The optimal quantity of CBDC in a bank-based economy

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EEA-ESEM 2022

22 August 2022

Milan, Italy

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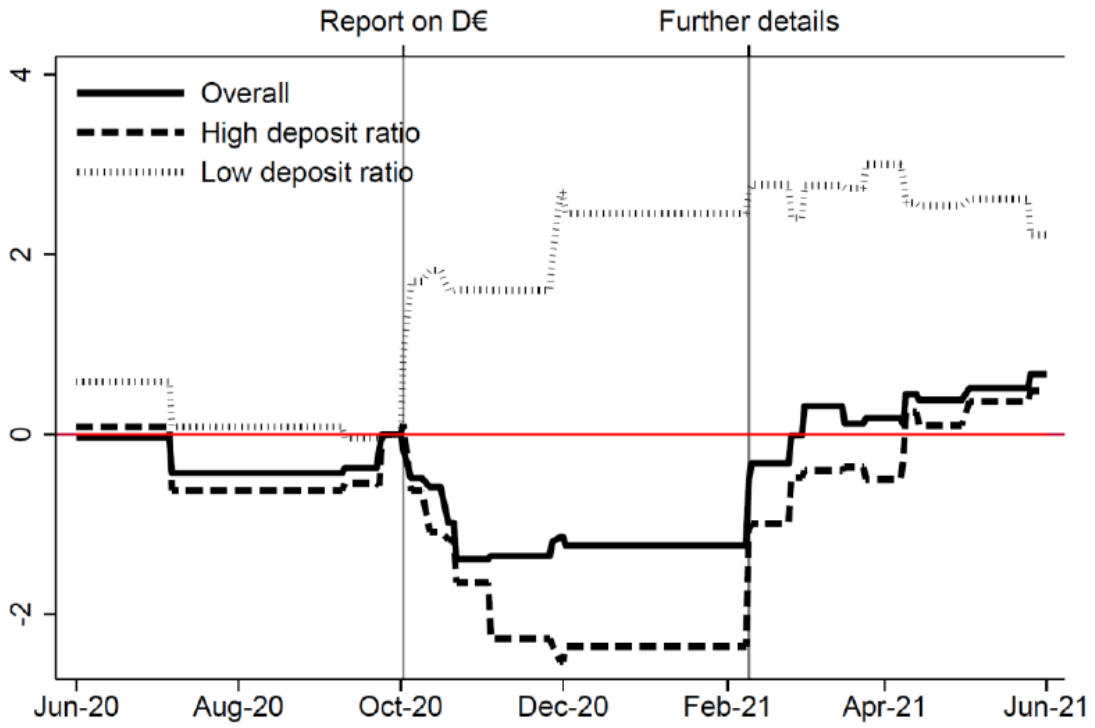
Overview

1. Motivation: Empirical Evidence
2. Model, Calibration, and Transmission Mechanism
3. Quantitative Welfare Analysis
4. Conclusions

Empirical Evidence: Event study and cross-sectional analysis

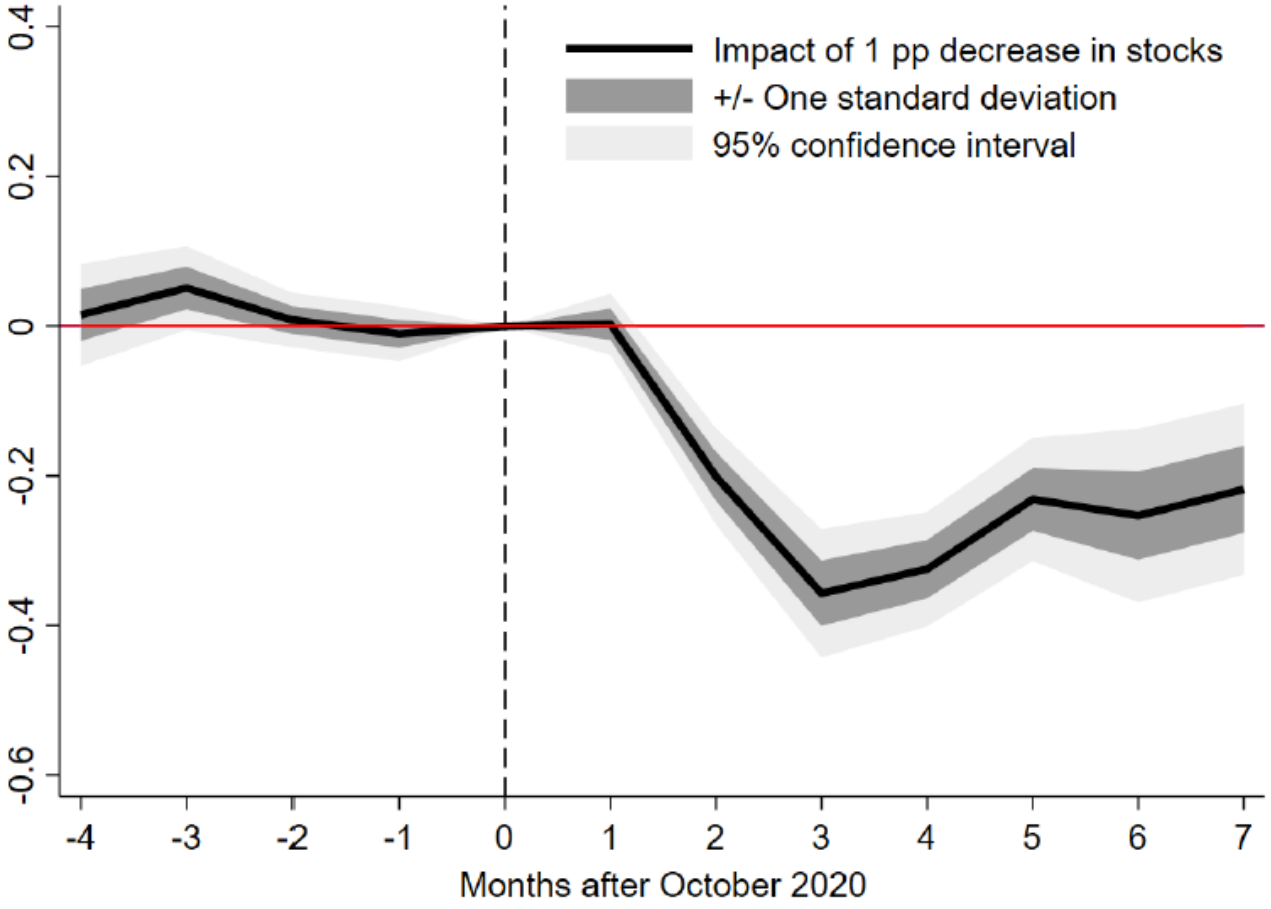
Figure 1: Stock market reactions to CBDC news by euro area banks (percentage points)



