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Cash or Cache? Distributional and business cycle implications of CBDC holding limits☆

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ABSTRACT

Many central banks are discussing the introduction of a Central Bank Digital Currency (CBDC). Empirical evidence suggests that households differ in their demand for a CBDC. This paper investigates the macroeconomic and distributional effects of different CBDC regimes within a New Keynesian model with a heterogeneous household sector. Households prefer to hold part of their income in CBDC as a means of payment as it facilitates transactions. If they cannot hold their preferred share of CBDC, they will face transaction costs. We find that the introduction of a binding limit on CBDC holdings can increase the shock absorption capabilities of an economy. If the limit is used as a monetary policy instrument, prices will be stabilized more effectively after shocks. However, a CBDC implies distributional effects across households.

1. Introduction

Central banks worldwide are considering and debating the introduction of a Central Bank Digital Currency (CBDC).[1] A CBDC is a digital form of money issued by a central bank. In general, existing forms of digital central bank money, such as reserves, are only available to financial institutions. The introduction of a retail CBDC would, therefore, enable central banks to provide the broader public with access to a digital form of central bank money. Currently, the broader public can only use cash to pay with central bank money. However, due to a changed shopping and payment behavior, the use of cash is declining as people increasingly prefer to pay digitally (Deutsche Bundesbank, 2021a; European Central Bank, 2022). In this context, Bordo and Levin (2017) emphasize that a CBDC can facilitate payment transactions. In the same vein, central banks point out that the potential introduction of a CBDC is aimed at providing an additional means of payment rather than an additional means to store value (Panetta, 2022). Planned design

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[1] For an overview of the rationale for introducing a CBDC and the design options see, for example, Bank for International Settlements (2018), Adrian and Mancini-Griffoli (2021), Roesl and Seitz (2022), and Goodell et al. (2024). With respect to the current (December 2024) stage of the introduction of a digital euro see European Central Bank (2023) and the "Proposal for a Regulation of the European Parliament and of the Council on the establishment of the digital euro COM/2023/369 final".

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features, such as non-interest bearing and limited CBDC holdings, underline the strong focus on the payment function of a CBDC.[2] Existing studies identify a demand for a CBDC (Deutsche Bundesbank, 2021b; Bijlsma et al., 2024) but households differ in the extent to which they are willing to hold CBDC, depending on their socioeconomic status (Li, 2023; Meyer and Teppa, 2024). For instance, households with relatively low income tend to have a lower preference for digital payment options than households with relatively high income. Against this background, this paper analyzes macroeconomic and distributional effects of the introduction of a CBDC as an additional means of payment in a New Keynesian model with a heterogeneous household sector. Our main results are: (i) The introduction of a CBDC leads to higher economy-wide utility. (ii) Imposing a binding maximum amount of CBDC each household is allowed to hold, i.e., introducing a CBDC in a constrained manner, can improve the shock absorption capability of the economy. (iii) Using the CBDC limit as a monetary policy instrument allows to stabilize prices more effectively. (iv) The introduction of a CBDC in a constrained manner and its use as a monetary policy instrument has distributional effects across households.

We reach these conclusions by analyzing four different CBDC regimes within our model. In the first regime, no CBDC exists ("no-CBDC regime"). In the second regime, each household may hold an unlimited amount of CBDC ("unconstrained regime"). In the third regime, the central bank sets a maximum amount of CBDC each household is allowed to hold ("constrained regime"). In the fourth regime, the central bank uses the CBDC as a monetary policy instrument by adjusting the limit ("monetary policy regime"). We capture the intended exclusive means of payment function of a CBDC in several ways: CBDC holdings are not interest bearing, they can be limited by the central bank, and they can only be used to buy consumption goods. The main advantage of using a CBDC, namely the facilitation of payment transactions, is modeled by introducing transaction costs. If households are not able to hold as much CBDC as they want to hold, i.e., if their actual share of CBDC holdings in their overall holdings is below their optimal share, they will incur transaction costs.[3]

These transaction costs are the main driver for our results. In the no-CBDC regime, households face transaction costs, meaning part of their income has to be used to cover these costs and cannot be used for consumption. The introduction of a CBDC thus decreases transaction costs, allows for higher consumption and, therefore, increases utility. A binding limit on CBDC holdings implies that households' transaction costs per unit of consumption change with the consumption level: If households consume less, they will need less money. However, as long as the constraint on CBDC holdings is binding, they will reduce their conventional money holdings only. Consequently, households get closer to their preferred mix of money holdings and transaction costs per unit of consumption decrease. This is the driving force behind the improved shock absorption capability under the regimes with binding CBDC constraints. After a negative demand shock, for instance, households reduce their consumption expenditures. Consequently, their demand for money decreases. However, due to the binding constraint on CBDC holdings, households reduce their conventional money holdings only. As a result, the CBDC constraint becomes less binding, and transaction costs per unit of consumption decrease. This dampens the effects of the shock on output and prices. If the central bank uses the CBDC limit as a monetary policy instrument, it will further relax the constraint, thereby amplifying the dampening effects. Naturally, the extent to which households benefit from the introduction and existence of a CBDC depends on their preference for CBDC holdings. Differences in preferences imply that holding limits on CBDC in the steady state and, in particular, the use of these limits as a monetary policy instrument after adverse shocks, have distributional effects across households.

This paper relates to the literature in the following ways. First, we contribute to the literature that develops DSGE models to analyze implications of the introduction of a CBDC on business cycle dynamics. Barrdear and Kumhof (2022) utilize a New Keynesian model to examine the macroeconomic effects of the transition to an economy with a CBDC as well as the effects of the existence of a CBDC on the transmission of shocks. They find that the issuance of a CBDC leads to an increase in GDP in the steady state as well as to an improved stabilization after adverse shocks. Assenmacher et al. (2023) explicitly model the means of exchange function to examine business cycle implications. They find that the introduction of a CBDC mitigates responses to adverse shocks by stabilizing the liquidity premium, i.e., the difference between the interest rate on CBDC and bank deposits relative to returns on government bonds. Mishra and Prasad (2024) analyze the trade-offs between cash and CBDC. They find that these two forms of universally accessible central bank money mainly differ in their transaction efficiency and that different government measures can influence the relative shares of cash and CBDC holdings. Gross and Schiller (2021) use a money-in-the-utility approach to analyze the impact of a CBDC on the banking sector. Another part of the literature addresses the implications of introducing a CBDC in an open economy: Bacchetta and Perazzi (2022) analyze the macroeconomic effects of a CBDC on the banking sector and find that a CBDC reduces distortions in an open economy. George et al. (2020) examine welfare effects of introducing a CBDC in a small open economy. Most closely related is the work by Ferrari Minesso et al. (2022), who assess the implications of a CBDC in a two-country model. They find that a CBDC increases international linkages and spillover-effects by creating a new arbitrage opportunity, thereby asymmetrically affecting the optimal monetary policy in the two countries. In their model, households face a Hotelling linear city setup, where they aim to minimize the distance between the available payment instruments and their respective preferences. Payment instruments are explicitly included in the households' utility function. If their preferred mix of payment instruments deviates from their actual mix, they will incur a utility loss. As they consider two countries, they include a representative household from each, assuming identical preferences for payment instruments across countries. Assenmacher et al. (2024) extend this model by including financial frictions. The authors find that the introduction of a CBDC improves welfare.

[2] One of the reasons to consider a limit is to address concerns of bank disintermediation and a potential decline in bank profitability (Adalid et al., 2022; Burlon et al., 2022; Fegatelli, 2022; Bellia and Calès, 2025; Kumhof et al., 2023; Muñoz and Soons, 2023). For an investigation of how a CBDC might affect the stability of the banking system and potential bank runs see Keister and Monnet (2022), Azzone and Barucci (2023), and Luu et al. (2023).

[3] These costs may be interpreted as a sort of shoe-leather costs, as households have to replace online purchases by an in-store alternative, for example, or as the costs of safeguarding privacy when using a private payment service provider.

However, macroeconomic volatility increases with higher steady-state demand for CBDC. These effects can be mitigated by policies such as binding caps on CBDC holdings. In another related work, Agur et al. (2022) model households as also facing a Hotelling linear city setup but with an absolute-value loss function in the utility function and a focus on network externalities.

We contribute to this first strand of the literature in several ways. While many papers study interest-bearing CBDC holdings (and thus also consider CBDC as a store of value) that cannot be limited by the central bank, we take a more realistic approach. We consider a CBDC that is non-interest-bearing and potentially limited in its holdings, as it is planned, for example, in the euro area. In particular, we assume that a deviation of the actual mix of payment instruments from the preferred mix entails additional costs for households (see Footnote 3), implying that households have less of their income available for consumption expenditure. This allows us to explicitly consider the means of payment function of a CBDC, the function that is also explicitly put forward by, for example, the ECB. In addition, we contribute to this literature by adding a heterogeneous household sector to study the distributional effects of a CBDC. In particular, we specifically focus on the distributional effects of a CBDC when households differ in terms of income and preferences for payment instruments.

Second, our paper is related to the literature on CBDC design and monetary policy. Several papers analyze different CBDC design options or specific design features such as anonymity. Key contributions in this area are Bech and Garratt (2017), Mancini-Griffoli et al. (2018), Allen et al. (2020), Assenmacher et al. (2021), Borgonovo et al. (2021), Kumhof and Noone (2021), Ahnert et al. (2022), Agur et al. (2022), and Auer et al. (2022). Another part of this literature focuses on the impact of specific CBDC design features on financial stability. Brunnermeier and Niepelt (2019) consider the relationship between public and private money and establish an equivalence condition. Fernández-Villaverde et al. (2021) confirm these main equivalence results, but also show the limits of this equivalence condition in the case of an impaired banking sector. Other papers emphasize the implications for monetary policy. Respective examples include Bjerg (2017), Bordo and Levin (2017), Engert and Fung (2017), Uhlig and Xie (2020), and Davoodalhosseini (2022). We contribute to this literature by analyzing the distributional and business cycle effects of using the maximum amount of CBDC each household is allowed to hold as a monetary policy instrument.

Third, our paper relates to the literature that analyzes the effects of household heterogeneity and monetary policy in New Keynesian models as in Debortoli and Galí (2024) and Kaplan et al. (2018).[4] We contribute to this strand of the literature by assessing the distributional effects of a CBDC as well as the relevance of household heterogeneity for the impact of a CBDC on macroeconomic outcomes.

The paper is organized as follows. Section 2 describes the model. Section 3 states the model calibration and provides a steady-state analysis of introducing different CBDC regimes. Furthermore, we examine the consequences of a demand and a supply shock under different CBDC regimes and analyze the role of household heterogeneity. Section 4 concludes.

2. Model

2.1. Households

The household sector consists of a continuum of households with two types $k = H, L$. Household H is a representative household with high income and household L is a representative household with low income. The share of H-households is κ, the share of L-households $1 - \kappa$. A household derives utility from consumption and disutility from work. Its respective periodic utility is given by

$$U_t^k = Z_t log\left(C_t^k - \Psi^k C_{t-1}^k\right) - \chi \frac{{N_t^k}^{1+\eta^k}}{1+\eta^k}, \tag{1}$$

where C_t^k is consumption, N_t^k is the number of hours worked, η^k the inverse Frisch elasticity of labor supply, and χ is a scaling parameter that determines the weight of labor disutility. The parameter Ψ^k captures habit formation. Z_t is a demand shock following an AR(1) process. Consumption C_t^k is a composite consumption good described by the constant elasticity of substitution (CES) function

$$C_t^k = \left(\int_0^1 {c_{j,t}^k}^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}, \tag{2}$$

where $c_{j,t}^k$ is the consumption of a particular variety j and θ is the elasticity of substitution between varieties. A household's expenditure minimization for a given level of consumption yields the optimal consumption of a variety j given by

$$c_{j,t}^k = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta} C_t^k, \tag{3}$$

where $P_{j,t}$ is the price of variety j and $P_t \equiv \left(\int_0^1 P_{j,t}^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$ is the overall price index.

Each household maximizes its discounted expected lifetime utility

$$\mathbb{E}_t\left[\sum_{\iota=0}^{\infty} \beta^{\iota} U_{t+\iota}^k\right], \tag{4}$$

[4] See Kaplan and Violante (2018) for a comprehensive overview.

with β denoting the discount factor, subject to its budget constraint

$$P_t \left(1 + \zeta_t^k\right) C_t^k + B_t^k = W_t^k N_t^k + (1 + i_{t-1}) B_{t-1}^k + D_t^k. \tag{5}$$

The left-hand side (LHS) of the household's budget constraint shows its nominal expenditures, consisting of its expenditures for consumption $P_t \left(1 + \zeta_t^k\right) C_t^k$ and for one-period, risk-free bonds B_t^k at price unity. The term $\zeta_t^k C_t^k \geq 0$ reflects the fact that there may be transaction costs associated with the purchase of goods. These transaction costs play a crucial role in our analysis. We will discuss these costs in more detail below. The right-hand side (RHS) shows the household's nominal income, consisting of its labor income, where W_t^k denotes the nominal wage, of principal and interest payments on the bonds purchased by the household in the previous period, with i_t being the risk-free interest rate, and of dividends D_t^k resulting from the household's ownership of firms.

