Central bank digital currency in an open economy

Massimo Ferrari
European Central Bank

Arnaud Mehl
European Central Bank
& CEPR

Livio Stracca
European Central Bank

2022 ASSA meeting
8 January 2022

Disclaimer: The views expressed in this paper are solely those of the authors and do not represent the views of either the ECB or the ESCB.

Introduction

Finance is evolving in the digital age

- ✓ Digital & private money (Diem, Tether...) prompt central banks to consider upgrading concept and provision of money

Finance is evolving in the digital age

- ✓ Digital & private money (Diem, Tether...) prompt central banks to consider upgrading concept and provision of money
- ✓ More than 80% of central banks worldwide are working towards a CBDC

Finance is evolving in the digital age

- ✓ Digital & private money (Diem, Tether...) prompt central banks to consider upgrading concept and provision of money
- ✓ More than 80% of central banks worldwide are working towards a CBDC
- ✓ *economically* a CBDC gives access to central bank reserves "for all" agents (not new! Tobin (1987), pre-WW2 experience)

Finance is evolving in the digital age

- ✓ Digital & private money (Diem, Tether...) prompt central banks to consider upgrading concept and provision of money
- ✓ More than 80% of central banks worldwide are working towards a CBDC
- ✓ *economically* a CBDC gives access to central bank reserves "for all" agents (not new! Tobin (1987), pre-WW2 experience)
- ✓ Several relevant *closed-economy* implications:

Finance is evolving in the digital age

- ✓ Digital & private money (Diem, Tether...) prompt central banks to consider upgrading concept and provision of money
- ✓ More than 80% of central banks worldwide are working towards a CBDC
- ✓ *economically* a CBDC gives access to central bank reserves "for all" agents (not new! Tobin (1987), pre-WW2 experience)
- ✓ Several relevant *closed-economy* implications:
  - → Equivalence result, Brunnermeier & Niepelt (2019)
  - → Impact on banking sector, Andolfatto (2021)
  - → Effects of different design alternatives & preferences, Agur et al. (2021) Auer & Boehme (2021)
  - → Financial stability issues, Fernández-Villaverde et al. (2020)
  - → Technical literature on design, Bindseil & Panetta (2020)

Our contribution

✓ Limited literature on the *open-economy* implications of CDBCs, Benigno et al. (2019), Ikeda (2020), George et al. (2020), Kumhof et al. (2021)

Our contribution

- ✓ Limited literature on the *open-economy* implications of CDBCs, Benigno et al. (2019), Ikeda (2020), George et al. (2020), Kumhof et al. (2021)

- ✓ We build a two-country macro model drawing from Eichenbaum et al (2021) and add a CBDC to the menu of monetary assets

Our contribution

- ✓ Limited literature on the *open-economy* implications of CDBCs, Benigno et al. (2019), Ikeda (2020), George et al. (2020), Kumhof et al. (2021)
- ✓ We build a two-country macro model drawing from Eichenbaum et al (2021) and add a CBDC to the menu of monetary assets
- ✓ CBDC choice is micro-founded in three dimensions: *preferences*, *liquidity*, *remuneration*

Our contribution

- ✓ Limited literature on the *open-economy* implications of CDBCs, Benigno et al. (2019), Ikeda (2020), George et al. (2020), Kumhof et al. (2021)

- ✓ We build a two-country macro model drawing from Eichenbaum et al (2021) and add a CBDC to the menu of monetary assets

- ✓ CBDC choice is micro-founded in three dimensions: *preferences*, *liquidity*, *remuneration*

- ✓ Main findings:

Our contribution

- ✓ Limited literature on the *open-economy* implications of CDBCs, Benigno et al. (2019), Ikeda (2020), George et al. (2020), Kumhof et al. (2021)

- ✓ We build a two-country macro model drawing from Eichenbaum et al (2021) and add a CBDC to the menu of monetary assets

- ✓ CBDC choice is micro-founded in three dimensions: *preferences*, *liquidity*, *remuneration*

- ✓ Main findings:
  - → Derive a new cross-country parity condition between interest rates, CBDC remuneration & exchange rates
  - → CBDC amplifies international spillovers of shocks
  - → Design features matter
  - → CBDC reduces monetary policy autonomy in foreign economies

The model

a. Preferences: augmented utility function

Household choose consumption (C), labor (L), M1 money (M), bond holdings (B,B^*), deposits (D) and CBDC (DC).

