E_t\left\{\Lambda_{t,t+1}\Omega_{b,t+1}^{-1/\sigma}\left[\frac{r_{g,t} + 1 - \delta^e}{\pi_{t+1}}\right]\right\} \tag{C20}$$

- FOC w.r.t. $\tilde{R}_{b,t}$:

$$\Omega_{b,t}^{-1/\sigma} - \mu_{e,t}\gamma_{\tilde{R}} - \mu_{\tilde{R},t} = E_t\left\{\Lambda_{t,t+1}\Omega_{b,t+1}^{-1/\sigma}\left[\frac{r_{\tilde{R},t} + 1 - \delta^e}{\pi_{t+1}}\right]\right\} \tag{C21}$$

- FOC w.r.t. D_t:

$$\Omega_{b,t}^{-1/\sigma} - \mu_{e,t} - \mu_{\tilde{R},t}\theta_{R,t} = E_t\left\{\Lambda_{t,t+1}\Omega_{b,t+1}^{-1/\sigma}\left[\frac{r_{d,t} + 1 - \delta^e}{\pi_{t+1}}\right]\right\} \tag{C22}$$

- FOC w.r.t. f_t:

$$\Omega_{b,t}^{-1/\sigma} - \mu_{e,t} - \mu_{f,t} = E_t\left\{\Lambda_{t,t+1}\Omega_{b,t+1}^{-1/\sigma}\left[\frac{r_{f,t} + 1 - \delta^e}{\pi_{t+1}}\right]\right\} \tag{C23}$$

- The capital adequacy, liquidity, and collateral constraints are also included in the set of optimality conditions.

C.4 Entrepreneurial Managers

Entrepreneurial managers maximize the present value of profits and solve the following optimization problem:

$$\begin{aligned}
\max_{\Omega_{e,t},l_{e,t},k_{e,t},h_{e,t},u_t} \quad & E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} f(\Omega_{e,t}) \\
\text{s.t.} \quad & \Omega_{e,t} + R_{e,t}\frac{l_{e,t-1}}{\pi_t} + q_{k,t}\left[k_{e,t} - (1-\delta_t^k)k_{e,t-1}\right] + q_t\left(h_{e,t} - h_{e,t-1}\right) = \\
& r_{h,t}h_{e,t-1} + r_{k,t}u_t k_{e,t-1} + l_{e,t} + J_{er,t} \\
\text{and} \quad & l_{e,t} \leq m_{K,t}E_t\left[\frac{q_{k,t+1}}{R_{e,t+1}}(1-\delta_{t+1}^k)k_{e,t}\pi_{t+1}\right]
\end{aligned}$$

where

$$\delta_t^k(u_t) = \delta_0^k + \delta_1^k(u_t - 1) + \frac{\delta_2^k}{2}(u_t - 1)^2 \tag{C24}$$

Assuming the borrowing constraint binds in the neighborhood of the steady state, we obtain the following optimality conditions:

- FOC w.r.t. $h_{e,t}$:

$$E_t\left\{\beta_p \frac{\lambda_{t+1}^p}{\lambda_t^p}\Omega_{e,t+1}^{-1/\sigma}\left(r_{h,t+1} + q_{t+1}\right)\right\} = q_t\Omega_{e,t}^{-1/\sigma} \tag{C25}$$

- FOC w.r.t. $k_{e,t}$:

$$\begin{aligned}
&\Omega_{e,t}^{-1/\sigma}\left\{m_{K,t}E_t\left[\frac{q_{k,t+1}}{R_{e,t+1}}\left(1-\delta_{t+1}^k\right)\pi_{t+1}\right] - q_{k,t}\right\} + \\
&\beta_p E_t\left[\frac{\lambda_{t+1}^p}{\lambda_t^p}\Omega_{e,t+1}^{-1/\sigma}\left\{r_{k,t+1}u_{t+1} + q_{k,t+1}\left(1-\delta_{t+1}^k\right)\left(1-m_{K,t}\right)\right\}\right] = 0
\end{aligned} \tag{C26}$$

- FOC w.r.t. u_t:

$$r_{k,t} = \delta_1^k + \delta_2^k[u_t - 1] \tag{C27}$$

C.5 Entrepreneurial Retailers

Entrepreneurial retailers solve a two-stage optimization problem. In the first stage, they take input prices as given and rent factors of production in a perfectly competitive market. Hence, each retailer j solves:

$$\min_{k_{e,t-1}(j),h_{e,t-1}(j),N_t(j)} \quad r_{k,t}k_{e,t-1}(j) + r_{h,t}h_{e,t-1}(j) + w_t N_t(j)$$
$$\text{s.t.} \quad Y_t(j) = A_t\left[k_{e,t-1}(j)\right]^{\alpha} h_{e,t-1}(j)^{\nu} N_t(j)^{1-\alpha-\nu}$$

- FOC w.r.t $k_{e,t-1}(j)$ (where $\bar{\lambda}_t$ is the Lagrange multiplier on the production constraint):

$$r_{k,t} - \bar{\lambda}_t\left(A_t\alpha\left[k_{e,t-1}(j)\right]^{\alpha-1} h_{e,t-1}(j)^{\nu} N_t(j)^{1-\alpha-\nu}\right) = 0$$

$$r_{k,t} - \bar{\lambda}_t\left(\alpha\left[k_{e,t-1}(j)\right]^{\alpha-1} \frac{Y_t(j)}{k_{e,t-1}(j)^{\alpha}}\right) = 0$$