- Initial negative reactions related to perceived risks of deposit substitution.
- Magnitude of response dependent on deposit funding reliance.
- Recovery as information on safeguards to calibrate CBDC supply was conveyed.
- **Main takeaway**: expected impact on banks crucially depends on deposit reliance and design features aimed at controlling CBDC supply.

Empirical Evidence: Impact assessment

Figure 2: Change in loan volumes to firms associated with reactions of bank stock prices (percentages of volumes in October 2020)



The Model: The environment

- Monetary, closed, time-discrete, decentralized economy.

- **Savers** (patient households) hold a variety of assets:
  - **deposits, cbdc, cash**, gov. bonds
- Borrowers get indebted against housing collateral (Iacoviello, 2005)
  - Impatient households
  - Entrepreneurs:
    - Managers
    - Retailers: Price-setters à la Calvo (1983)
- **Banks**
  - Intermediate between patient HHs and impatient HHs & NFCs (deposits – loans)
  - Capital and liquidity requirements: Iacoviello (2015), Brunnermeier and Koby (2019)
  - Borrow from central bank against government bonds as collateral

- Capital and Final Goods Producers
- Public Sector
  - **Government**
  - **Central Bank**

The Model: Patient Households

- The representative patient household seeks to maximize

$$E_0 \sum_{t=0}^{\infty} \beta_p^t \left[u\left(c_{p,t}, h_{p,t}, n_{p,t}, z_t\right) \right]$$

where

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

- Subject to

$$c_{p,t} + q_t(h_{p,t} - h_{p,t-1}) + m_t + f(m_t) + cbdc_t + d_t + b_{p,t} + \theta_T T_t = \frac{m_{t-1}}{\pi_t} + R_{cbdc,t-1}\frac{cbdc_{t-1}}{\pi_t} + R_{d,t-1}\frac{d_{t-1}}{\pi_t} + R_{g,t-1}\frac{b_{p,t-1}}{\pi_t} + w_t n_{p,t} + \Omega_{e,t} + \Omega_{b,t}$$

CBDC is technologically superior to cash

$$f(m_t) = \left(\frac{\psi_m}{2} m_t^2\right)$$

The Model: Banks

- Banks seek to maximize

$$E_0 \sum_{t=0}^{\infty} \Lambda_{t,t+1} \left[f\left(\Omega_{b,t}\right) \right]$$

- Subject to

1. **Balance sheet identity**

$$L_t + b_{b,t} + \widetilde{R}_{b,t} = e_t + D_t + f_t$$

1. **Cash-flow restriction** (bank profits)

$$\Omega_{b,t} + e_t - (1-\delta_e)\frac{e_{t-1}}{\pi_t} = \frac{\left(r_{i,t-1} L_{i,t-1} + r_{e,t} L_{e,t-1} + r_{g,t-1} b_{b,,t-1} + r_{\widetilde{R},t-1} \widetilde{R}_{b,t-1} - r_{d,t-1} D_{t-1} - r_{f,t-1} f_{t-1} \right)}{\pi_t}$$

2. **Borrowing constraint** (capital requirements)

$$D_t + f_t \leq \gamma_i L_{i,t} + \gamma_e L_{e,t} + \gamma_b b_{b,t} + \gamma_R \widetilde{R}_{b,t}$$

3. **Liquidity (reserves) requirements**

$$\theta_{R,t} D_t \leq \widetilde{R}_{b,t}$$

4. **Central bank collateral requirements**

$$f_t \leq \theta_{b,t} E_t \left(\frac{b_{b,t}}{R_{f,t}} \pi_{t+1} \right)$$

The Model: Government

- Government expenditure:

$$G_t = \varrho Y^{ss}$$

- Government intertemporal budget constraint:

$$R_{g,t-1}\frac{B_{g,t-1}}{\pi_t} + G_t = T_t + B_{g,t} + \Omega_{cb,t}$$

- Fiscal feedback rule:

$$T_t = \phi_p b_{p,t-1} + \phi_b b_{b,t-1}$$

The Model: Central Bank

- Lending rate (Taylor Rule):

$$r_{f,t} = \rho_r r_{f,t-1} + (1-\rho_r)\left(r_f^{ss} + \alpha_\pi \tilde{\pi}_t + \alpha_Y \tilde{y}_t\right) + e_{rf,t}$$