Intra-period utility is:

$$U_t = \exp\left(e_t^C\right) \ln(C_t - hC_{t-1}) - \frac{\chi}{1+\varphi} L_t^{1+\varphi} - \overbrace{\chi_{DC} \mathcal{G}\left(\frac{M_t}{M_t + DC_t}, \Gamma\right)}^{\text{Preferences over payment instruments}}$$

with $\exp\left(e_t^C\right)$ a preference shock

a. Preferences: augmented utility function

$$U_t = \exp\left(e_t^C\right) \ln(C_t - hC_{t-1}) - \frac{\chi}{1+\varphi} L_t^{1+\varphi} - \chi_{DC} \mathcal{G}\left(\frac{M_t}{M_t + DC_t}, \Gamma\right)$$

- ✓ χ_{DC} scale parameter
- ✓ $\frac{M_t}{M_t+DC_t}$ optimal cash/CBDC ratio **chosen** by households
- ✓ Γ **preferred** cash/CBDC ratio by households; this is driven by preferences over anonymity, payment habits and other tastes

a. Preferences: augmented utility function

$$U_t = \exp\left(e_t^C\right)\ln(C_t - hC_{t-1}) - \frac{\chi}{1+\varphi}L_t^{1+\varphi} - \chi_{DC}\mathcal{G}\left(\frac{M_t}{M_t + DC_t}, \Gamma\right)$$

→ $\mathcal{G}(\bullet)$ **utility loss** if $\Gamma \neq \frac{M_t}{M_t+DC_t}$

- ✓ $\mathcal{G}(0) = 0$, global minimum for $\frac{M_t}{M_t+DC_t} = \Gamma$
- ✓ $\mathcal{G}'(x_0)$ exists $\forall\ x_0 \in \mathbb{R}$ (differentiability)
- ✓ $\mathcal{G}(\bullet)' > 0$, $\mathcal{G}(\bullet)'' < 0$, (concavity)

→ **Intuition**: households have different members, some prefer paying with cash, the others with CBDC

b. Liquidity: CIA constraint

Households need liquidity to consume:

$$C_t = \mathcal{L}_t \left(M_t, DC_t, \right)$$

→ $\mathcal{L}(\bullet)$ liquidity aggregator of cash and CBDC

- ✓ in baseline $\mathcal{L}'_{M_t}(x_0) = \mathcal{L}'_{DC_t}(x_0)$ (same marginal liquidity)
- ✓ in extensions $\mathcal{L}'_{M_t}(x_0) > \mathcal{L}'_{DC_t}(x_0)$; $\mathcal{L}'_{M_t}(x_0) < \mathcal{L}'_{DC_t}(x_0)$

→ **Intuition**: households need liquidity services to make transactions, CBDC and cash are (imperfect) substitutes

c. Remuneration: budget constraint

Households balance returns across all asset classes to smooth consumption across periods:

$$P_t C_t + B_t^H + NER_t B_t^F + D_t + M_t + DC_t \leq W_t L_t +$$
$$+ R_t B_{t-1}^H + R_t^* NER_t B_{t-1}^F - \frac{\phi^B}{2} \left(\frac{NER_t B_t^F}{P_t} \right)^2 P_t +$$
$$+ D_{t-1} R_t^D + \xi^\$ M_{t-1} + R_t^{DC} DC_{t-1} + \Pi_t$$

→ households balance returns on cash, bonds (domestic and foreign) deposits and CBDC

→ $\xi^\$$ storage cost for cash ($= 1$ in baseline)

→ $R^{DC} = 1$ in baseline (no remuneration on CBDC)

→ $\phi^B > 0$ cross-country bond holding costs (imperfect risk-sharing, UIP fails)