Households need money to buy consumption goods and to cover potential transaction costs. Denoting a household's holdings of real money balances by m_t^k, this constraint is therefore given by

$$m_t^k = C_t^k \left(1 + \zeta_t^k\right). \tag{6}$$

A household has the possibility to hold conventional money and CBDC. In practice, there are different types of conventional money, such as cash and deposits. In our model, however, we abstract from different types of conventional money holdings but subsume all types of conventional money under this term. For our analysis, the allocation of the household's conventional money among its different types is irrelevant. In particular, we focus on the impact of the introduction of a CBDC on the payment behavior of a heterogeneous household sector – specifically, the extent to which households replace payments made with conventional money with those made using a CBDC – and the resulting distributional effects as well as the implications for business cycle dynamics. Not explicitly considering different types of conventional money (particularly deposits) allows us to exclude a banking sector from our model, i.e., we do not address potential problems of a possible disintermediation.[5] We assume that each household wants to hold a specific mix of these two types of money. Denoting real conventional money holdings by $m_{C,t}^k$ and real CBDC holdings by $m_{CB,t}^k$, we capture the household's money holdings preference by the following CES function for a household's demand for real money balances

$$m_t^k = \left(\left(\omega^k\right)^{\frac{1}{\varphi^k}} {m_{C,t}^k}^{\frac{\varphi^k - 1}{\varphi^k}} + \left(1 - \omega^k\right)^{\frac{1}{\varphi^k}} {m_{CB,t}^k}^{\frac{\varphi^k - 1}{\varphi^k}} \right)^{\frac{\varphi^k}{\varphi^k - 1}}, \tag{7}$$

where $0 \leq \omega^k \leq 1$ determines the weight on the demand for conventional money and $1 - \omega^k$ on the demand for CBDC respectively. The parameter φ^k is the elasticity of substitution between conventional money and CBDC. Eq. (7) reveals that high- and low-income households may differ with respect to their preferred mix of money holdings. Our model thus allows to consider that high-income households may have a more pronounced willingness to use CBDC than low-income households, as shown by, for example, Li (2023) and Meyer and Teppa (2024).

A household's total demand for money m_t^k will always be satisfied. The central bank adjusts the aggregate money supply to match total demand. However, the central bank may limit the amount of CBDC that each household is allowed to hold (as is currently being discussed in for example, the euro area), i.e.,

$$0 \leq m_{CB,t}^k \leq m_{CB,t}^{max}, \tag{8}$$

with $m_{CB,t}^{max}$ being the maximum amount of CBDC in real terms that each household is allowed to hold.[6] We discuss our assumptions regarding the central bank's behavior in more detail in Section 2.3. If the constraint on CBDC holdings is binding, the total demand for money will be satisfied by a correspondingly higher supply of conventional money, and the composition of aggregate real money holdings will deviate from the household's preferred mix.[7] A household's actual share of conventional money holdings in its total money holdings Γ_t^k is thus given by[8]

$$\Gamma_t^k = \frac{m_{C,t}^k}{m_{C,t}^k + m_{CB,t}^k} = \begin{cases} \Gamma_t^{uncon,k} = \frac{m_{C,t}^k}{m_{C,t}^k + m_{CB,t}^{uncon,k}} & \text{if} \quad m_{CB,t}^k \leq m_{CB,t}^{max}, \\ \Gamma_t^{con,k} = \frac{m_{C,t}^k}{m_{C,t}^k + m_{CB,t}^{max}} & \text{if} \quad m_{CB,t}^k > m_{CB,t}^{max}. \end{cases} \tag{9}$$

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5 An important and intense debate exists concerning potential disintermediation effects associated with the introduction of a CBDC. However, this issue lies beyond the scope of our paper. We deliberately abstract from including a banking sector in order to maintain a focus on the distributional implications of changes in household payment behavior, as well as the impact on business cycle fluctuations following the introduction of a CBDC. Concerning the issues of potential disintermediation, we refer to the respective literature (see Footnote 2.)

6 Note that we assume that shocks (as well as the potential response of the central bank) are sufficiently small such that the constraint is not occasionally binding. Thus, households know that they either face a binding constraint at all times, or that the constraint is not binding for all t.

7 Note that if a central bank does not provide CBDC, $m_{CB,t}^{max} = 0$ and $m_t^k = m_{C,t}^k$ will hold.

8 A somewhat related approach can be found in Ferrari Minesso et al. (2022). They include a preferred mix of payment instruments in the utility function, thereby capturing households' preferences with respect to conventional money and CBDC. We deviate from this approach by specifically considering that CBDCs may facilitate transactions, i.e., that the availability of CBDCs may reduce transaction costs. Our approach thus specifically captures the means of payment function of CBDC.

with $\Gamma_t^{con,k}$ being the share of conventional money holdings in the total money holdings if the constraint is binding and $\Gamma_t^{uncon,k}$ if it is not binding. If the constraint on CBDC holdings is binding, the respective household will incur transaction costs given by

$$T_t^k = \zeta_t^k C_t^k, \tag{10}$$

with ζ_t^k being defined as the (scaled) deviation of actual money holdings from the optimal mix[9]

$$\zeta_t^k = \frac{\gamma}{2}\left(\Gamma_t^k - \Gamma_t^{uncon,k}\right)^2 \begin{cases} = 0 & \text{if} \quad m_{CB,t}^k \leq m_{CB,t}^{max}, \\ > 0 \text{ and } \zeta_{C,t}^k = 0 & \text{if} \quad m_{CB,t}^k > m_{CB,t}^{max} = 0, \\ > 0 \text{ and } \zeta_{C,t}^k > 0 & \text{if} \quad m_{CB,t}^k > m_{CB,t}^{max} > 0, \end{cases} \tag{11}$$

with $\zeta_{C,t}^k$ being defined as the change of this deviation in household k's consumption and γ denoting a scaling factor that allows us to realistically calibrate transaction costs. If the preferred mix of money holdings $\Gamma_t^{uncon,k}$ cannot be realized, i.e., if $\zeta_t^k > 0$ and $T_t^k > 0$, household k will incur transaction costs. This implies an increase in overall consumption expenditure $P_t\left(1+\zeta_t^k\right)C_t^k$, as online purchases, for example, have to be replaced by in-store purchases or higher costs of safeguarding privacy are incurred. Another interpretation is that transaction costs reduce the amount of transactions for a given amount of expenditures. Thus, they can also be viewed as the transactions not undertaken by a household due to the unavailability of the preferred payment option. Note that the quadratic form of Eq. (11) implies that transaction costs increase disproportionately with the deviation of the actual mix of money holdings from the preferred mix. We assume that the functional form of transaction costs is similar to other types of commonly used cost functions, such as price and capital adjustment costs, or balance sheet and management costs. Moreover, Ferrari Minesso et al. (2022) assume the same functional form in a similar context. While their approach includes preferences over payment options in the utility function, we relate them to households' consumption expenditures. The general intuition, however, is the same.

Transaction costs per unit of consumption given by $\frac{T_t^k}{C_t^k} =: AT_t^k = \zeta_t^k$ are constant in the no-CBDC and the unconstrained regime, while they vary in the constrained and the monetary policy regimes. Intuitively, the transaction costs per unit of consumption are at a maximum and constant in the no-CBDC regime as the share of conventional money is always unity. Conversely, AT_t^k is zero in the unconstrained regime as the household can always hold its preferred mix of money. If a CBDC exists and if there is a binding constraint on CBDC holdings, the transaction costs per unit of consumption will increase in consumption. The binding constraint implies that the household will hold the maximum amount of CBDC possible. An increase in consumption then implies an increase its conventional money holdings only. The household's mix of money holdings will deviate even more from its preferred mix, and transaction costs per unit of consumption will increase. Thus, the specification of transaction costs does not make a (qualitative) difference for our results as long as transaction costs depend positively on the share of conventional money in overall money holdings. Any specification that includes this property implies constant transaction costs per unit of consumption in the unconstrained and the no-CBDC regimes and increasing transaction costs per unit of consumption in consumption when there is a binding CBDC constraint.

The first order conditions (FOCs) for a household's optimal mix of money holdings are[10]

$$(\omega^k)^{\frac{1}{\varphi^k}}\left(m_{C,t}^k\right)^{-\frac{1}{\varphi^k}} \leq (1-\omega^k)^{\frac{1}{\varphi^k}}\left(m_{CB,t}^k\right)^{-\frac{1}{\varphi^k}}, \tag{12}$$

$$\left[(1-\omega^k)^{\frac{1}{\varphi^k}}\left(m_{CB,t}^k\right)^{-\frac{1}{\varphi^k}} - (\omega^k)^{\frac{1}{\varphi^k}}\left(m_{C,t}^k\right)^{-\frac{1}{\varphi^k}}\right]\left[m_{CB,t}^{max} - m_{CB,t}^k\right] = 0, \tag{13}$$

and

$$m_{CB,t}^{max} - m_{CB,t}^k \geq 0. \tag{14}$$

The FOCs reveal that if the constraint the central bank imposes on a household's CBDC holdings is not binding, its marginal benefits of conventional money holdings (LHS of (12)) will equal those of CBDC holdings (RHS of (12)). However, if the constraint is binding, the household's marginal benefits from holding CBDC will be higher than those from holding conventional money, but it will not be possible to balance marginal benefits and the household will hold the maximum amount of CBDC set by the central bank.

Furthermore, each household has to decide on its optimal amount of labor and its optimal consumption path over time. Defining the marginal utility of consumption as $U_{c,t}^k \equiv \left(\frac{Z_t}{C_t^k - \Psi^k C_{t-1}^k} - \frac{\mathbb{E}_t[Z_{t+1}]\Psi^k\beta}{\mathbb{E}_t\left[C_{t+1}^k\right] - \Psi^k C_t^k}\right)$, the respective optimality conditions are

$$\chi^k {N_t^k}^{\eta^k} = U_{c,t}^k \frac{W_t^k}{P_t}\Phi_t^k, \tag{15}$$

$$U_{c,t}^k = \beta(1+i_t)\mathbb{E}_t\left[U_{c,t+1}^k \frac{P_t}{P_{t+1}}\frac{\Phi_{t+1}^k}{\Phi_t^k}\right], \tag{16}$$

[9] A different specification of transaction costs would not change our results as long as it exhibits certain characteristics. We address this in more detail throughout this section. In addition, we show that our model results remain qualitatively unchanged by an alternative specification of ζ_t^k in Appendix B.

[10] Although we do not explicitly model the costs associated with demanding and receiving conventional money or CBDC, we assume that households seek to achieve a given level of overall money holdings in the most efficient, i.e., "cost-minimizing" way consistent with their preferences.

with

$$\Phi_t^k \equiv \frac{1}{1+\zeta_t^k} - \frac{\zeta_{m_{C,t}}^k C_t^k}{m_{m_{C,t}}^k \left(1+\zeta_t^k\right)}, \tag{17}$$

where $\zeta_{m_{C,t}}^k$ denotes the change in the deviation of money holdings from the optimum in household k's conventional money holdings, and $m_{m_{C,t}}^k$ its marginal total demand for money with respect to the conventional money holdings, given by

$$\zeta_{m_{C,t}}^k = \gamma(\Gamma_t^k - \Gamma_t^{uncon,k}) \frac{m_{CB,t}^k}{(m_{C,t}^k + m_{CB,t}^k)^2}, \tag{18}$$

$$m_{m_{C,t}}^k = \left(m_t^k\right)^{\frac{1}{\varphi^k}} (\omega^k)^{\frac{1}{\varphi^k}} \left(m_{C,t}^k\right)^{-\frac{1}{\varphi^k}}. \tag{19}$$

If the constraint on CBDC holdings is not binding, no transaction costs will be incurred, $\zeta_t^k = 0$ and $\Phi_t^k = 1$, since $\zeta_{m_{C,t}}^k = 0$ as shown in Eq. (18). Intuitively, if households can hold as much CBDC as they wish, no transaction costs will be incurred, and Eqs. (15) and (16) then represent the standard FOCs for a household's optimal amount of labor and the Euler equation.

If the constraint on CBDC holdings is binding, transaction costs will be incurred ($\zeta_t^k > 0$ and $\Phi_t^k < 1$) and the optimal behavior of the household will change. The marginal utility of labor decreases as part of the wage cannot be used any longer to pay for beneficial consumption, but has to be used to pay for transaction costs. The expression $(1-\Phi_t^k)U_{c,t}^k \frac{W_t^k}{P_t}$ thus reflects by how much the household's marginal utility of labor decreases due to transaction costs, i.e., due to the imposed constraint on CBDC holdings. Obviously, as shown in (17), this decrease will be more pronounced the more the household's actual mix of money holdings deviates from its preferred mix. Consequently, the lower the Φ_t^k is, the more the household suffers from the imposed restriction. Eq. (16) shows that the constraint may also be a "disturbance factor" to consumption smoothing. If a household expects its future marginal utility of labor to be lower than today ($\Phi_{t+1}^k < \Phi_t^k$), optimality requires working and consuming more in period t than in $t+1$.[11]

The shared bond market implies risk sharing in the form of

$$U_{c,t}^k = \phi^k (U_{c,t}^{-k}) \frac{\Phi_t^{-k}}{\Phi_t^k}, \tag{20}$$

with $\phi^k \equiv \frac{U_{c,SS}^k}{U_{c,SS}^{-k}} \frac{\Phi_{SS}^k}{\Phi_{SS}^{-k}}$, where SS denotes the zero inflation steady state, $U_{c,SS}^k = \frac{1-\Psi^k \beta}{(1-\Psi^k)C_{SS}^k}$, and $-k$ the respective other household not captured by k.

2.2. Firms

There is a continuum of firms indexed by $j \in [0,1]$ using identical technology. Each firm produces a differentiated good and supplies it on a monopolistically competitive market. We assume price rigidities à la (Calvo, 1983), by assuming that only a fraction $1-\Lambda$ of firms is able to adjust their prices in each period. The CES production function of the firm is given by

$$Y_{j,t} = \left(\alpha N_{j,t}^{H\,\frac{\varphi^N-1}{\varphi^N}} + (1-\alpha) N_{j,t}^{L\,\frac{\varphi^N-1}{\varphi^N}}\right)^{\frac{\varphi^N}{\varphi^N-1}}, \tag{21}$$

with $\alpha > (1-\alpha)$, ensuring higher wages for household H, and φ^N being defined as the elasticity of substitution between the labor of households H and L.