- Deposit facility rate

$$r_{\widetilde{R},t} = r_{f,t} - \mu$$

- Balance sheet

$$F_t = \widetilde{R}_t + M_t + CBDC_t$$

- Central bank profits

$$\Omega_{cb,t} = \widetilde{R}_t + M_t + CBDC_t + R_{f,t-1}\frac{F_{t-1}}{\pi_t} - R_{\widetilde{R},t-1}\frac{\widetilde{R}_{t-1}}{\pi_t} - \frac{M_{t-1}}{\pi_t} - R_{cbdc,t-1}\frac{cbdc_{t-1}}{\pi_t} - F_t$$

- **CBDC policy rule (baseline)**

$$CBDC_t = \phi_{Y,t} Y^{ss}$$

Calibration in the three steps: first moments

Table 5: Steady state ratios

Variable	Description	Model	Data
Bank statistics			
l_i^{ss}/Y^{ss}	HH loans-to-GDP ratio	2.0431	2.0918
l_e^{ss}/Y^{ss}	NFC loans-to-GDP ratio	1.7585	1.7820
b_b^{ss}/Y^{ss}	Bank government bonds-to-GDP ratio	0.6825	0.6473
l_i^{ss}/A^{ss}	HH loans-to-bank assets ratio	0.4243	0.4313
l_e^{ss}/A^{ss}	NFC loans-to-bank assets ratio	0.3652	0.3675
$\widetilde{R}_b^{ss}/A^{ss}$	Reserves-to-bank assets ratio	0.0671	0.0677
$b_b^{ss}//A^{ss}$	Bank government bonds-to-bank assets ratio	0.1417	0.1335
D^{ss}/A^{ss}	Deposits-to-bank assets ratio	0.7877	0.8081
f^{ss}/A^{ss}	Central bank funding-to-bank assets ratio	0.1400	0.0861
e^{ss}/l^{ss}	Equity-to-risk weighted assets ratio	0.0916	0.1050
Central bank statistics			
$\widetilde{R}^{ss}/Y^{ss}$	Reserves-to-GDP ratio	0.3315	0.3284
M^{ss}/Y^{ss}	Cash-to-GDP ratio	0.3428	0.3443
$\widetilde{R}^{ss}/F^{ss}$	Reserves-to-CB assets ratio	0.4917	0.4882
M^{ss}/F^{ss}	Cash-to-CB assets ratio	0.5083	0.5118
Macroeconomic statistics			
C^{ss}/Y^{ss}	Private consumption-to-GDP ratio	0.5549	0.5479
I^{ss}/Y^{ss}	Gross fixed capital formation-to-GDP ratio	0.2125	0.2124
G^{ss}/Y^{ss}	Public consumption-to-GDP ratio	0.2070	0.2070

Note: All series in Euros are seasonally adjusted and deflated. Data targets have been constructed from euro area quarterly data for the period 2000:I-2021:II. The exception is the target for the bank capital-to-risk weighted assets, which has been based on the Basel III regime. Abreviations HH, NFC refer to households, and non-financial corporations (entrepreneurs), respectively.Data sources are Eurostat and ECB.

Calibration in the three steps: first moments (cont'd)

Table 6: Steady state rates and spreads

Variable	Description	Model	Data
$(r_{le}^{ss} - r_d^{ss})x\ 400$	Annualized Bank lending (to NFCs) spread	3.2316	3.0474
$(r_f^{ss} - r_R^{ss})x\ 400$	Annualized lending-deposit facility corridor	2.3600	1.3860
$(r_R^{ss} - r_d^{ss})x\ 400$	Annualized Reserves-deposits spread	0.2682	0.2650
$r_d^{ss}\ x\ 400$	Annualized interest rate on bank deposits	2.2376	2.3000
$(\bar{\pi} - 1)\ x\ 400$	Inflation target	2.0000	2.0000

Note: Data targets for spreads and interest rates have been constructed from euro area quarterly data. While the period for which data targets for spreads have been constructed is 2000:I-2021:II, as standard in this strand of the macro-banking literature, the data target for the nominal interest rate on bank deposits is based on the pre-crisis period. The data target for the inflation target corresponds to the quantitative definition of the ECB's price stability objective. Abreviation NFC refers to non-financial corporations (entrepreneurs). Data sources are Eurostat and ECB.