Optimal CBDC demand

Preferences, liquidity, remuneration (relative to other assets) all matter:

$$\overbrace{\mathcal{L}'_{DC,t}\gamma_t}^{\substack{\text{Value of}\\ \text{liquidity services}}} \quad - \underbrace{\chi_{DC}\mathcal{G}'_{DC,t}}_{\text{Utility loss}} = \lambda_t - E_t \overbrace{\left(\beta R_t^{DC} \frac{\lambda_{t+1}}{\pi_{t+1}}\right)}^{\text{Expected returns}}$$

Similar setting with key differences

- ✓ No CBDC in the foreign country, foreign household can buy the CBDC issued in the domestic country
- ✓ Exchange rate value effects matter when choosing CBDC demand in the foreign economy
- ✓ There are costs (≈ transaction limits) in cross-border CBDC transactions ($\phi^*_{DC}\left(DC^*_t, NER_t\right)$)

Optimality condition

$$\overbrace{\mathcal{L}^{*,\prime}_{DC,t}\gamma^*_t}^{\substack{\text{Value of}\\ \text{liquidity services}}} - \overbrace{\chi^*_{DC}\mathcal{G}^{*,\prime}_{DC,t}}^{\text{Utility loss}} =$$

$$\underbrace{\lambda^*_t \phi^{*,\prime}_{DC}\left(DC^*_t, NER_t\right)}_{\substack{\text{Limits to}\\ \text{cross-border transactions}}} + \frac{\lambda^*_t}{NER_t} - E_t \underbrace{\left(\beta^* \frac{\lambda^*_{t+1}}{NER_{t+1}} \frac{R^{DC}_t}{\pi^*_{t+1}}\right)}_{\text{Expected returns}}$$

The key mechanism

Combining CBDC and bond demands in the foreign economy leads to a (linearized) new UIP condition:

$$r_t^* = r_t^{DC} + ner_t - E_t ner_{t+1} + m_t$$

where m_t is a mark-up depending on liquidity services (↑), preferences for cash (↓) and cross-border costs (↓). $r_t^{DC} = 0 \forall t$ (CBDC not remunerated in baseline).

Implications:

→ if $E_t ner_{t+1} > 0$, $ner_t < 0$ (stronger FX overshooting)

→ if $E_t ner_{t+1} > 0$, $r_t^* < 0$ (stronger policy response)

→ if $r_t^{DC} \neq 0$, above effects should be smaller

Derivations. Comparison with standard UIP.

Results

TFP shock in the domestic economy

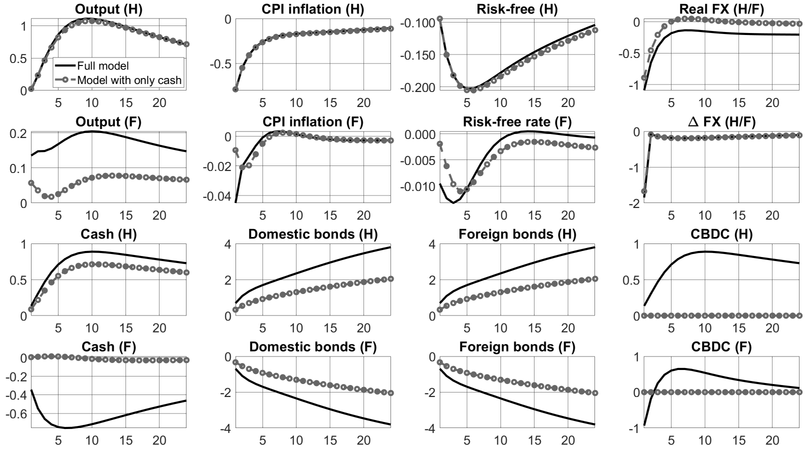


Figure: Response of selected variables to a one standard deviation expansionary total factor productivity shock in the domestic economy. Solid lines refer to the baseline calibration with a CBDC, dashed lines with circles to a simulation without a CBDC. **Notes**: Responses are reported in deviations from the steady state.