Firm j's real total costs are given by

$$TC_{j,t} = A_t \left(w_t^H N_{j,t}^H + w_t^L N_{j,t}^L\right), \tag{22}$$

with w_t^k being defined as the real wage. A_t is an AR(1) cost-push shock. Cost minimization for a given level of output requires

$$\frac{\alpha}{1-\alpha} \left(\frac{N_{j,t}^H}{N_{j,t}^L}\right)^{-\frac{1}{\varphi^N}} = \frac{w_t^H}{w_t^L}. \tag{23}$$

By choosing $P_{j,t}$, firms maximize their expected discounted stream of real profits given by

$$\mathbb{E}_t \left[\sum_{\iota=0}^{\infty} \beta^\iota \Lambda^\iota \Omega_{t,t+\iota} \left(\frac{P_{j,t}}{P_{t+\iota}} Y_{j,t+\iota|t} - TC\left(Y_{j,t+\iota|t}\right)\right)\right], \tag{24}$$

subject to

$$Y_{j,t+\iota|t} = \left(\frac{P_{j,t}}{P_{t+\iota}}\right)^{-\theta} Y_{t+\iota}, \tag{25}$$

[11] Assume that $\beta = 1$, $i_t = 0$, and $P_t = P_{t+1}$. Then $(\Phi_{t+1}^k < \Phi_t^k)$ requires $U_{c,t+1}^k > U_{c,t}^k$ and thus $C_{t+1}^k < C_{c,t}^k$ to fulfill the FOC given by (16).

where $\beta^{\iota}\Omega_{t,t+\iota}$ is the stochastic discount factor, with $\Omega_{t,t+\iota} \equiv \frac{\kappa U^H_{c,t+\iota}+(1-\kappa)U^L_{c,t+\iota}}{\kappa U^H_{c,t}+(1-\kappa)U^L_{c,t}}$. $Y_{j,t+\iota|t}$ denotes the output in period $t+\iota$ for a firm that is able to adjust its price in the present period and $Y_{t+\iota}$ denotes the economy-wide output. Marginal costs can be determined as

$$mc_t = \frac{A_t\left(w_t^H + w_t^L\left(\frac{1-\alpha}{\alpha}\frac{w_t^H}{w_t^L}\right)^{\varphi^N}\right)}{\left(\alpha + (1-\alpha)\left(\frac{1-\alpha}{\alpha}\frac{w_t^H}{w_t^L}\right)^{\varphi^N-1}\right)^{\frac{\varphi^N}{\varphi^N-1}}}. \tag{26}$$

Note that we drop the index j as marginal costs are independent of the output produced by an individual firm. The optimal price is then given by

$$p_t^* = \mu\frac{x_{1,t}}{x_{2,t}}, \tag{27}$$

where $p_t^* \equiv \frac{P_t^*}{P_t}$, $\mu \equiv \frac{\theta}{\theta-1}$, and the auxiliary variables are defined as

$$x_{1,t} \equiv U_{c,t}Y_t mc_t + \Lambda\beta\mathbb{E}_t\left[\Pi_{t+1}^{\theta}x_{1,t+1}\right], \tag{28}$$

$$x_{2,t} \equiv U_{c,t}Y_t + \Lambda\beta\mathbb{E}_t\left[\Pi_{t+1}^{\theta-1}x_{2,t+1}\right], \tag{29}$$

where $U_{c,t} \equiv \kappa U^H_{c,t} + (1-\kappa)U^L_{c,t}$ and $\Pi_t \equiv \frac{P_t}{P_{t-1}}$. Eqs. (27), (28), and (29) are the standard conditions for optimal price setting behavior in New Keynesian models, relating the price to current and expected future marginal costs and the expected development of the price level.

2.3. Central bank

The central bank potentially has two monetary policy instruments at its disposal: the nominal interest rate and the maximum amount of CBDC that each household is allowed to hold. It sets the nominal interest rate according to the following reaction function

$$i_t = \rho + \phi_{\pi,i}\pi_t, \tag{30}$$

with $\rho \equiv log\left(\frac{1}{\beta}\right)$ and $\pi_t \equiv log(\Pi_t)$. The parameter $\phi_{\pi,i} > 1$ determines the strength of the central bank's response to changes in inflation.

Total money supply is denoted by m_t^S. We assume that the central bank always adjusts m_t^S to the households' total demand for money.[12] Therefore, the households' total demand is always satisfied, but potentially not in the preferred composition, as the central bank can set a maximum amount of real CBDC holdings, $m^{max}_{CB,t}$, that each household is allowed to hold. This can be interpreted as a perfectly inflation-indexed maximum nominal amount of CBDC (which makes sense as CBDC is considered to be a pure means of payment). Naturally, the no-CBDC regime implies $m^{max}_{CB,t} = 0 \forall t$. Conversely, the unconstrained regime implies that the central bank always satisfies the demand for CBDC. The central bank's behavior with respect to this constraint is therefore relevant only in the constrained regime and the monetary policy regime. It is captured by

$$log(m^{max}_{CB,t}) = log(m^{max}_{CB,SS}) - \phi_{\pi,m}log(\pi_t), \tag{31}$$

where $m^{max}_{CB,SS}$ is the maximum amount of CBDC holdings in the steady state, and $\phi_{\pi,m}$ is the reaction coefficient of the central bank to inflation. In the constrained CBDC regime, $\phi_{\pi,m} = 0$, i.e., the amount of CBDC each household is allowed to hold is exogenously set by the central bank. In the monetary policy regime, $\phi_{\pi,m} > 0$, i.e., the central bank adjusts the real limit.[13] For instance, if the central bank observes inflation, it will decrease the real amount of CBDC that each household is allowed to hold.[14] This implies that

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12 We therefore assume that the central bank provides the household sector with all the conventional money and CBDC it needs. In practice, the main types of conventional money are cash and deposits. The former is produced by the central bank, the latter by commercial banks. However, through its monetary policy, the central bank has a significant influence on how much credit is granted by the commercial banks and thus how much deposits are created. In our model, we abstract from the different producers of conventional money and simply assume that all the money in our economy, conventional money and CBDC, is provided by the central bank. This allows us to abstain from modeling a banking sector which we do not need for our analysis.

13 In our model, this implies that the central bank reacts to inflation with two different measures. In reality, the interest rates set by a central bank naturally depend on many different factors, and the monetary policy toolbox consists of many different instruments. Thus, we are interested in examining the addition of the CBDC limit to this existing toolbox, i.e., the Taylor rule in our model.

14 Naturally, implementing such a policy has to be technically feasible. Current discussions revolving around CBDCs seem to make considerations like ours possible. The ECB, for instance, plans to implement the digital euro via wallets that are most likely connected to the users bank account (Dombrovskis and Panetta, 2023). Thus, a decrease in the CBDC limit could easily be achieved. If necessary, the CBDC-amount held above the new limit could simply be transferred to the user's bank account ("waterfall approach", see the "Proposal for a Regulation of the European Parliament and of the Council on the establishment of the digital euro COM/2023/369 final".)

households whose preferred CBDC holdings exceed the limit set by the central bank incur higher transaction costs, consumption decreases, which implies a dampening effect on inflation (and vice versa for negative inflation deviations from the steady state).

The introduction of a CBDC adds an additional item to the liabilities side of the central bank's balance sheet.[15] To keep matters simple, we consider a simplified version of the central bank's balance sheet such as $a_t = m_t^S$. The variable a_t serves as an adjustment item in the central bank's balance sheet, ensuring that changes in money supply are balanced.[16] This implies that there are no seigniorage effects, allowing us to focus only on the distributional and business cycle effects resulting from changes in households' payment behavior due to the introduction of a CBDC. However, relevant analyses on seigniorage can be found in Bindseil et al. (2024).

2.4. Equilibrium

The goods market clears

$$Y_t = \left(1 + \zeta_t^H\right) C_t^H + \left(1 + \zeta_t^L\right) C_t^L, \tag{32}$$

i.e., overall production covers consumption demand and transaction costs. Labor market clearing implies

$$\int_0^1 N_{j,t}^k dj = N_t^k. \tag{33}$$

Bonds are in zero net supply

$$B_t^k + B_t^{-k} = 0. \tag{34}$$

The money market clears

$$m_t^S = m_t^L + m_t^H. \tag{35}$$

In particular, demand for conventional money is always satisfied. Denoting the supply of conventional money as $m_{C,t}^S$, the market clearing condition is given by

$$m_{C,t}^S = m_{C,t}^L + m_{C,t}^H. \tag{36}$$

Concerning CBDC, we have to distinguish between two cases: if the demand for CBDC exceeds the supply, the central bank will determine the amount of CBDC held by households. If demand is lower than supply, each household will determine its CBDC holdings. Considering that only household H might face a binding CBDC limit, the market clearing condition is

$$m_{CB,t}^S = \begin{cases} m_{CB,t}^L + m_{CB,t}^H & \text{if} \quad m_{CB,t}^H \le m_{CB,t}^{max}, \\ m_{CB,t}^L + m_{CB,t}^{max} & \text{if} \quad m_{CB,t}^H > m_{CB,t}^{max}, \end{cases} \tag{37}$$

where $m_{CB,t}^S$ denotes the supply of CBDC.

3. Model analysis

3.1. Calibration

Table 1 depicts the model calibration. In order to obtain an appropriate level of income (and, hence, consumption) inequality across households, a realistic constraint on CBDC holdings, preferences for conventional money or CBDC, and transaction costs, we identify and target relevant moments in the data. In particular, we use Eurostat data on the "mean consumption expenditure by income quintile" to identify the share of households potentially affected by a CBDC constraint of 3000 euros, a value currently contemplated by the ECB (Panetta, 2022). Assuming an average weight of 0.5 on both conventional money and CBDC in overall money holdings, as in Ferrari Minesso et al. (2022), the two highest income quintiles could potentially face a binding CBDC constraint given their consumption expenditures.[17] Thus, we set κ to 0.4. We then calibrate α to match the relative consumption expenditure of households H and L, with high-income households spending 56% more on consumption than low-income households. We incorporate the fact that households with higher income exhibit higher preferences for digital payment options by setting $\omega_L > \omega_H$. Meyer and Teppa (2024) show that higher income quintiles prefer digital means of payments by approximately 10 percentage points (pp), depending on the type of digital payment option. Li (2023) shows that the differences in CBDC demand could be much larger across income groups, depending on the specific CBDC design. We consider a 10 pp gap between households H and

[15] In practice, this could result in a simple exchange of liabilities by reducing cash and/or excess bank reserves, or in an expansion of the balance sheet through increased lending to commercial banks and/or increased holdings of securities on the asset side of the central bank's balance sheet. Analyses regarding CBDC and the role of the central bank's operational framework, see, for example, Abad et al. (2025), Bindseil et al. (2024), and Fraschini et al. (2024).

[16] This adjustment item is comparable to the "revaluation accounts" and the "counterparty of special drawing rights allocated by the IMF" in the balance sheet of the Bundesbank and the ECB.

[17] See Appendix A for details.

Table 1
Calibration.

	Description	Value	Target/Source
Households			
κ	Share of H-households	0.4	Eurostat
Ψ_k	Habit parameter	0.8	Albonico et al. (2019)
χ	Scaling parameter labor	1	Galí (2015)
η_k	Inverse Frisch elasticity	2	Albonico et al. (2019)
θ	Elasticity of substitution between varieties	6	Ferrari Minesso et al. (2022)
β	Discount factor	0.995	Annual interest rate: 2%
ω_H	Weight on conventional money H	0.44	Ferrari Minesso et al. (2022), Meyer and Teppa (2024), calibrated
ω_L	Weight on conventional money L	0.54	Ferrari Minesso et al. (2022), Meyer and Teppa (2024), calibrated
φ_k	Elasticity of substitution between conventional money and CBDC	0.5	Ferrari Minesso et al. (2022)
γ	Transaction cost parameter	0.074	Krüger and Seitz (2014), calibrated
Firms			
α	Productivity household H	0.647	Eurostat, calibrated
φ_N	Elasticity of substitution between labor of H and L	2	Acemoglu (2002)
Λ	Price stickiness parameter	0.75	Average price duration: 4 quarters
Central Bank			
$\phi_{\pi,i}$	Central bank reaction coefficient: interest rate	1.5	Galí (2015)
$\phi_{\pi,m}$	Central bank reaction coefficient: CBDC	20	Analysis Parameter

L to ensure that our results constitute a lower bound.[18] The weighted average preference for CBDC is set to 0.5 as in Ferrari Minesso et al. (2022), yielding $\omega_L = 0.54$ and $\omega_H = 0.44$. Based on these preferences and the households' average consumption expenditures, we can set a value for the CBDC constraint that is equivalent to a 3000-euro limit.[19] Finally, we calibrate the value of γ to obtain an empirically plausible value for transaction costs. Following Krüger and Seitz (2014), who show that the total transaction costs for different types of payment methods amount to values around 1% of GDP for European countries, the value of γ is calibrated in a way that transaction costs amount to 1% of GDP in the model when CBDC is not available.[20]

The remaining parameters are set as follows. As Ferrari Minesso et al. (2022) we set the elasticity of substitution between good varieties to 6 and the elasticity of substitution between conventional money and CBDC to 0.5.[21] We further choose the habit parameter and the inverse Frisch elasticity of labor supply to values that are realistic for European countries (see Albonico et al., 2019). We set the elasticity of substitution between labor from households H and L to 2, thereby following Acemoglu (2002), who presents this value for the elasticity of substitution between skilled and unskilled labor. Finally, standard parameters such as the scaling parameter on labor, the degree of price stickiness, and the central bank's reaction coefficient of inflation are chosen as in Galí (2015).

3.2. Steady-state analysis

We compare the steady-state values of the model under the no-CBDC regime, the unconstrained regime, and the constrained regime.[22] Comparing the no-CBDC regime with the unconstrained regime first, Table 2 shows that the introduction of a CBDC increases the utility of both households. Both consume more without working more. Note that despite the higher consumption per hour of work, households have no incentive to change their labor supply. The introduction of a CBDC in an unconstrained manner reduces ζ to zero, i.e., total output is consumed. Consider Eq. (15): If the household worked more, marginal disutility of labor (LHS) would increase. However, more output would then be produced, leading to higher consumption, which implies a decrease in the marginal utility of labor (RHS). Marginal disutility and marginal utility of labor would diverge.[23] As both households can

[18] We consider a larger difference of household preferences for CBDC when discussing the relevance of household heterogeneity in Section 3.4.