Calibration in the three steps: second moments

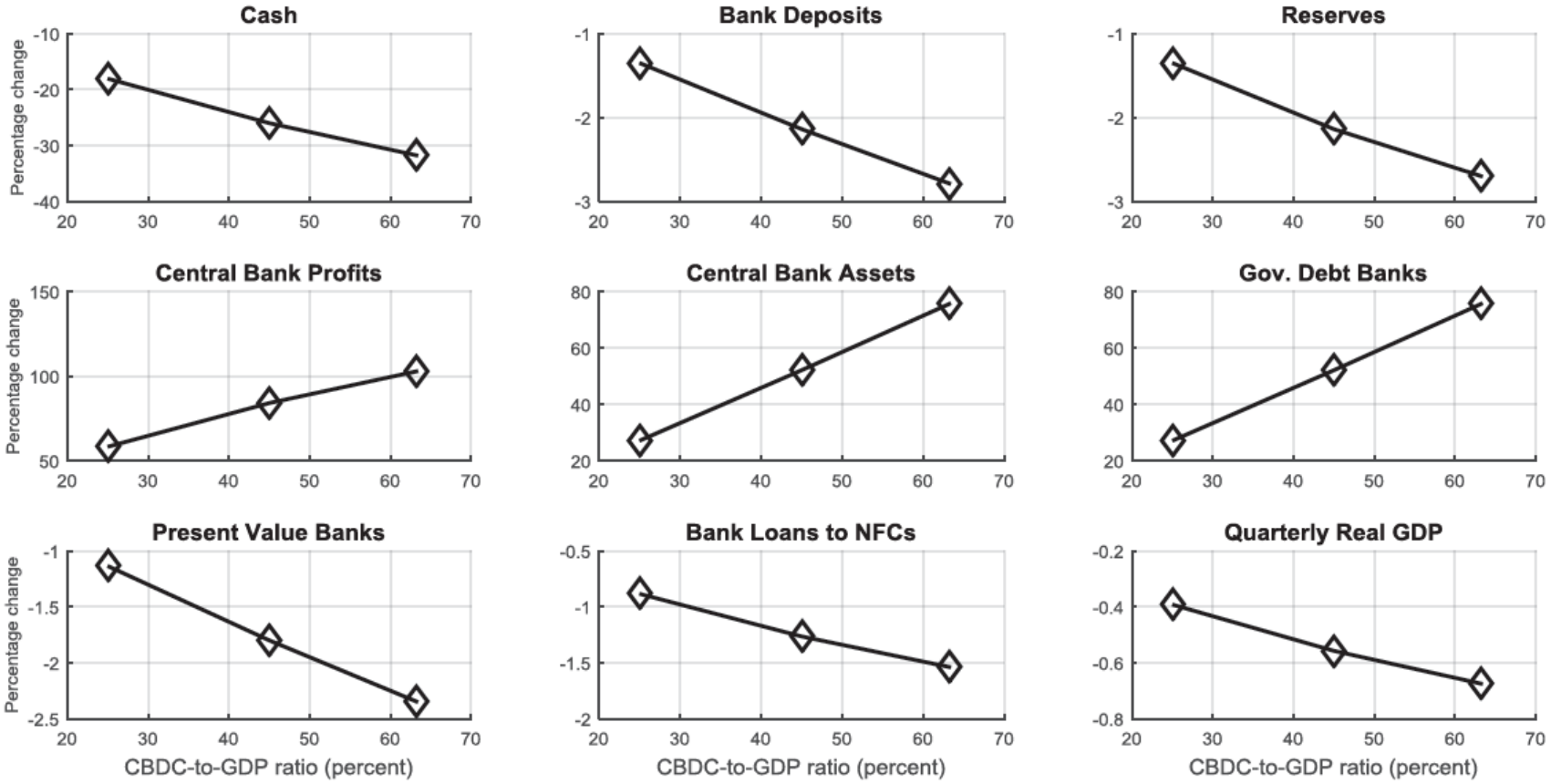
Table 8: Second moments (relative volatilities)

Variable	Description	Model	Data
Bank statistics			
$\sigma_{\Omega_b} \ / \ \sigma_Y$	Std. bank dividends/Std(GDP)	9.7168	9.6434
$\sigma_L \ / \ \sigma_Y$	Std.bank loans/Std(GDP)	2.3979	2.4741
$\sigma_e \ / \ \sigma_Y$	Std. bank capital/Std(GDP)	2.1877	2.8820
$\sigma_D \ / \ \sigma_Y$	Std. bank deposits/Std(GDP)	2.7164	2.4620
$\sigma_{r_d} \ / \ \sigma_Y$	Std. bank deposit interest rate/Std(GDP)	5.1142	7.1691
Central bank statistics			
$\sigma_M \ / \ \sigma_Y$	Std. banknotes/Std(GDP)	3.2769	2.6871
$\sigma_R \ / \ \sigma_Y$	Std. reserves/Std(GDP)	11.9641	11.8348
$\sigma_F \ / \ \sigma_Y$	Std. central bank assets/Std(GDP)	5.2022	5.0259
Macroeconomic statistics			
$\sigma_I \ / \ \sigma_Y$	Std. investment/Std(GDP)	2.5411	2.0193
$\sigma_C \ / \ \sigma_Y$	Std consumption/Std(GDP)	0.8208	1.1626
$\sigma_Y \ x \ 100$	Std(GDP) x 100	3.3593	3.3368

Note: Series expressed in Euro amounts are seasonally adjusted and deflated, and their log value has been linearly detrended before computing standard deviation targets.These data targets have been constructed from euro area quarterly data for the period 2000:I-2021:II. For each variable, its relative volatility has been computed by dividing its standard deviation (Std) by the standard deviation of quarterly real GDP. The standard deviation of GDP is in quarterly percentage points. The standard deviation of bank dividends has been taken from the dataset used in Muñoz (2021).

Steady state impact of CBDC issuance

Figure 3: Transmission and steady state effects of CBDC issuance



Transmission channels: Balance sheet adjustments (CBDC/Y = 0.00)