Alternative design choices

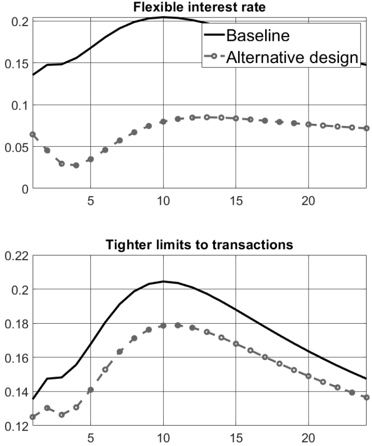


Figure: Response of foreign output to a one standard deviation expansionary total factor productivity shock in the domestic economy under alternative CBDC designs. **Notes**: Responses are reported in deviations from the steady state.

Optimal monetary policy with and without CDBC

	No CBDC	Fixed interest rate	Flexible interest rate	Marked-down interest rate
		Domestic economy		
γ	0.001	0.001	0.001	0.001
θ_π	3.57	4.00	3.60	4.00
θ_y	0.00	0.17	0.00	0.00
$\Delta E(\mathcal{W})$	0.00	7.40	1.02	1.21
		Foreign economy		
γ^*	0.823	0.827	0.832	0.830
θ_π^*	1.20	4.00	4.00	4.00
θ_y^*	0.33	2.26	2.65	2.67
$\Delta E(\mathcal{W})$	0.00	-40.65	-17.04	-14.90
C.E.	0.00	-1.00	-0.99	-1.00

Notes: Optimal parameters of the monetary policy rule for different CBDC designs: col. (1) baseline model (without CBDC); col. (2) CBDC with a fixed interest rate; col. (3) CBDC with a flexible (Taylor rule) interest rate; col. (4) CBDC with a marked-down interest rate. The key parameters optimized are interest rate smoothing (γ), sensitivity to inflation (θ_π) and sensitivity to output (θ_y). Welfare is computed as the stochastic mean of the welfare function $\mathcal{W}_t = U_t + \beta E_t(\mathcal{W}_{t+1})$ at the second order with pruning.

Conclusions

- ✓ CBDC amplifies international spillovers of shocks
- ✓ Technical design features matter
  - Capital controls and flexible CBDC interest rate reduce spillovers
  - Quantitative restrictions less effective than interest rate flexibility
- ✓ CBDC increases asymmetries in the international monetary system
- ✓ CBDC reduces monetary policy autonomy in foreign economy (stronger reaction to output and inflation)
- ✓ Extensions:
  - monetary policy shock
  - different preferences; χ_{DC}; ξ
  - zero lower bound
  - optimization of CBDC remuneration rule

Thank you!
Questions?

contact: massimo.ferrari1@ecb.europa.eu

Appendix

Andolfatto, D., 2021. *Assessing the Impact of Central Bank Digital Currency on Private banks.* The Economic Journal 131, 525–540.

Agur, I., Ari, A., Dell'Ariccia, G., 2021. *Designing Central Bank Digital Currencies.* Journal of Monetary Economics.

Auer, R., Boehme, R., 2020. *The Technology of Retail Central Bank Digital Currency.* BIS Quarterly Review March, 85–100.

Benigno, P., Schilling, L.M., Uhlig, H., 2019. *Cryptocurrencies, Currency Competition, and the Impossible Trinity.* NBER Working Papers 26214.

Bindseil, U., Panetta, F., 2020. *Central Bank Digital Currency Remuneration in a World with Low or Negative Nominal Interest Rates.* VoxEU.

Brunnermeier, M.K., Niepelt, D., 2019. *On the Equivalence of Private and Public Money.* Journal of Monetary Economics 106, 27–41.

Ferńandez-Villaverde, J., Sanches, D., Schilling, L., Uhlig, H., 2021. *Central Bank Digital Currency: Central Banking for All?* Review of Economic Dynamics 41, 225–242.