Finally:

$$\bar{\lambda}_t = \frac{r_{k,t}}{\alpha\frac{Y_t(j)}{k_{e,t-1}(j)}} \tag{C28}$$

- Similarly, FOC w.r.t. $h_{e,t-1}(j)$:

$$r_{h,t} - \bar{\lambda}_t\left(\nu\frac{Y_t(j)}{h_{e,t-1}(j)}\right) = 0 \tag{C29}$$

- Similarly, FOC w.r.t. $N_t(j)$:

$$w_t - \bar{\lambda}_t\left((1-\alpha-\nu)\frac{Y_t(j)}{N_t(j)}\right) = 0 \tag{C30}$$

Substituting the FOC with respect to $k_{e,t-1}(j)$ into the other two FOCs, we obtain:

$$\frac{r_{h,t}}{r_{k,t}} = \frac{\nu k_{e,t-1}(j)}{\alpha h_{e,t-1}(j)}$$

$$\frac{w_t}{r_{k,t}} = \frac{(1-\alpha-\nu)k_{e,t-1}(j)}{\alpha N_t(j)}$$

Note that all firms choose the same optimal input ratios. Assuming a unit mass of firms and imposing the market-clearing conditions (as in Fernández-Villaverde and Rubio-Ramírez, 2006):

$$\int_0^1 k_{e,t-1}(j)dj = u_t k_{e,t-1}$$

and

$$\int_0^1 h_{e,t-1}(j)dj = h_{e,t-1}$$

and

$$\int_0^1 N_t(j)dj = N_t$$

we obtain the following equations:

$$\frac{r_{h,t}}{r_{k,t}} = \frac{\nu u_t k_{e,t-1}}{\alpha h_{e,t-1}} \tag{C31}$$

$$\frac{w_t}{r_{k,t}} = \frac{(1-\alpha-\nu)u_t k_{e,t-1}}{\alpha N_t} \tag{C32}$$

Substituting these input-price ratios into the objective function, we obtain the total real cost of firm j:

$$TC_t(j) \equiv \frac{1}{\alpha} r_{k,t} k_{e,t-1}(j)$$

Given the CRS property of the production function $Y_t(j)$, we can derive the real marginal cost mc_t. Specifically, normalizing output to one (i.e. $Y_t(j) = 1$) and substituting the optimality conditions for the firm's input demands, we obtain:

$$\begin{aligned}
Y_t(j) &= A_t \left[k_{e,t-1}(j)\right]^\alpha h_{e,t-1}(j)^\nu N_t(j)^{1-\alpha-\nu} \\
&= k_{e,t-1} A_t \left(\frac{\nu}{\alpha}\frac{r_{k,t}}{r_{h,t}}\right)^\nu \left(\frac{1-\alpha-\nu}{\alpha}\frac{r_{k,t}}{w_t}\right)^{1-\alpha-\nu} = 1 \\
k_{e,t-1} &= \left[A_t \left(\frac{\nu}{\alpha}\frac{r_{k,t}}{r_{h,t}}\right)^\nu \left(\frac{1-\alpha-\nu}{\alpha}\frac{r_{k,t}}{w_t}\right)^{1-\alpha-\nu}\right]^{-1}
\end{aligned}$$

Substituting the expression for $k_{e,t-1}$ into the total cost function TC_t yields:

$$mc_t = \frac{r_{k,t}^\alpha r_{h,t}^\nu w_t^{1-\alpha-\nu}}{A_t \alpha^\alpha \nu^\nu (1-\alpha-\nu)^{1-\alpha-\nu}} \tag{C33}$$

In the second stage, firms choose prices to maximize discounted real profits subject to Calvo-type price rigidity. They solve the following problem:

$$\begin{aligned}
\max_{p_{i,t}} \quad & E_t \sum_{\tau=0}^{\infty} (\beta\theta_p)^\tau \frac{\lambda_{t+\tau}}{\lambda_t} \left\{ \left(\prod_{s=1}^{\tau} \Pi_{t+s-1}^{\chi} \frac{p_{i,t}}{p_{t+\tau}} - mc_{t+\tau} \right) y_{i,t+\tau} \right\} \\
\text{s.t.} \quad & y_{i,t+\tau} = \left(\prod_{s=1}^{\tau} \Pi_{t+s-1}^{\chi} \frac{p_{i,t}}{p_{t+\tau}} \right)^{-\varepsilon} y_{t+\tau}^d
\end{aligned}$$

Substituting the constraint into the objective function and differentiating with respect to $p_{i,t}$ yields the standard optimality conditions.

C.6 Capital and Final Goods Producers

Final goods producers maximize profits and solve the following problem:

$$\begin{aligned} \max_{Y_t(j)} \quad & P_t Y_t - \int_0^1 P_t(j) Y_t(j) dj \\ \text{s.t.} \quad & Y_t = \left[\int_0^1 Y_t(j)^{(\varepsilon-1)/\varepsilon} dj \right]^{\varepsilon/(\varepsilon-1)} \end{aligned}$$

Profit maximization yields the optimal demand for intermediate good j, given aggregate demand:

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

Capital goods producers solve the following problem:

$$\begin{aligned} \max_{\bar{x}_t, I_t} \quad & E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left(q_t^k \Delta \bar{x}_t - I_t \right) \\ \text{s.t.} \quad & \bar{x}_t = \bar{x}_{t-1} + I_t \left[1 - \frac{\psi_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] \end{aligned}$$

where $\Delta \bar{x}_t = K_t - (1 - \delta_t^k) K_{t-1}$. The first-order conditions are standard.