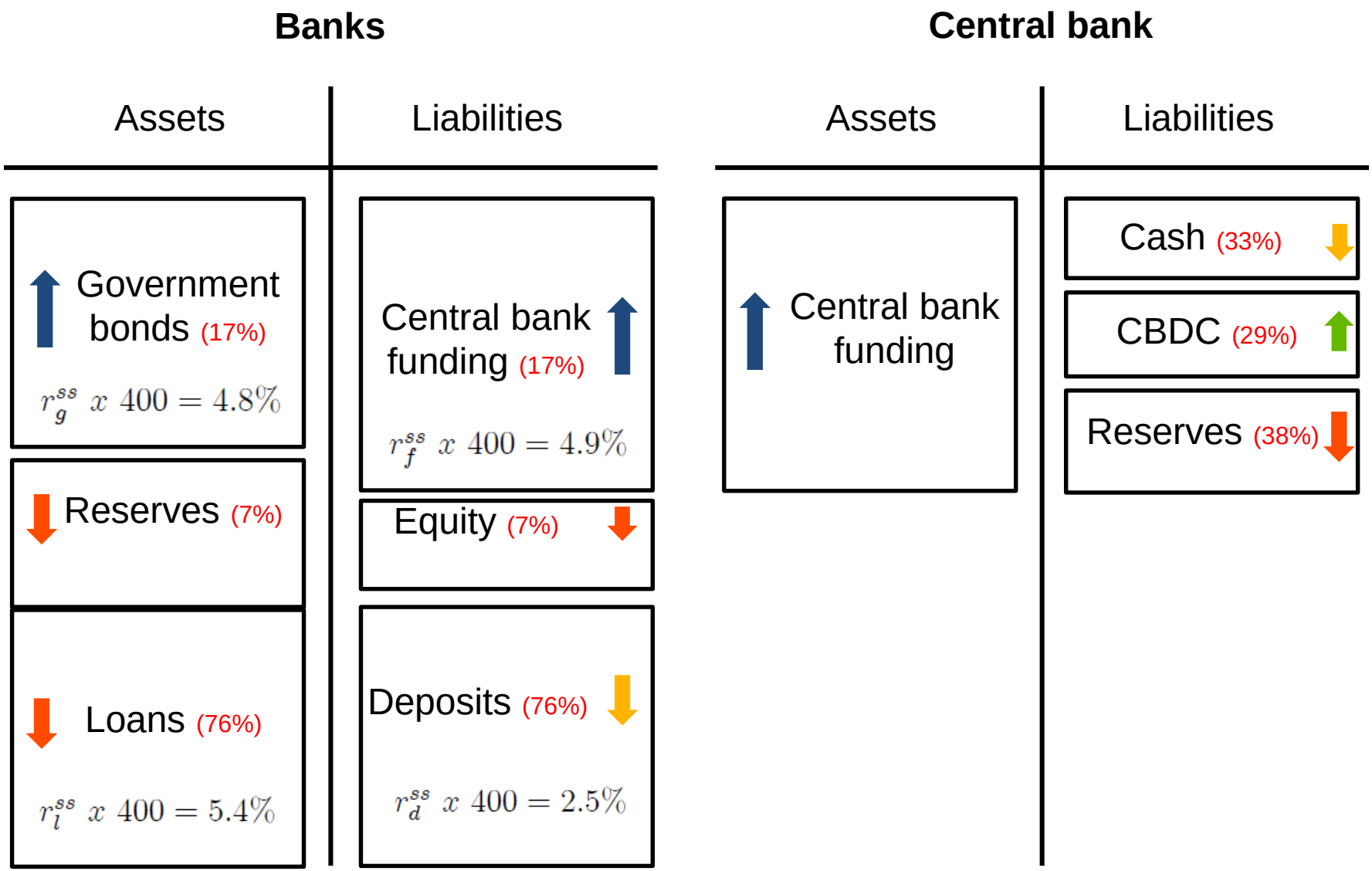
Banks

Assets	Liabilities
Government bonds (14%) $r_g^{ss} \; x \; 400 = 4.9\%$	Central bank funding (14%) $r_f^{ss} \; x \; 400 = 4.8\%$
Reserves (7%) $r_R^{ss} \; x \; 400 = 2.5\%$	Equity (7%)
Loans (79%) $r_l^{ss} \; x \; 400 = 5.1\%$	Deposits (79%) $r_d^{ss} \; x \; 400 = 2.2\%$

Central bank

Assets	Liabilities
Central bank funding	Cash (51%)
	Reserves (49%)

Transmission channels: Balance sheet adjustments (CBDC/Y = 0.25)



CBDC Policy Scenarios

- Baseline scenario

$$CBDC_t = 0$$

- CBDC policy scenarios

  - **CBDC quantity rules**

    (i) $$CBDC_t = \phi_Y Y_t$$

    (ii) $$CBDC_t = \phi_Y Y^{ss}$$

    (iii) $$CBDC_t = \rho_{cbdc} CBDC_{t-1} + (1 - \rho_{cbdc}) \left[\phi_Y Y^{ss} + \phi_X \widetilde{X}_t \right]$$