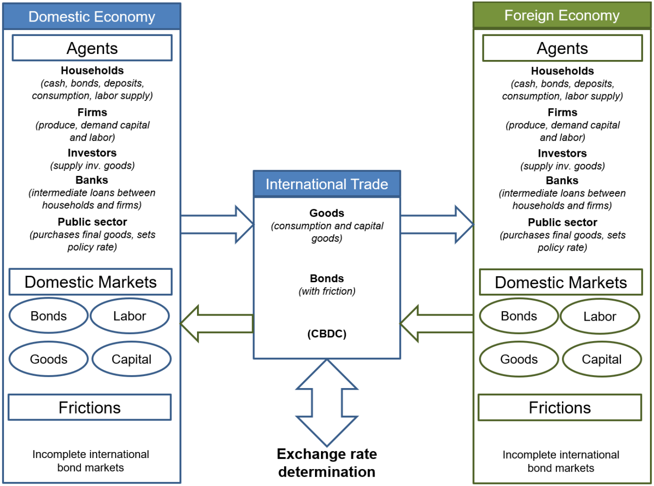
Eichenbaum, M., Johannsen, B.K., Rebelo, S., 2021. *Monetary Policy and the Predictability of Nominal Exchange Rates.* Review of Economic Studies 88, 192–228.

George, A., Xie, T., Alba, J., 2018. *Central bank digital currency with adjustable interest rate in small open economies.* mimeo.

Kumhof, M., Rungcharoenkitkul, P., Pinchetti, M., Sokol, A., (2021). *Central bank digital currencies, exchange rates and gross capital flows*, mimeo.

Ikeda, D., 2020. *Digital Money as a Unit of Account and Monetary Policy in Open Economies*. IMES Discussion Paper Series 20-E-15. Institute for Monetary and Economic Studies, Bank of Japan.

Model's chart



Go back

Derivation of key mechanism

Consider the FOCs for bonds and CBDC in the foreign economy:

$$R_t^* = E_t\left(\frac{\lambda_t^*}{\lambda_{t+1}^*}\frac{\pi_{t+1}^*}{\beta^*}\right)$$

$$E_t\left(\frac{\lambda_t^*}{\lambda_{t+1}^*}\frac{\pi_{t+1}^*}{\beta^*}\right) =$$

$$R_t^{DC} E_t\left(\frac{NER_t}{NER_{t+1}}\right)\left[1+\chi_{DC}^*\frac{\mathcal{G}_{DC,t}^{*,\prime} NER_t}{\lambda_t^*}-\frac{\mathcal{L}_{DC,t}^{*,\prime} NER_t\gamma_t^*}{\lambda_t^*}+\phi^{*,DC}\frac{DC_t^*}{NER_t}\right]^{-1}$$

Equating $E_t\left(\frac{\lambda_t^*}{\lambda_{t+1}^*}\frac{\pi_{t+1}^*}{\beta^*}\right)$ allows to link the domestic interest rate and the CBDC rate.

◂ Go back

Derivation of key mechanism, con't

$$R_t^* =$$

$$R_t^{DC} E_t \left(\frac{NER_t}{NER_{t+1}} \right) \left[1 + \chi_{DC}^* \frac{\mathcal{G}_{DC,t}^{*,\prime} NER_t}{\lambda_t^*} - \frac{\mathcal{L}_{DC,t}^{*,\prime} NER_t \gamma_t^*}{\lambda_t^*} + \phi^{*,DC} \frac{DC_t^*}{NER_t} \right]^{-1}$$

taking logs:

$$\ln R_t^* = \ln R_t^{DC} + \ln NER_t - E_t(\ln NER_{t+1}) +$$
$$- \ln \left[1 + \chi_{DC}^* \frac{\mathcal{G}_{DC,t}^{*,\prime} NER_t}{\lambda_t^*} - \frac{\mathcal{L}_{DC,t}^{*,\prime} NER_t \gamma_t^*}{\lambda_t^*} + \phi^{*,DC} \frac{DC_t^*}{NER_t} \right]$$

and the mark-up μ_t is defined as:
$\left[1 + \chi_{DC}^* \frac{\mathcal{G}_{DC,t}^{*,\prime} NER_t}{\lambda_t^*} - \frac{\mathcal{L}_{DC,t}^{*,\prime} NER_t \gamma_t^*}{\lambda_t^*} + \phi^{*,DC} \frac{DC_t^*}{NER_t} \right]$.