[19] We discuss the relevance of the holding limit's value in Section 3.5.

[20] Note that we interpret the transaction costs in our model in a broader sense (transactions not undertaken by a household due to the unavailability of the preferred payment option, for instance) than the ones in Krüger and Seitz (2014). Thus, these costs constitute a lower bound.

[21] Assenmacher et al. (2021) use a value of 2 for the elasticity of substitution between deposits and CBDC relating to a firm's decision on how to finance capital purchases. We check the robustness of our results to this parameter choice in Appendix C.

[22] In steady state, the monetary policy regime coincides with the constrained regime as monetary policy reacts only to shocks.

[23] To clarify this, we drop the indices k and t and neglect habit formation ($\Psi = 0$) for the sake of simplicity. Then, in steady state, (15) reduces to $\chi N^{\eta} = \frac{W}{P}\frac{1}{C(1+\zeta)}\left(1 - \frac{\zeta_{m_C} C}{m_{m_C}}\right) = \frac{W}{P}\frac{1}{Y}\left(1 - \frac{\zeta_{m_C} C}{m_{m_C}}\right)$, and in the no-CBDC regime as well as in the unconstrained regime to $\chi N^{\eta} = \frac{W}{P}\frac{1}{C(1+\zeta)} = \frac{W}{P}\frac{1}{Y}$. See also Footnote 25.

Table 2
Steady-state comparison.

		Relative steady-state value		
Variable	Description	No CBDC	CBDC constr.	CBDC unconstr.
C^L_{SS}	Consumption L	1	1.006	1.008
C^H_{SS}	Consumption H	1	1.007	1.012
$Y_{C,SS}$	Consumption-relevant output	1	1.007	1.010
Y_{SS}	Output	1	0.997	1
N^L_{SS}	Labor L	1	1	1
N^H_{SS}	Labor H	1	0.996	1
$m^L_{C,SS}$	Conventional money holdings L	1	0.539	0.540
$m^H_{C,SS}$	Conventional money holdings H	1	0.727	0.440
$m^L_{CB,SS}$	CBDC holdings L	–	1	1.002
$m^H_{CB,SS}$	CBDC holdings H	–	1	1.316
U^L_{SS}	Utility L	1	1.001	1.001
U^H_{SS}	Utility H	1	1.001	1.002

Notes. All values relative to the case without CBDC. Exception: CBDC holdings, which are displayed relative to the case where a CBDC constraint imposed by the central bank. $Y_{C,SS} \equiv C^L_{SS} + C^H_{SS}$.

realize their preferred mix of money holdings, no transaction costs arise anymore. This means that no output has to be used to cover transaction costs, but total output is consumed. Due to its higher preference for using CBDC, household H benefits more from its introduction. Household H's greater preference for using CBDC is also reflected by the relatively larger decrease in its conventional money holdings after it becomes possible to use CBDC.

However, the introduction of a CBDC in such a way that households are allowed to hold as much CBDC as they wish, is not being considered by central banks, but a limit on CBDC holdings is being discussed (see Introduction). Therefore, we proceed by analyzing the more realistic constrained regime, in which the amount of CBDC each household is allowed to hold is limited. We assume that this constraint is only binding for household H.[24] The calibrated CBDC limit corresponds to about three quarters of the household's preferred level of CBDC holdings (equivalent to 3000 euros).

Table 2 shows that in the constrained regime household H consumes more and works less: The possibility of using CBDC as a means of payment, even in a constrained way, implies an increase in consumption, since less of the total output has to be used to cover transaction costs. However, transaction costs are still incurred ($\zeta^H_t > 0$), so that the increase in consumption after the introduction of a CBDC is lower than in the unconstrained regime. Crucially, compared to the other regimes, the constrained household H actually works less, since the introduction of a binding constraint on CBDC holdings causes the marginal disutility of labor to be higher than the marginal utility.[25] This behavior allows it to reduce its transaction costs per unit of consumption, i.e., to use a higher share of its income for consumption: Working less implies a lower income and a decrease in consumption. Consequently, the household needs less money. Due to the constraint, it reduces its conventional money holdings only. The share of CBDC holdings in its total money holdings increases and transaction costs decrease. As a result, the household uses a larger share of its income for consumption. In the other regimes this possibility does not exist.[26]

Note that the reduced labor supply of household H implies that its marginal productivity increases so that the relative marginal productivity of household L decreases. Consequently, L's real wage decreases. At the same time, the reduction in transaction costs has a similar effect on household L as it does on household H. Thus, unlike household H, household L faces two opposing effects on its consumption. In our calibration, the positive effect outweighs the negative one, so that household L also increases its consumption. It is noteworthy, however, that in other reasonable calibrations (especially those involving larger transaction costs), the net effect on household L's consumption (and utility) could be negative. In this case, household L's consumption would be partly crowded out by the consumption of household H. In general, the introduction of CBDC implies distributional effects, as household H benefits more from its introduction than household L. However, also in a constrained way, the introduction of a CBDC implies an increase in economy-wide output, consumption, and utility.

3.3. Dynamic analysis

3.3.1. Demand shock

Fig. 1 shows the impulse responses of the model to a negative 1% demand shock that affects both households symmetrically. The impulse responses are shown for the four different CBDC regimes. Regardless of the regime, the shock implies that households

[24] The qualitative results of our analysis would not change if both households were affected by the constraint. The quantitative results would be larger.

[25] Formally, the simplified version of Eq. (15) $\chi N^\eta = \frac{W}{P}\frac{1}{C(1+\zeta)}\left(1-\frac{\zeta_{m_C}C}{m_{m_C}}\right) = \frac{W}{P}\frac{1}{Y}\left(1-\frac{\zeta_{m_C}C}{m_{m_C}}\right)$ (see Footnote 23), shows that optimal behavior requires the household to reduce its labor supply when a constraint on CBDC holdings is introduced. In both the no-CBDC regime and in the unconstrained regime the term $1 \geq \left(1-\frac{\zeta_{m_C}C}{m_{m_C}}\right) > 0$ equals one, i.e., in both regimes optimality requires the same labor supply (see Footnote 23). However, if there is a binding constraint, the term is strictly smaller than 1.

[26] In the no-CBDC regime, the share of CBDC holdings in total money holdings is always zero, and in the unconstrained regime there are no transaction costs to reduce.

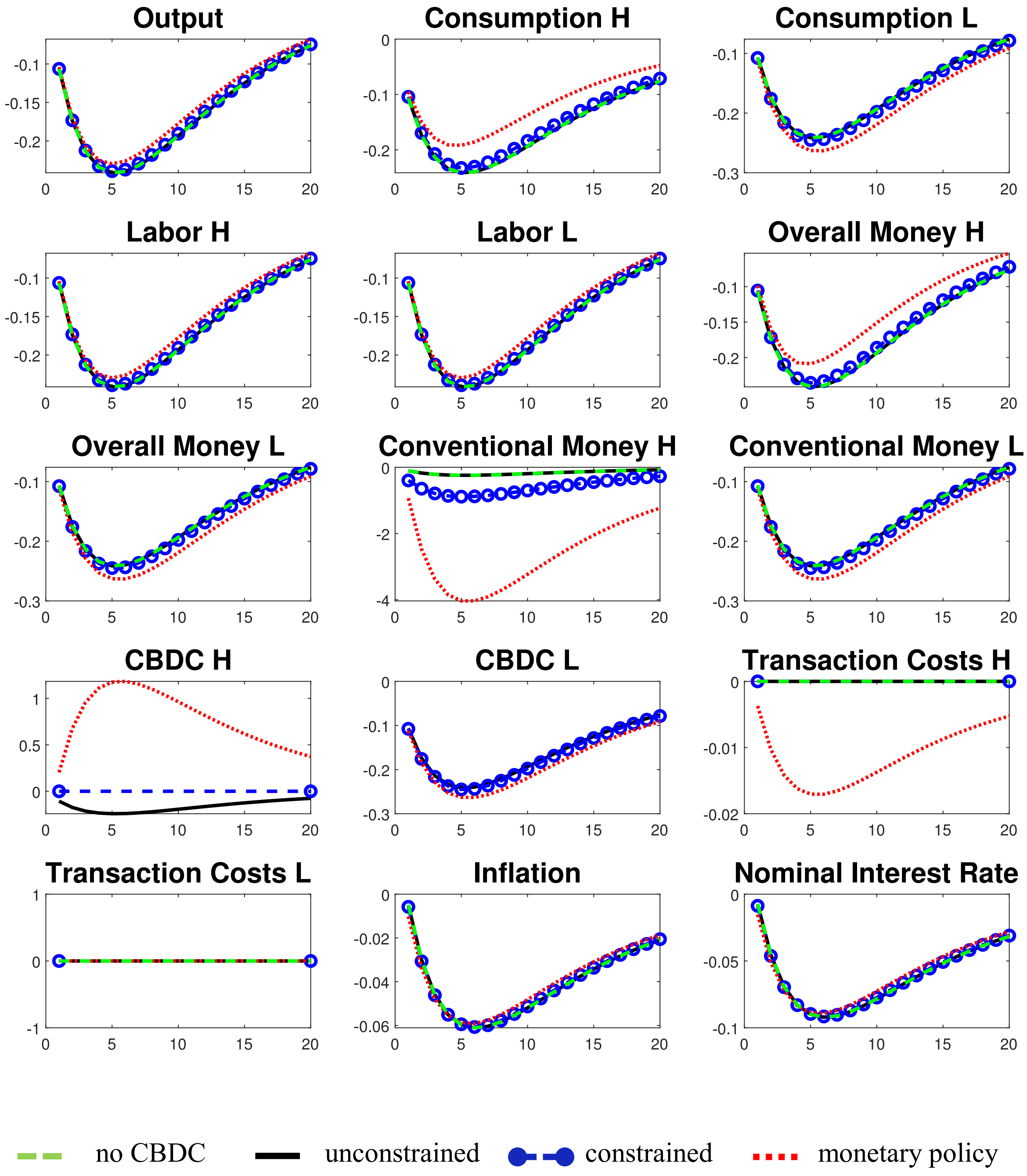

Fig. 1. Impulse responses to a negative 1% demand shock (Z_t^k) with persistence $\rho_Z = 0.9$.

consume less and thus hold less money. Firms produce less and hire less labor. Inflation decreases and the central bank reacts by decreasing the nominal interest rate to incentivize consumption and mitigate the effects of the shock.

To analyze the differences in the impulse responses of the different CBDC regimes, we start by comparing the no-CBDC and the unconstrained regime. In both regimes, the impulse response functions of all variables, except CBDC holdings, coincide. The reason is that in both regimes, the transaction costs per unit of consumption are constant (see Eq. (11)), i.e., they are not affected by the shock. Naturally, in the unconstrained regime CBDC holdings decrease proportionally to overall and conventional money holdings.

We continue by comparing the impulse responses of the no-CBDC/unconstrained regime with the regimes in which CBDC holdings are limited (constrained/monetary policy). In the constrained/monetary policy regime, the constraint is not binding for household L but is binding for household H. As a result, the optimal amount of CBDC is held by household L but not by household H.

However, in the constrained and the monetary policy regime, the deviations of output and inflation from their steady states are smaller. The negative demand shock implies a decrease in money demand. However, as the constraint on CBDC holdings is still binding for household H, it only reduces its conventional money. Therefore, the household moves closer to its preferred mix of money holdings implying a decrease in its transaction costs per unit of consumption, which is the main difference between the constrained/monetary policy regime and the no-CBDC/unconstrained regime, where these costs are constant (see Eq. (11)). In the constrained/monetary policy regime, household H thus experiences a less pronounced shock-induced decline in consumption. As a result, output and thus labor and inflation decrease less in this case. For our particular calibration, output and inflation decrease by up to 2% less in the constrained regime and up to 11.5% in the monetary policy regime. However, this occurs at the expense of household L's consumption as a higher consumption of household H implies higher prices and a decrease in household L's consumption. Overall, the shock absorption capabilities of the economy are strengthened in the constrained/monetary policy regime by stabilizing household H's consumption, but the consumption of household L decreases even further.

Upon comparing the constrained regime with the monetary policy regime, we find that the effects are more pronounced in the monetary policy regime. In response to a negative demand shock, the central bank relaxes the constraint by increasing the maximum amount of CBDC per household, causing household H's real CBDC holdings to increase and move closer to its preferred mix of money holdings. Transaction costs per unit of consumption decrease as household H moves closer to its optimal mix of money holdings. Household H reduces its consumption less, and aggregate output decreases less. However, household L's consumption decreases even more strongly. Overall, output and inflation can be stabilized and decrease less than in the case where CBDC is not used as a monetary policy instrument. However, the use of the CBDC limit as a monetary policy instrument increases the distributional effects of a CBDC limit.

3.3.2. Cost-push shock

Fig. 2 shows the impulse responses of the model to a 1% cost-push shock for the four CBDC regimes. In all cases, the increase in firms' costs leads to an increase in prices, which implies a decrease in consumption and thus money holdings. Firms hire less labor and produce less. The central bank reacts to the increase in inflation by increasing the nominal interest rate. As in the case of a demand shock, the impulse responses of all model variables in the no-CBDC and the unconstrained regime coincide (except for CBDC holdings).

Comparing the impulse responses of the constrained regime with those of the unconstrained/no-CBDC regime, we find that consumption of household H decreases less in the constrained regime. This is due to the possibility for household H to affect its transaction costs per unit of consumption. The decrease in consumption implies a lower money demand. However, household H only reduces its conventional money holdings as the CBDC limit is still binding. This leads to lower transaction costs per unit of consumption for H, as H is closer to its preferred money mix, implying a lower decrease in consumption. As a result, output decreases less but prices increase even more. This leads household L to reduce its consumption more in the constrained regime.