  - **CBDC Interest rate rules**

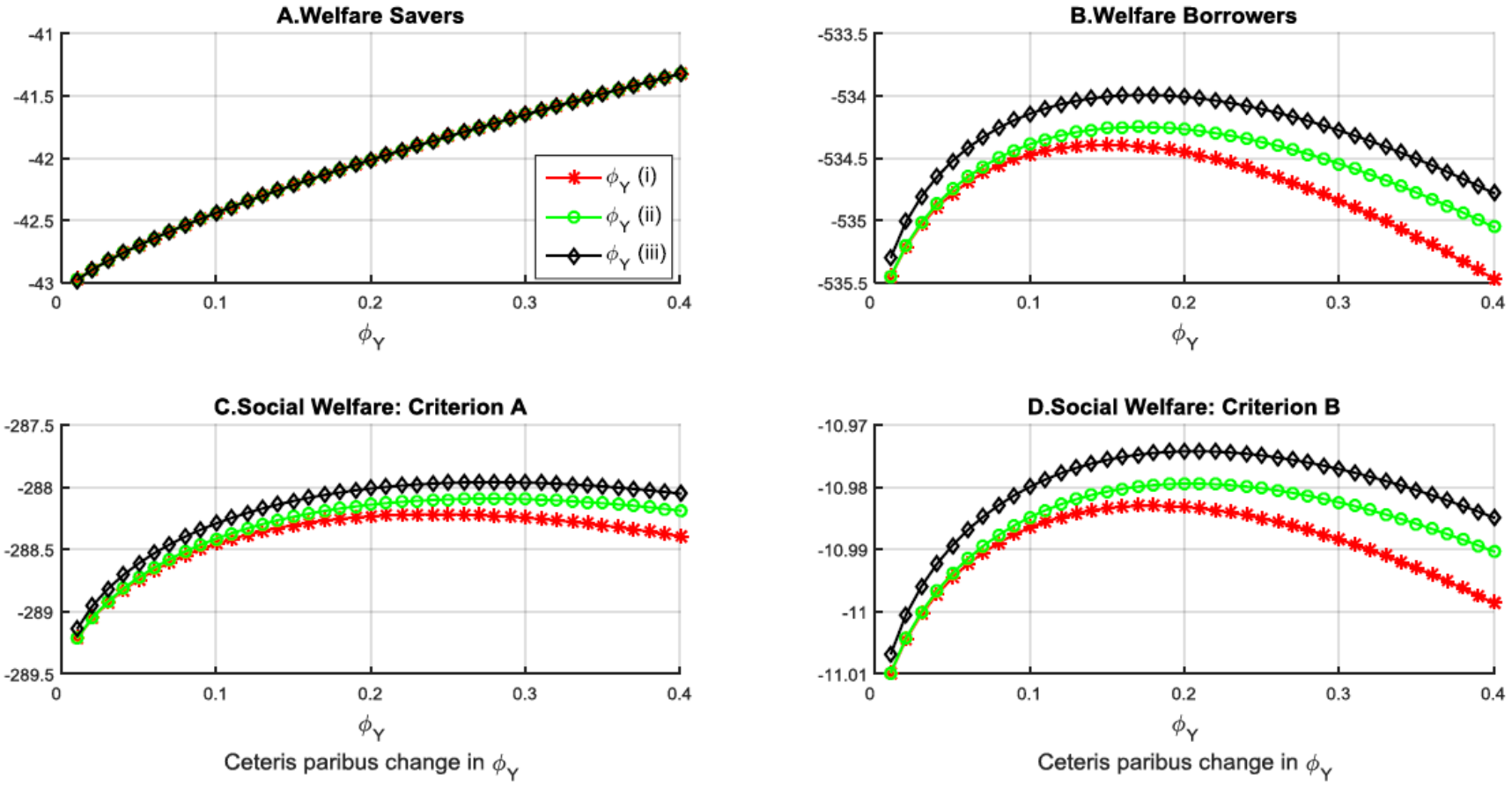
    (i) $$r_{cbdc,t} = 0$$

    (ii) $$r_{cbdc,t} = \phi_r r^{ss}_{\widetilde{R}}$$

    (iii) $$r_{cbdc,t} = \phi_r r_{\widetilde{R},t}$$

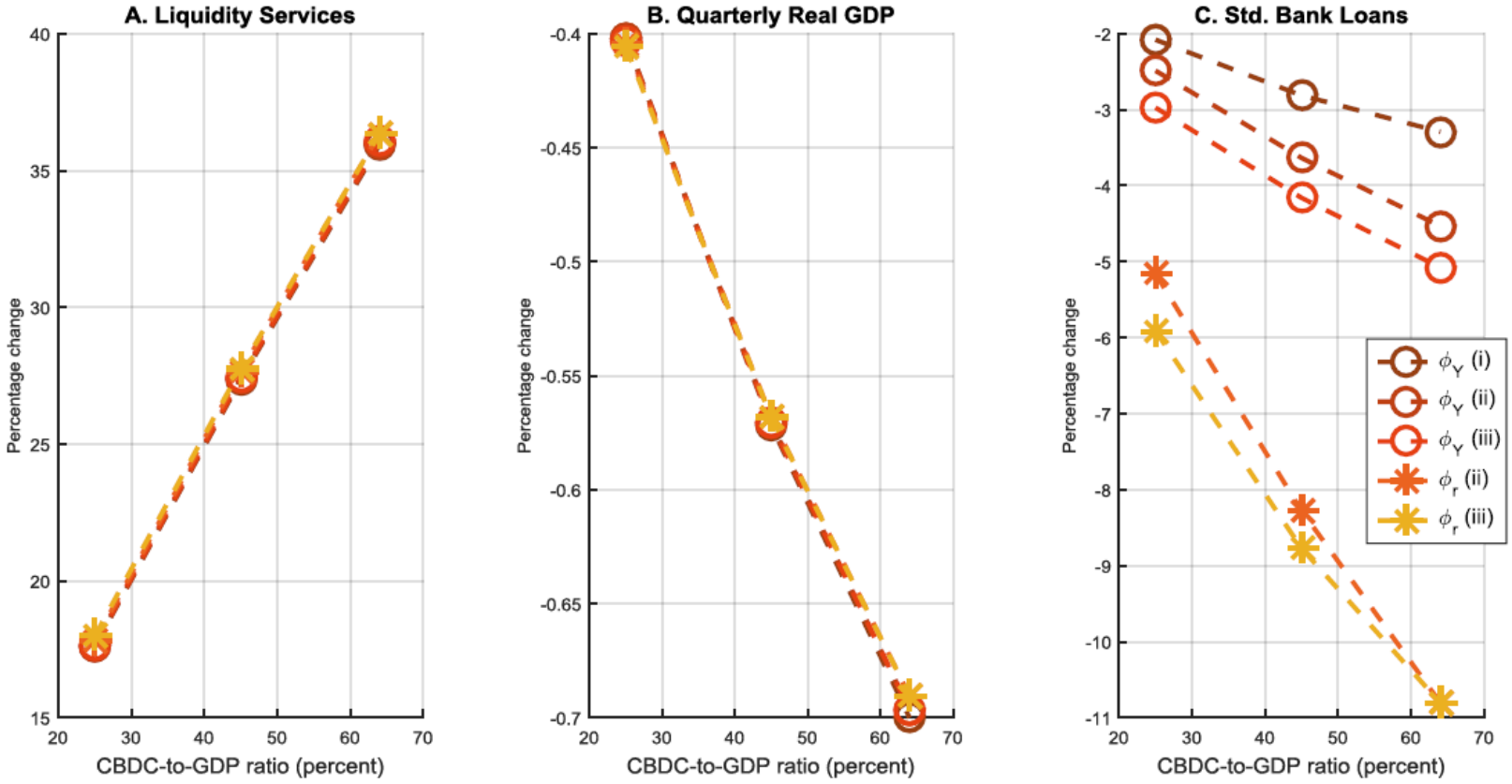