Go back

Comparison with standard UIP on bonds

Log-linearized UIP implies (with $\phi^{*,B} \approx 0$):

$$r_t^* - r_t = ner_t - E_t ner_{t+1}$$

The log-linearized UIP equation for the CBDC is:

$$r_t^* - r_t^{DC} = ner_t - E_t ner_{t+1} + m_t$$

Notice that:

- ✓ In standard UIP both r_t^* and r_t adjust
- ✓ In CBDC UIP only r_t^* can adjust adjust
- ✓ In CBDC UIP movements are amplified by the mark-up m_t
- ✓ Spillovers with CBDC are amplified

◂ Go back

Monetary policy shock in the domestic economy

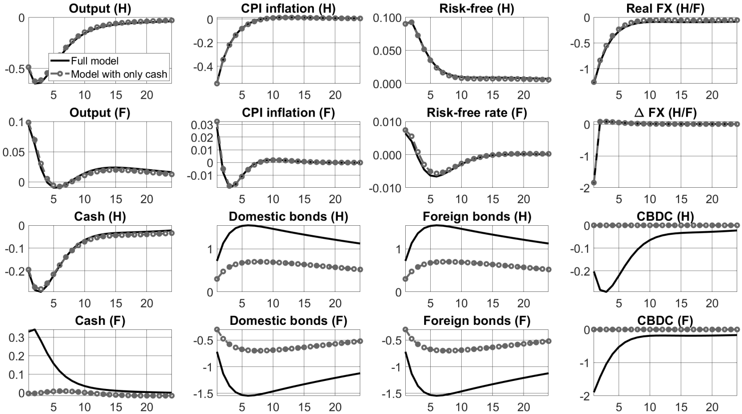


Figure: Response of selected variables to a one standard deviation contractionary monetary policy shock in the domestic economy.

Notes: Responses are reported in deviations from the steady state. Solid lines refer to the baseline calibration with a CBDC, dashed lines with circles to simulations without a CBDC. Go back.

Different preferences for CBDC (Γ)

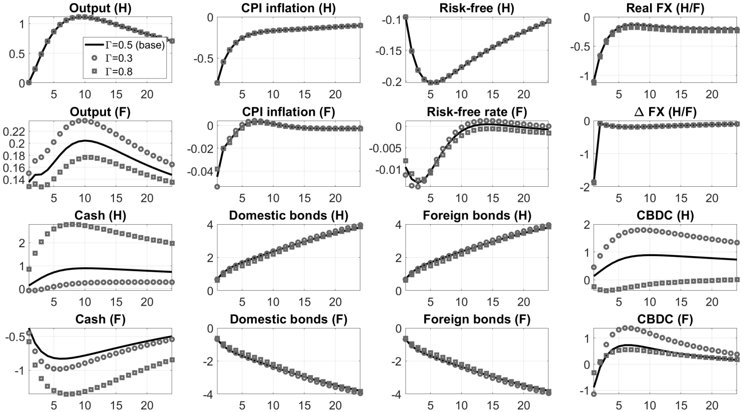


Figure: Response of selected variables to a one standard deviation expansionary total factor productivity shock in the domestic economy.

Notes: Responses are reported in deviations from the steady state. Go back.

Loading for CBDC in utility (χ_{dc})

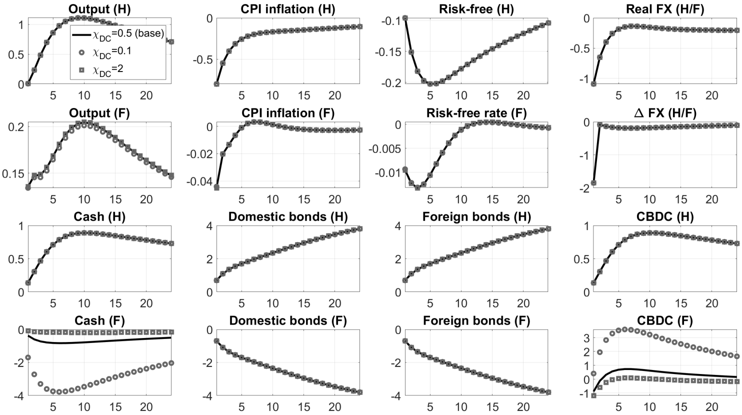


Figure: Response of selected variables to a one standard deviation expansionary total factor productivity shock in the domestic economy.