In the monetary policy regime, the central bank can stabilize inflation by adjusting the CBDC limit. In our calibration, the inflation rate increases by up to 10% less than in the unconstrained/no-CBDC regime. The central bank reacts to the increase in inflation by lowering the maximum amount of CBDC to further reduce consumption. The constraint thus becomes more restrictive but only for household H. Household H therefore holds even less CBDC than it would like to hold and increases its conventional money holdings in return. Transaction costs per unit of consumption increase. As a result, household H's consumption decreases more than in the other three regimes, while household L's consumption decreases less. Overall, inflation increases less than in the other regimes. However, output decreases even more as the central bank reduces the amount of CBDC (and thus negatively affects consumption). Monetary policy thus has a stronger impact on inflation. However, this also amplifies the negative effects on output. In addition, the use of CBDC as a monetary policy instrument implies distributional effects: The decrease in household H's consumption and the corresponding lower increase in prices leads household L to reduce its consumption less.

3.4. The relevance of household heterogeneity in CBDC preferences

We continue with discussing the role of households' CBDC preferences in our results. We start by increasing the difference between the preferences of households H and L for holding CBDC.

In particular, we decrease ω^H from 0.44 (baseline calibration) to 0.4 while increasing ω^L from 0.54 to 0.567, thereby keeping the (weighted) average preference for conventional money/CBDC constant at 0.5. This implies that the CBDC constraint becomes more binding for H. Thus, the discussed effects of the CBDC limit in the constrained and the monetary policy regime are amplified. In the following, we compare the impulse responses to a negative demand (Fig. 3) and a positive cost-push shock (Fig. 4) for both values of ω^k under the monetary policy regime in detail to provide some intuition for this result.

After a negative demand shock, we find that the use of the CBDC limit as a monetary policy instrument becomes even more effective in stabilizing prices when the difference in CBDC preferences is high. At the same time, the distributional effects across households increase. The intuition behind these results is straightforward: The more binding the constraint on CBDC is, the larger are the positive effects of relaxing the constraint. In particular, the central bank increases the CBDC limit in response to the decline in inflation. Household H increases its CBDC holdings, which, in turn, reduces its transaction costs per unit of consumption. This decrease in these costs is greater, the higher the preference for CBDC is, i.e., the more binding the constraint is for a household. This implies a less pronounced decrease in overall output and inflation. The smaller price decline induces household L to reduce consumption even more, implying larger distributional effects of monetary policy. Overall, the effects of using the CBDC limit as a monetary policy instrument are amplified by a higher preference for CBDC of the constrained household.

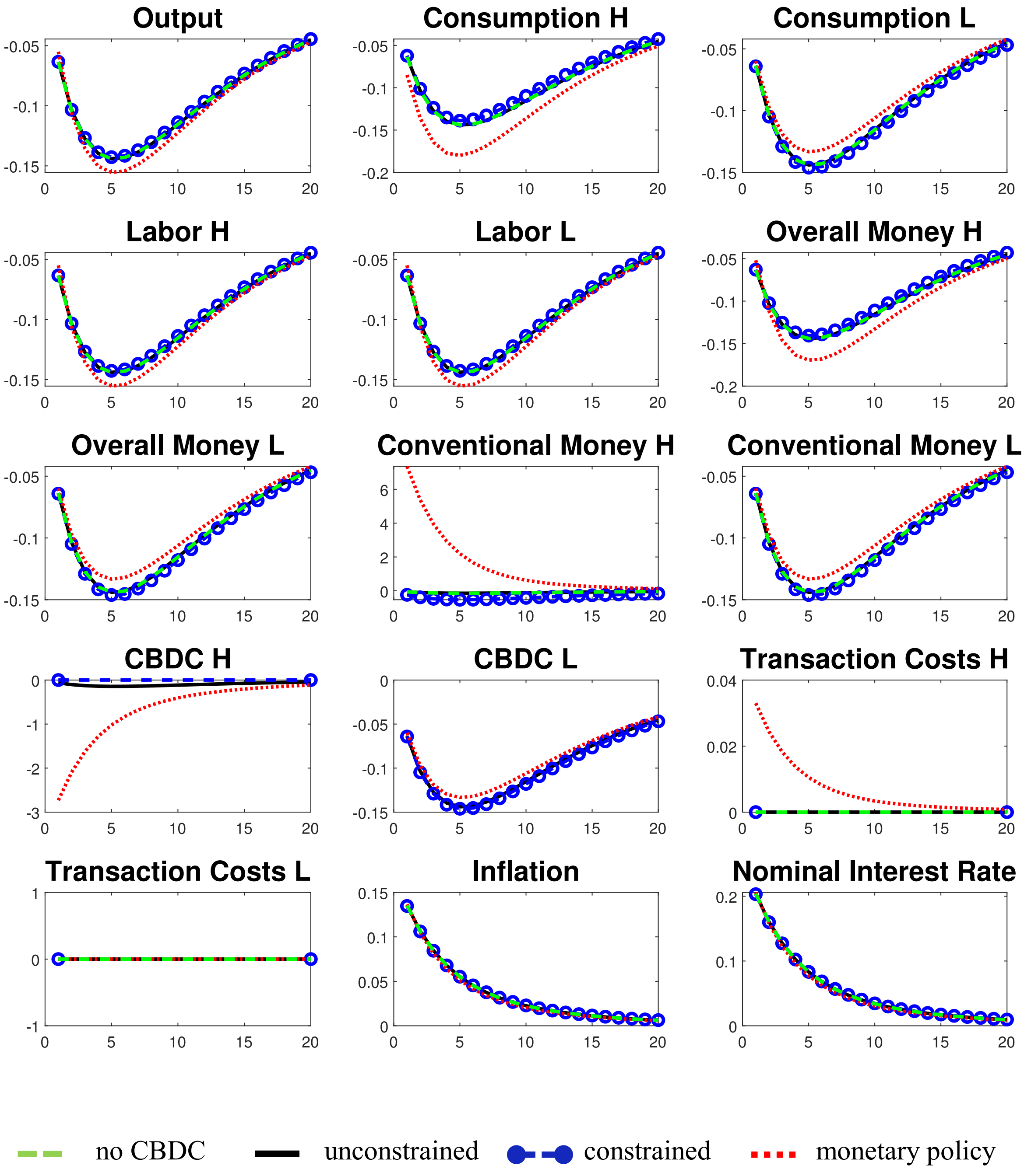

Fig. 2. Impulse responses to a 1% cost-push shock (A_t^k) with persistence $\rho_A = 0.9$.

Comparing the impulse response functions to a cost-push shock, we find similar results: The effects of using the CBDC limit as a monetary policy instrument are amplified relative to the baseline calibration when the preference for CBDC of the constrained household is larger. When prices increase after the shock, the central bank lowers the CBDC limit. Household H reduces its CBDC holdings, which increases transaction costs per unit of consumption for household H – more so if its CBDC preference is higher. Household H decreases its consumption even more, leading to a larger drop in output and a lower increase in prices if the CBDC preference of household H is higher. Household L, conversely, benefits from this muted increase in prices by reducing its consumption less. Overall, the effects of using the CBDC limit as a monetary policy instrument are again amplified by a higher CBDC preference of the constrained household.

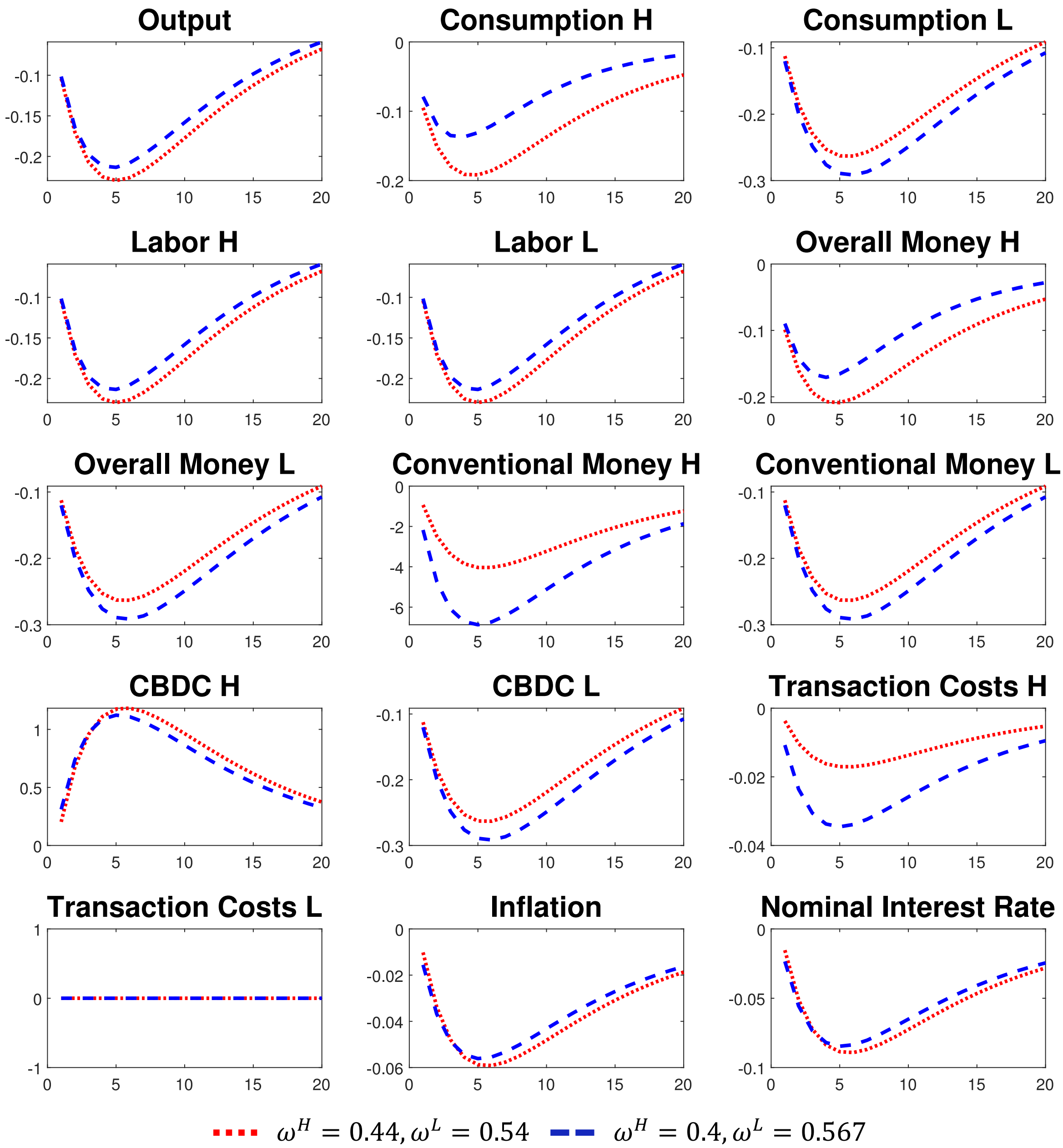

Fig. 3. Impulse responses in the monetary policy regime to a negative 1% demand shock (Z_t^k) with persistence $\rho_Z = 0.9$ for different CBDC preferences.

Finally, we assume that both households have the same preferences for CBDC, i.e., $\omega^k = 0.5$. In this case, the constraint is still (not) binding for household H (L), but to a lesser extent. Thus, the effects of using the CBDC limit as a monetary policy instrument are mitigated compared to the baseline calibration. The intuition behind this result is the same as outlined above (in the opposite direction). The impulse responses are shown in Appendix D.

3.5. The relevance of the amount of the CBDC limit

Next, we discuss the relevance of the chosen CBDC limit for our results. While our baseline calibration includes the equivalent of the 3000-euro limit contemplated by the ECB, an interesting exercise is the comparison of the model responses to shocks for different amounts of this (as of yet, unspecified) limit.

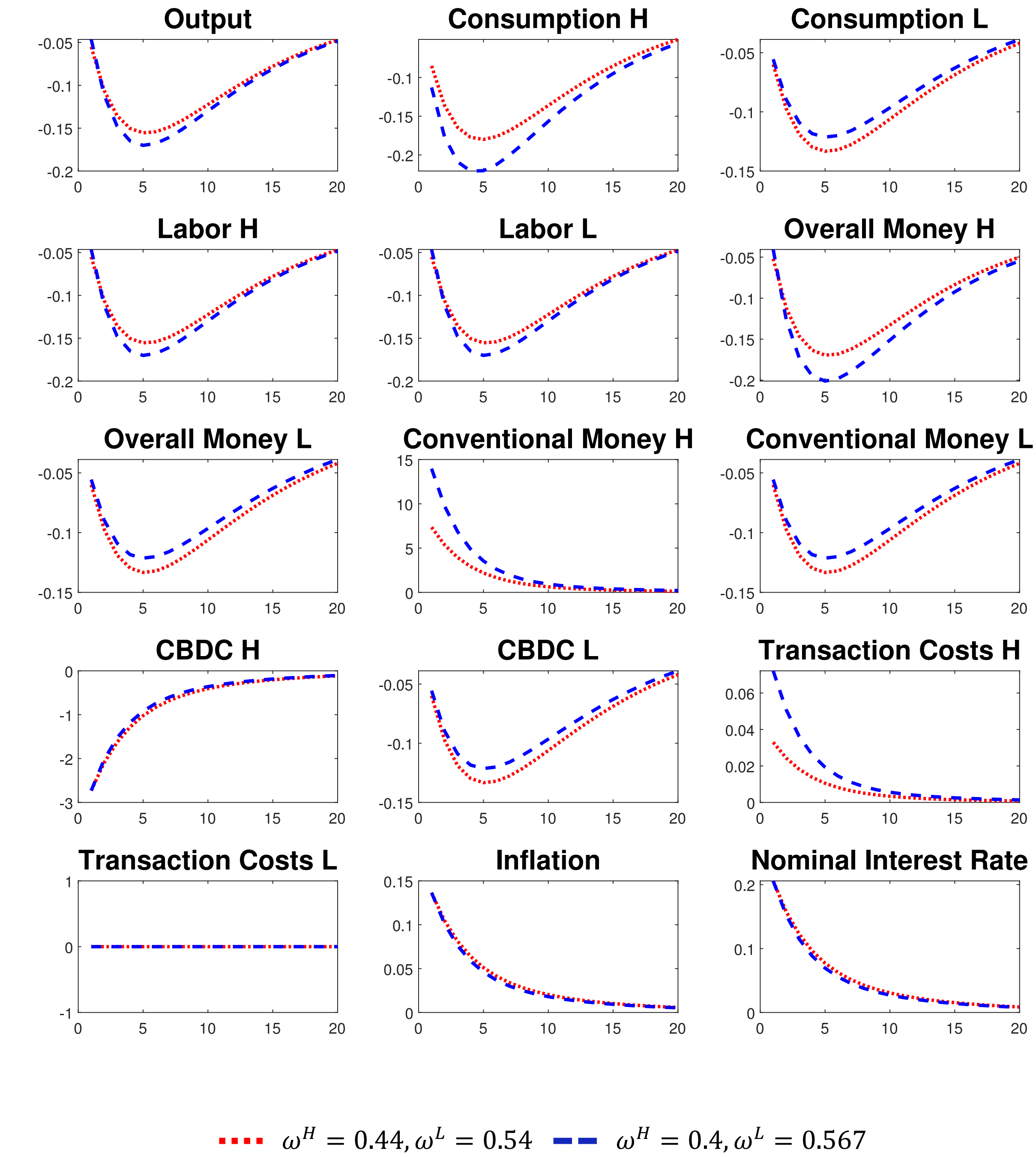

Fig. 4. Impulse responses in the monetary policy regime to a 1% cost-push shock (A_t^k) with persistence $\rho_A = 0.9$ for different CBDC preferences.