Welfare Analysis: Quantity rules

Figure 5: Welfare effects of CBDC quantity rules (welfare effects of ceteris paribus changes in ϕ_Y)



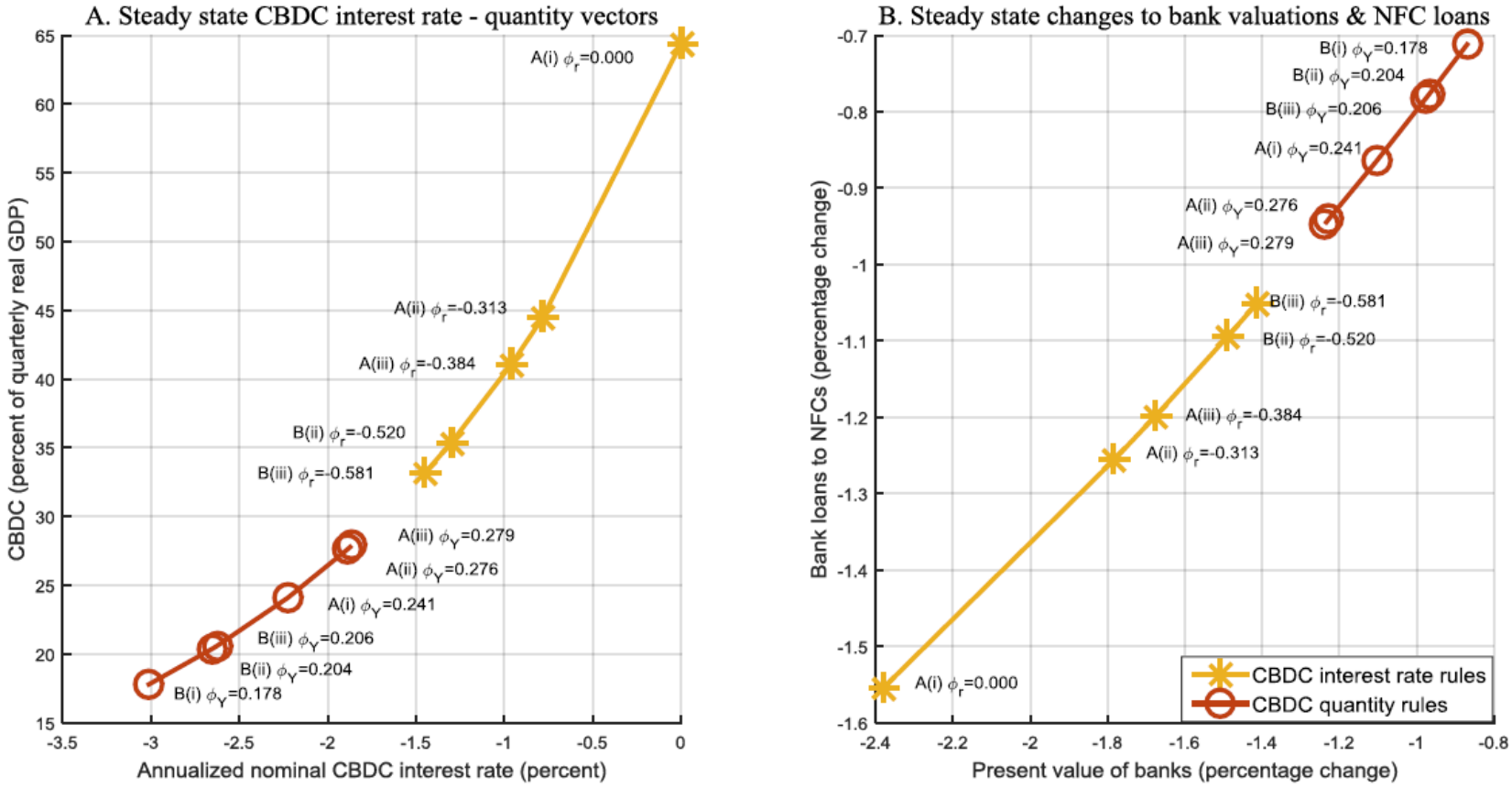
Welfare Analysis: Liquidity services, bank disintermediation, stabilisation