Notes: Responses are reported in deviations from the steady state. ◂ Go back.

Storage cost for money (ξ)

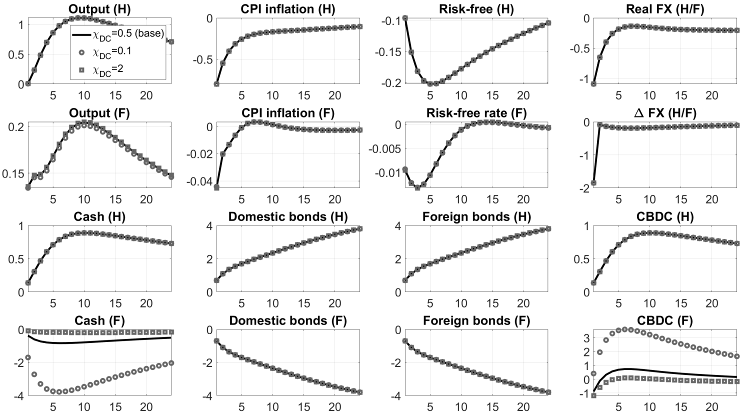


Figure: Response of selected variables to a one standard deviation expansionary total factor productivity shock in the domestic economy.

Notes: Responses are reported in deviations from the steady state. Go back.

Simulations at the zero lower bound

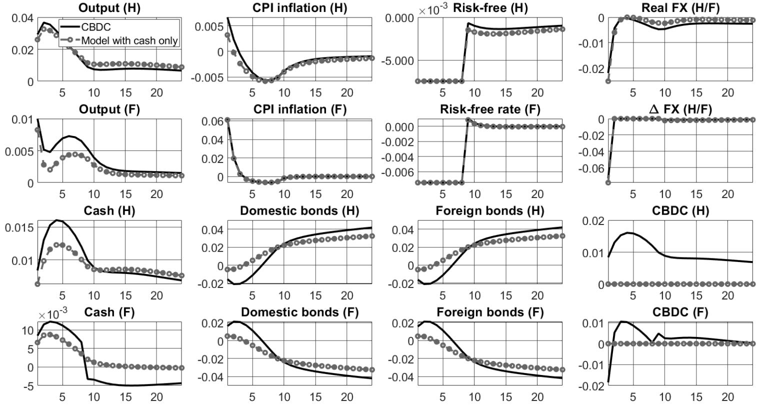


Figure: Response of selected variables to a 1% expansionary total factor productivity shock in the domestic economy. Solid lines refer to the baseline calibration with a CBDC, dashed lines with circles to a simulation without a CBDC. **Notes**: Responses are reported in deviations from the steady state. The model is simulated assuming that the ZLB binds on impact and then for 2 years. Go back.

Optimal CBDC remuneration rule

The Taylor rule and the CBDC remuneration rule are:

$$\ln R_t = (1-\varrho)\ln R_{t-1} + \varrho\left[R_{ss} + \theta_\pi \ln \pi_t + \theta_y\left(\ln Y_t - \ln Y_{ss}\right)\right] + \mathcal{E}_t$$

$$\ln R_t^{DC} = (1-\varrho_{DC})\ln R_{t-1}^{DC} + \varrho_{DC}\left[R_{ss}^{DC} + \theta_\pi^{DC}\ln \pi_t + \theta_y^{DC}\left(\ln Y_t - \ln Y_{ss}\right)\right]$$

	ϱ_{DC}	θ_π^{DC}	θ_y^{DC}	θ_Q^{DC}	ϱ	θ_π	θ_y
CBDC interest rate rule	0.506	0.230	1.056	0.294			
CBDC and monetary policy rules	0.947	2.714	1.6902	-0.031	0.001	1.561	0.000

Notes: Optimal parameters of the CBDC interest-rate rule and the monetary policy rule for the domestic economy. Welfare is computed as the stochastic mean of the welfare function $\mathcal{W}_t = U_t + \beta E_t(\mathcal{W}_{t+1})$ at the second order with pruning. When the interest rate on CBDC is optimized alone, we keep the parameters of the monetary policy rule at their baseline calibration.

◂ Go back