For instance, if the amount of CBDC available to households were so large that it was not a binding constraint on any household, the economy would effectively move towards the unconstrained case. More interestingly, the central bank could decide to impose a lower constraint.

We simulate the model responses including the equivalent of a 2500-euro limit. The responses to a demand and a cost-push shock under the monetary policy regime are shown in Figs. 5 and 6, respectively.

Generally, a lower limit implies that the constraint is more binding for household H. This again implies that the effects of the CBDC limit in the constrained as well as in the monetary policy regime are amplified when considering a (more binding) 2500-euro limit instead of 3000-euro limit. The same intuition as in Section 3.4 applies.

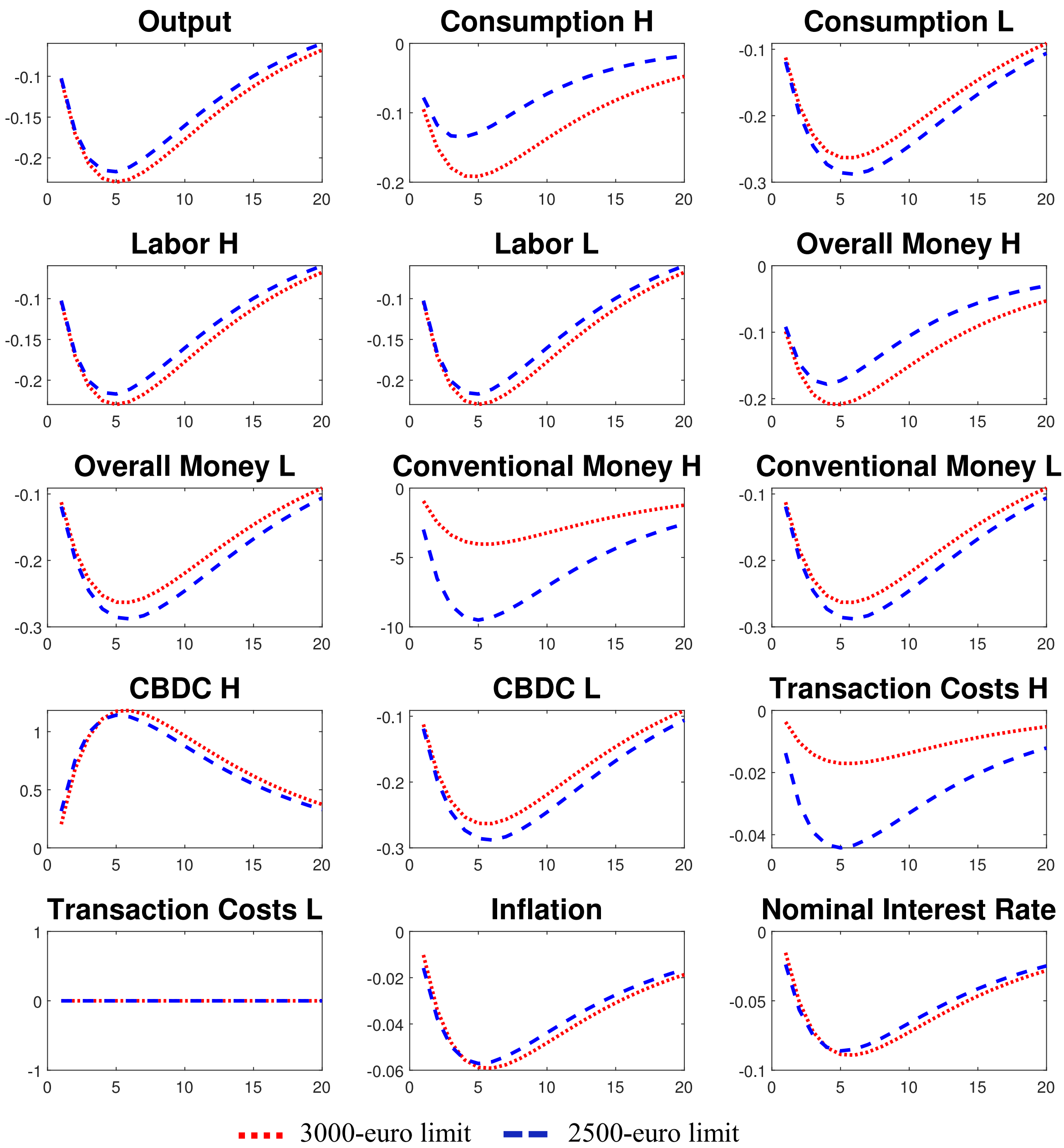

Fig. 5. Impulse responses in the monetary policy regime to a negative 1% demand shock (Z_t^k) with persistence $\rho_Z = 0.9$ for different CBDC limits.

4. Conclusion

Over the past years, there has been an ongoing debate about the advantages and disadvantages of introducing a CBDC, including questions about whether and how central banks should issue it. Moreover, households differ in their demand for a CBDC depending on their income. Against this background, we study the distributional and business cycle effects of a CBDC in an economy with a heterogeneous household sector.

Our paper develops a New Keynesian model in which households differ in their preferences for holding CBDC. We consider a high- and a low-income household, where the high-income household prefers to hold a larger amount of CBDC than the low-income household. CBDC serves as a means of payment for households. We analyze the macroeconomic consequences of four different CBDC regimes. In the first, no CBDC exists. In the second, access to CBDC is unconstrained for each household. In the third, the central

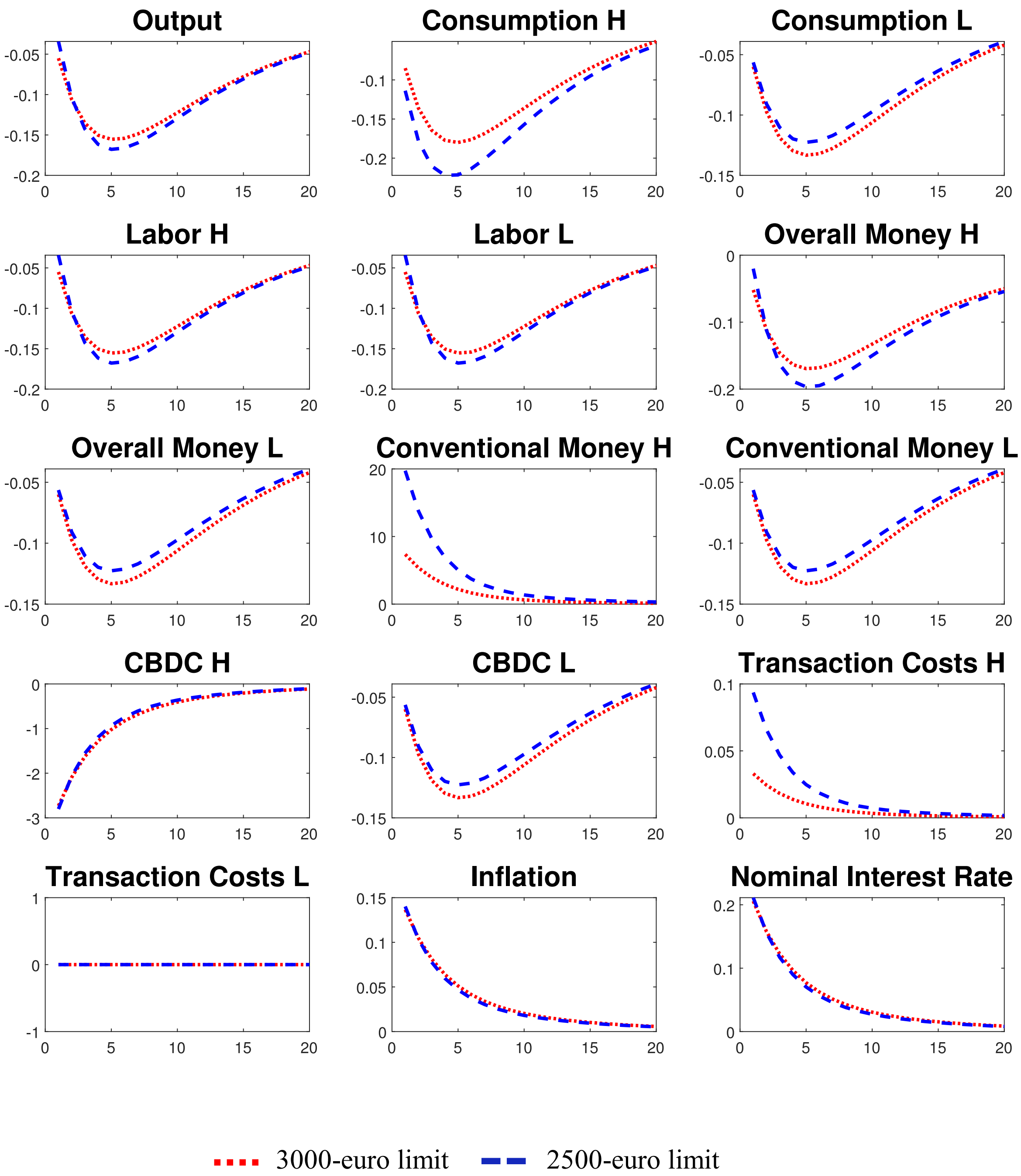

Fig. 6. Impulse responses in the monetary policy regime to a 1% cost-push shock (A_t^k) with persistence $\rho_A = 0.9$ for different CBDC limits.

bank sets a maximum amount of CBDC that each household may hold. In the fourth, the central bank uses this maximum amount of CBDC each household is allowed to hold as a monetary policy instrument, i.e., the central bank changes the limit to potentially stabilize prices after shocks.

We find that the introduction of a CBDC in a constrained way increases the economy's ability to absorb demand shocks. Both output and prices deviate less from their steady states after the shock. Following cost shocks, output deviations are similarly reduced, but prices deviate further from their steady state. Transaction costs are the main driver of these results. The introduction of a CBDC reduces transaction costs per unit of consumption. In the two regimes with a binding limit on CBDC holdings, transaction costs per unit of consumption increase with consumption, which explains the change in the economy's shock absorption capability in these regimes. In addition, by using the CBDC limit as a monetary policy tool, the central bank can stabilize prices more effectively. Note that these results are primarily driven by the presence of a binding constraint on CBDC holdings rather than household heterogeneity. The results would be quantitatively even stronger if the constraint were binding for both households. However, accounting for household heterogeneity allows us to show that introducing a CBDC, as well as using the CBDC limit as a monetary policy instrument, has distributional effects across households.

Our main focus is on the distributional and business cycle effects arising from changes in households' payment behavior due to the introduction of a new means of payment, i.e., CBDC. Therefore, we do not include a banking sector in our model. While this allows us to focus on our primary objectives, it has the drawback of not accounting for potential disintermediation effects or other monetary transmission mechanisms. However, to address the extensive ongoing discussion of these issues, we refer to the relevant literature (see references in Footnote 2).

Our findings also raise important questions about the implementation of monetary policy using a CBDC limit as a policy instrument. Similar to other monetary policy instruments or the considerations for interest-bearing CBDC, the use of the CBDC holding limit as a monetary policy instrument has drawbacks: An additional monetary policy instrument introduces a further source of uncertainty regarding monetary policy. This issue also poses an additional challenge for central bank communication. Moreover, our model shows that using the CBDC limit as a monetary policy tool also has distributional effects. This is particularly relevant as we consider an inflation-indexed limit in our model. In practice, this implies that a central bank that sets a nominal CBDC limit – and thus allows the real limit to fluctuate with inflation – would be operating within the monetary policy regime of our model. Consequently, setting a (nominal) 3000-euro limit, as contemplated by the ECB, would imply additional distributional effects.

Finally, there are several interesting avenues for future research. Analyzing the implications of even more alternative CBDC regimes in an economy with heterogeneous households, as well as extending our framework to analyze a heterogeneous monetary union model seem to be interesting for future research. Another relevant avenue is the consideration of financial inclusion aspects in a model with household heterogeneity, as this might imply distributional effects of a CBDC that specifically benefit households with lower income.

CRediT authorship contribution statement

Jana Anjali Magin: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Ulrike Neyer:** Writing – review & editing, Writing – original draft, Validation, Supervision. **Daniel Stempel:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Consumption expenditure data

We use consumption expenditure date to identify the share of households that could be affected by a 3000-euro CBDC limit. The latest Eurostat data on "mean consumption expenditure by income quintile" is available for 2020. As the data are not available for the euro area, we use consumption data for Germany as the largest euro area economy. The consumption expenditure by income quintile is shown in Table A.1. We convert annual expenditure to quarterly expenditure. Considering a 3000-euro limit as well as an average preference of 0.5 for CBDC, the constraint could potentially be binding for quintiles 4 and 5. The third row then reports the average quarterly consumption expenditures of income quintiles 1, 2, and 3 as well as quintiles 4 and 5, respectively.

Table A.1
Consumption expenditure by income quintile in Germany.

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Annual	13,305	18,504	22,162	25,030	31,368
Quarterly	3326	4626	5541	6258	7482
Average quarterly			4498		7050

Notes. Source: Eurostat. Values in euros. Average quarterly refers to the average consumption expenditure by income quintiles 1, 2, and 3 as well as quintiles 4 and 5, respectively.

Appendix B. Alternative specification of transaction costs

We check the robustness of our results derived in Section 3.3 with respect to the specification of transaction costs, in particular of ζ_t^k (Eq. (11)). Otherwise, we assume that household behavior remains unchanged. We consider the following specification

$$\zeta_t^k = \frac{\gamma}{2}\left(\Gamma_t^k\right)^2, \tag{B.1}$$

i.e., households generally face transaction costs when using conventional money. This specification implies that the criteria discussed in Section 2.1 are met: Transaction costs per unit of consumption are constant in the unconstrained and no-CBDC cases, and increase

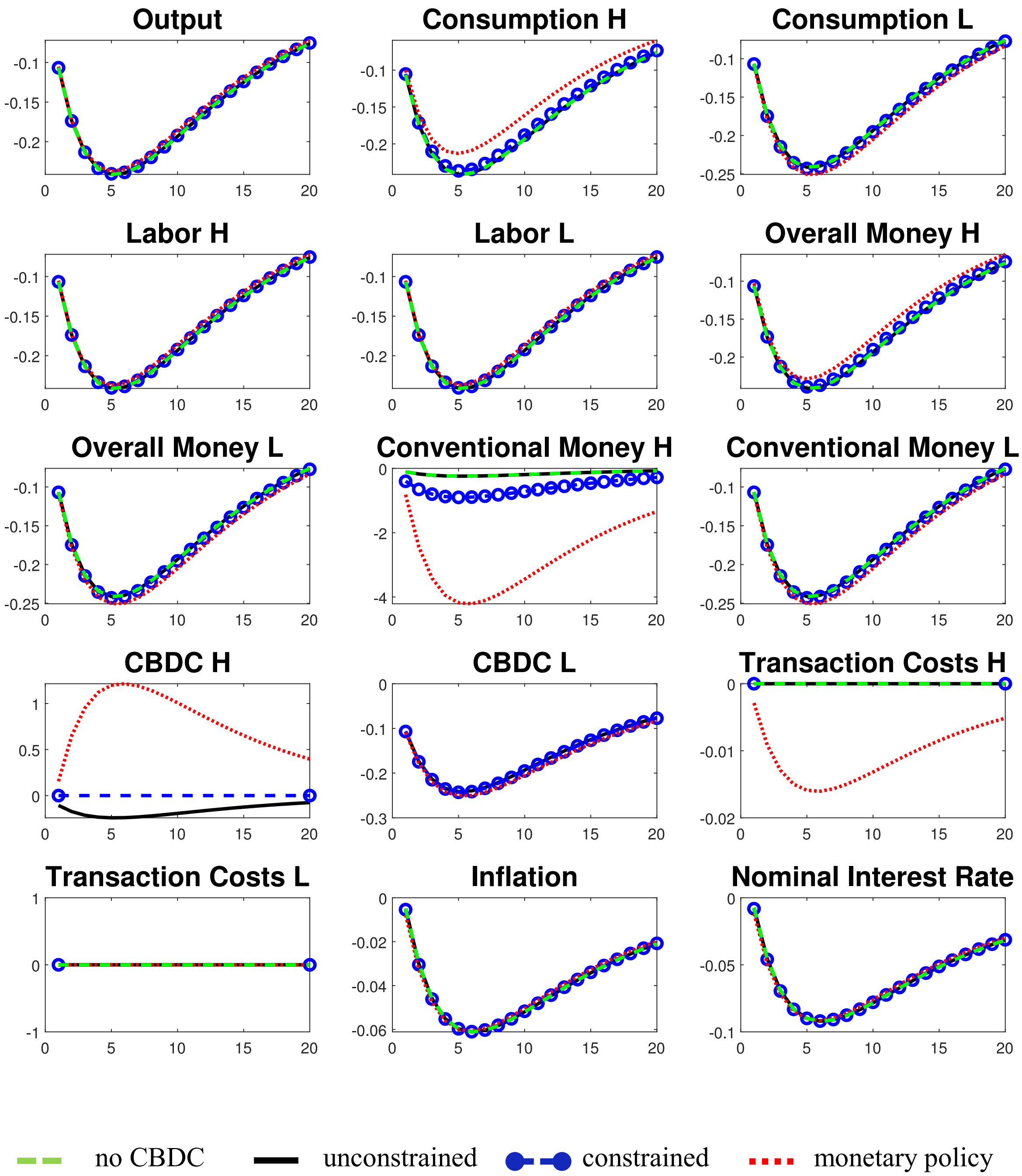

Fig. B.1. Impulse responses to a negative 1% demand shock (Z_t^k) with persistence $\rho_Z = 0.9$ and alternative specification of ζ_t^k.

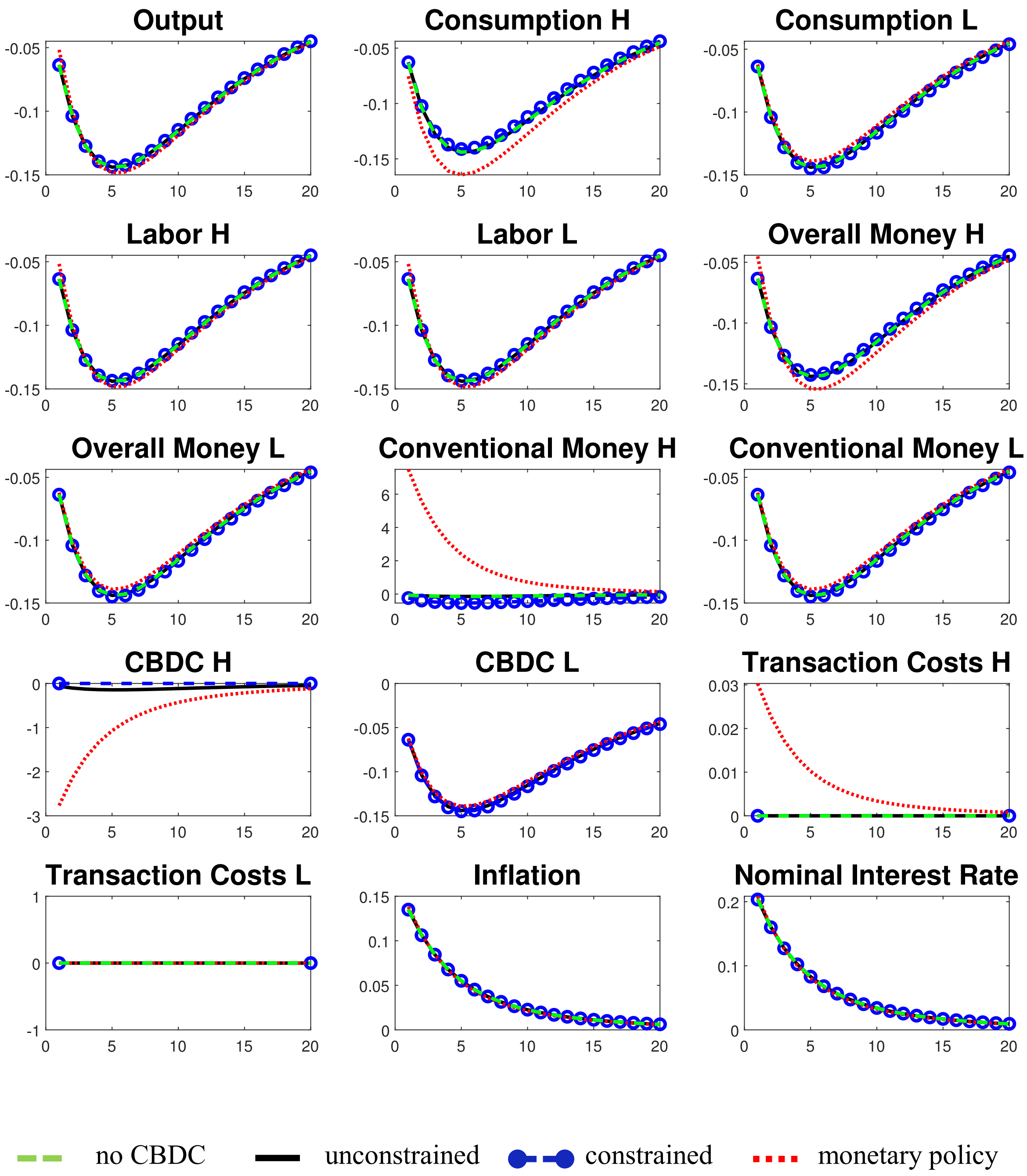

Fig. B.2. Impulse responses to a 1% cost-push shock (A_t^k) with persistence $\rho_A = 0.9$ and alternative specification of ζ_t^k.

in consumption when the constraint is binding. The parameter γ is calibrated in the same way as in the baseline calibration. Since households now incur transaction costs when they hold conventional money, γ is lower (0.02). Figs. B.1 and B.2 show the results for a demand and a cost-push shock, respectively. We find that our results remain qualitatively unchanged. Intuitively, both the effects of the constraint itself and the effectiveness of using it as a monetary policy tool diminish when γ is lower.

The stabilizing effect on output and inflation after a demand shock decreases to about 1% (from 2% in the baseline) in the constrained and to approximately 5.75% (from 11.5%) in the monetary policy regime. The inflation-stabilizing effect of the monetary policy regime after the cost-push shock declines to 3% (from 10%).

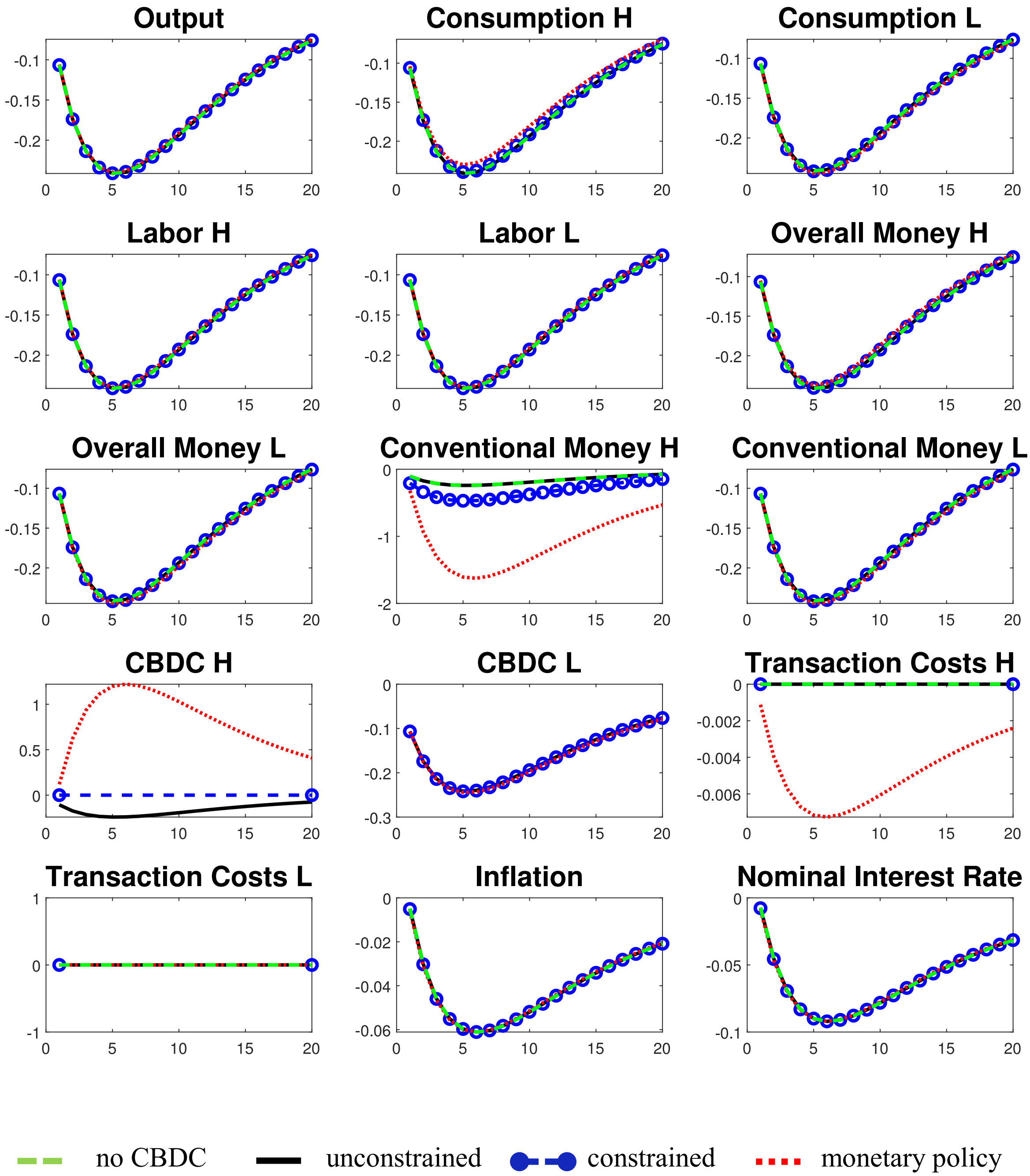

Fig. C.1. Impulse responses to a negative 1% demand shock (Z_t^k) with persistence $\rho_Z = 0.9$ and elasticity of substitution between conventional money and CBDC $\varphi_k = 2$.

Appendix C. Elasticity of substitution

We check the robustness of our results derived in Section 3.3 with respect to the elasticity of substitution between conventional money and CBDC.

While we set the elasticity of substitution to 0.5 in our baseline calibration, implying a relatively low degree of substitutability, our results remain qualitatively unchanged when we consider a higher elasticity of substitution ($\varphi_k = 2$), as shown in Figs. C.1 and C.2.

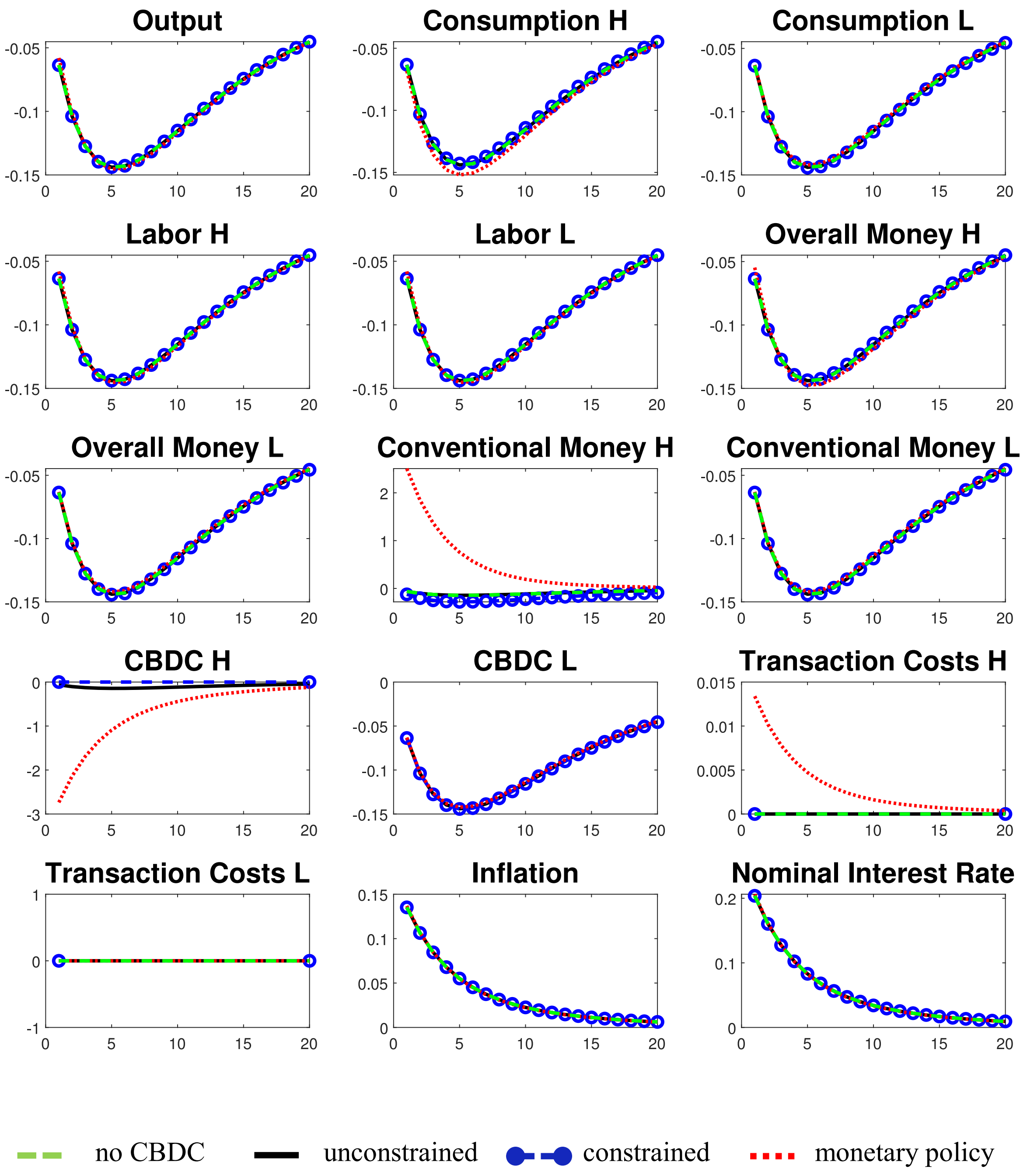

Fig. C.2. Impulse responses to a 1% cost-push shock (A_t^k) with persistence $\rho_A = 0.9$ and elasticity of substitution between conventional money and CBDC $\varphi_k = 2$.

Intuitively, the effects of the constraint, as well as the effectiveness of using the constraint as a monetary policy tool decreases in the elasticity of substitution, as CBDC can be more easily substituted by conventional money. Therefore, achieving the required level of overall money holdings is easier for households, implying a less pronounced role of transaction costs and the associated effects on the outcomes. In particular, the stabilizing effect of a CBDC in the constrained regime on output and inflation after a

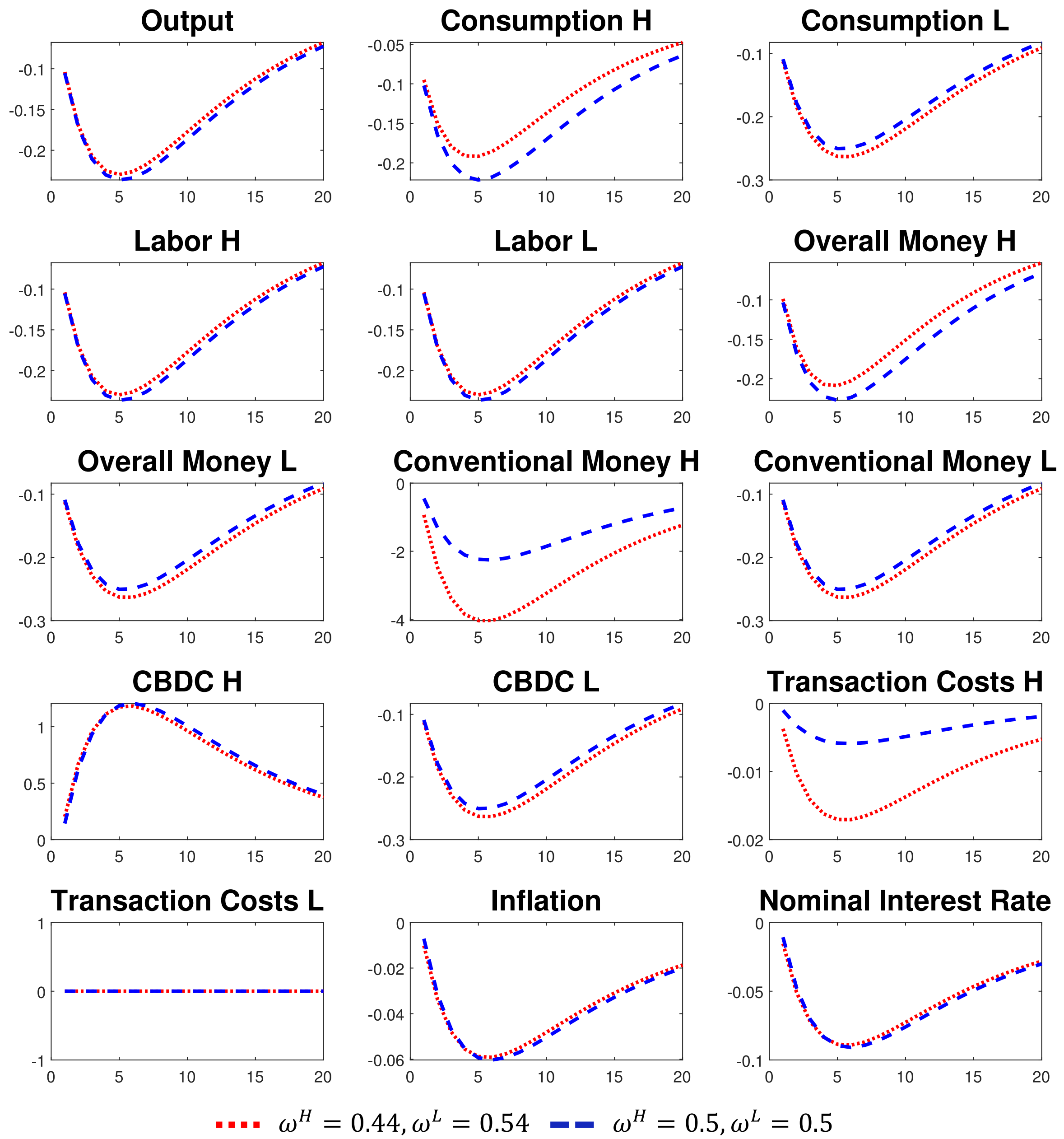

Fig. D.1. Impulse responses in the monetary policy regime to a negative 1% demand shock (Z_t^k) with persistence $\rho_Z = 0.9$ for different CBDC preferences.

demand shock decreases to 0.35% (from 2% in the baseline) and to 2.2% (from 11.5%) in the monetary policy regime. After the cost-push shock, the inflation-stabilizing effect in the monetary policy regime decreases to 1.9% (from 10%).

Appendix D. Equal CBDC preferences

Equal preferences across households for conventional money and CBDC implies that the constraint is still not binding for household L, but becomes less binding for household H. Thus, the (potentially stabilizing) effects of the CBDC constraint are lower after both shocks. Figs. D.1 and D.2 show this for the monetary policy regime under the baseline calibration and for equal CBDC preferences across households after a demand and a cost-push shock, respectively.

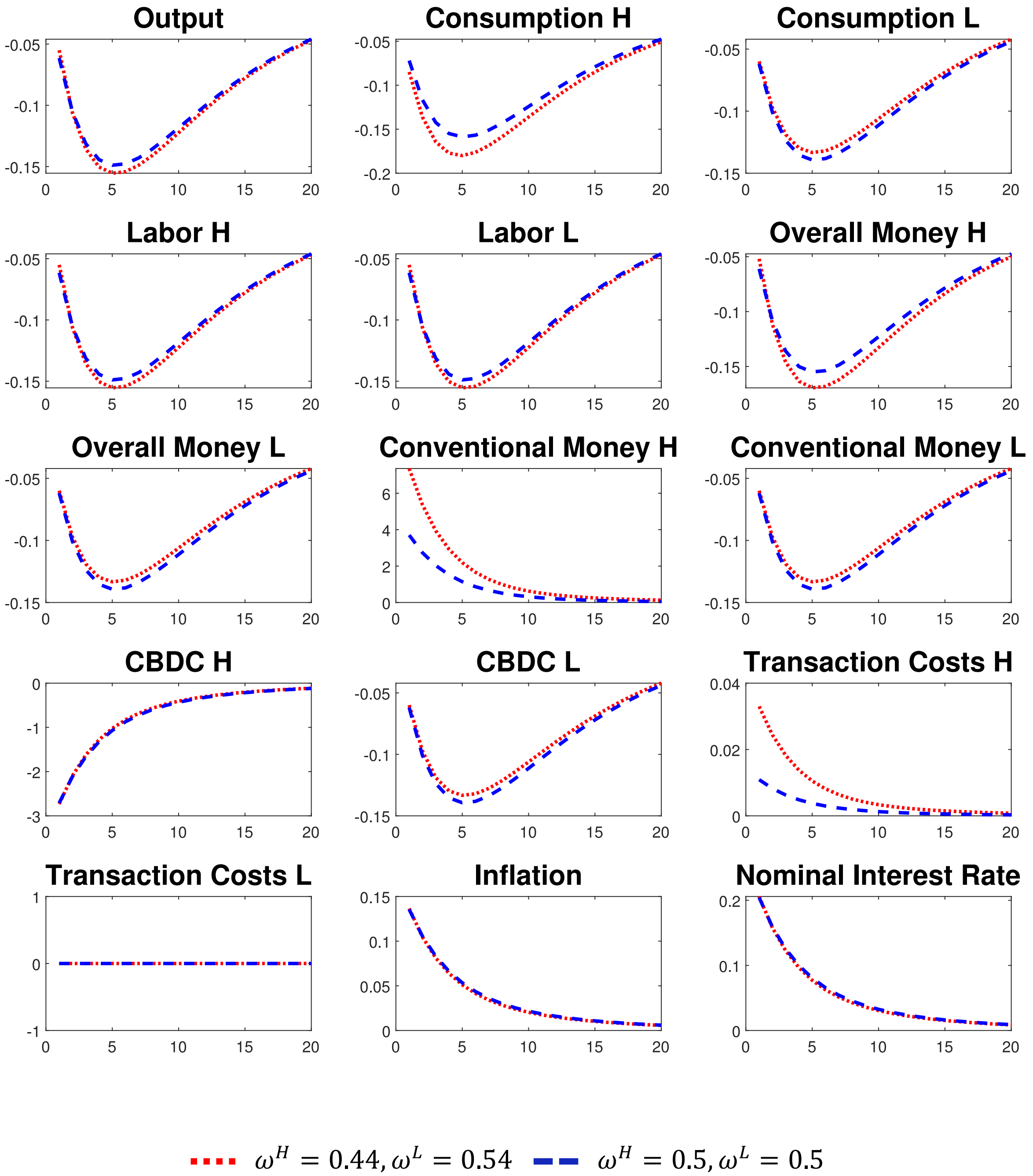

Fig. D.2. Impulse responses in the monetary policy regime to a 1% cost-push shock (A_t^k) with persistence $\rho_A = 0.9$ for different CBDC preferences.

Appendix E. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.intfin.2025.102161.

Data availability

No data was used for the research described in the article.

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