Figure 8: Liquidity services, bank disintermediation and stabilization effects



Steady State Effects of Optimal CBDC Policy Rules

Figure 9: Steady state effects of CBDC policy rules

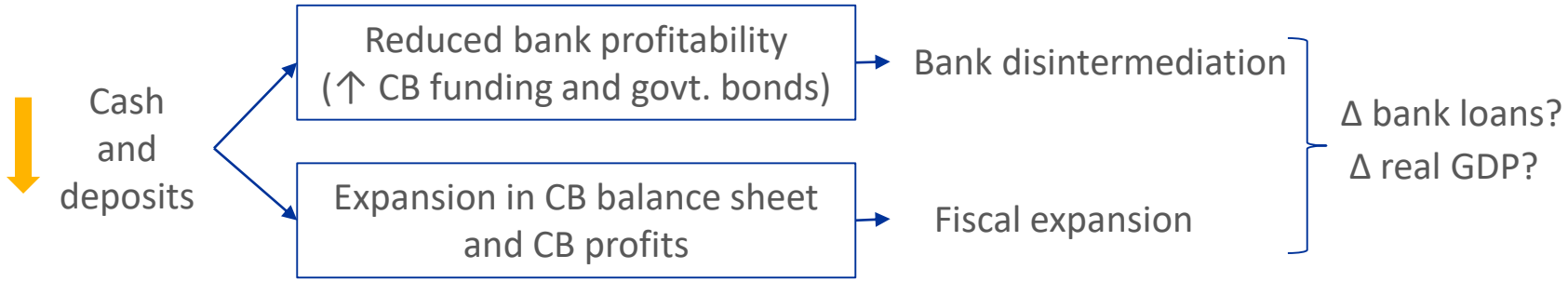


Conclusions: Main Findings

❑ Empirical evidence on impact of digital euro news on banks:

- Initial impact on EA bank valuations and lending was on average negative
- Impact was larger for banks more reliant on deposit funding
- Negative impact disappeared after news on CBDC issuance limits

❑ Transmission:



❑ Welfare implications:

Liquidity services effects (+)

Bank disintermediation effect (-)

Stabilization effect (+)

Welfare-maximizing analysis:

quantity and interest rate CBDC rules

Significant welfare gains for both CBDC holders and borrowers

Optimal quantity of CBDC (15% - 45% GDP)

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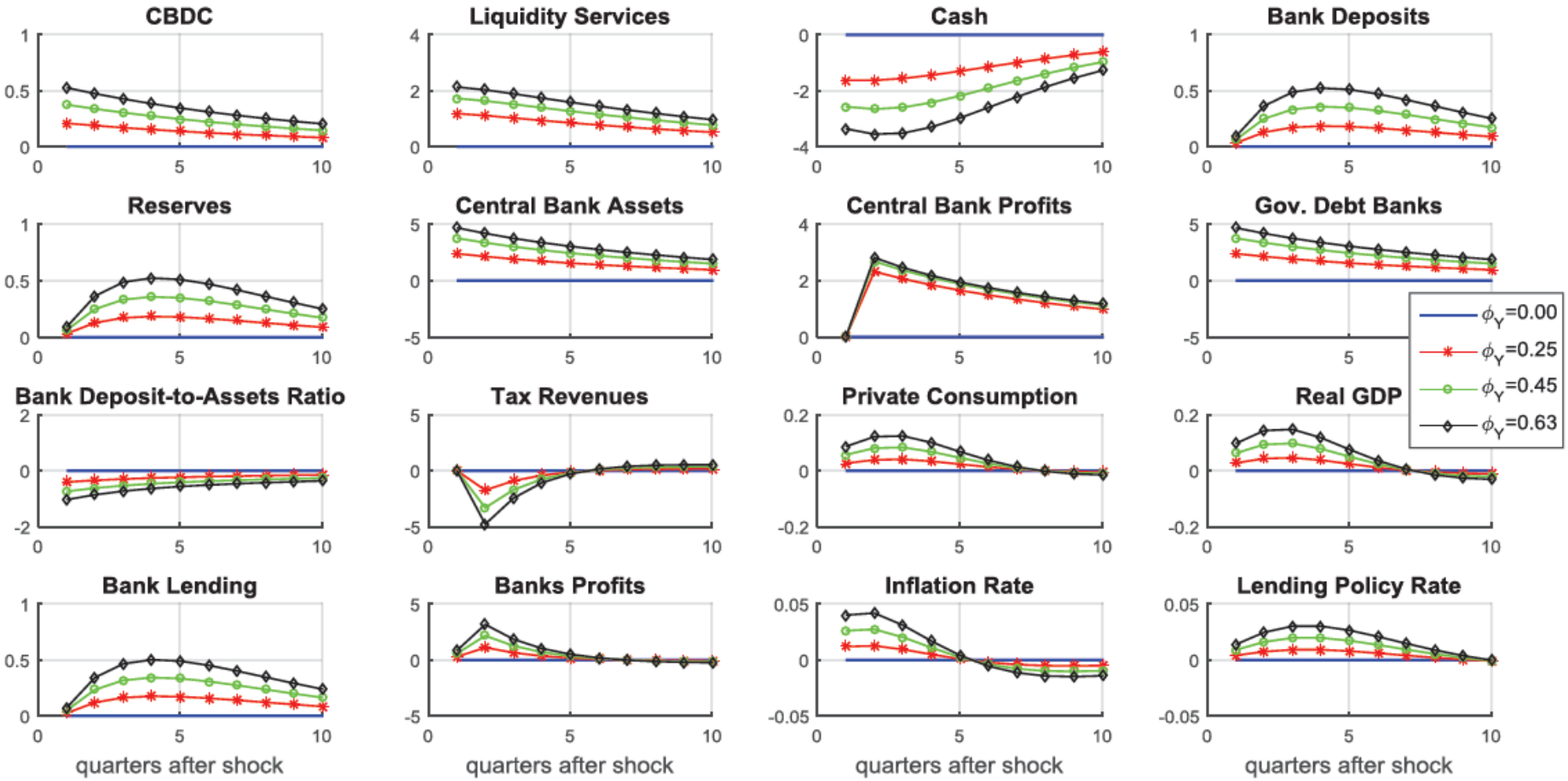
Thank you

Background Material

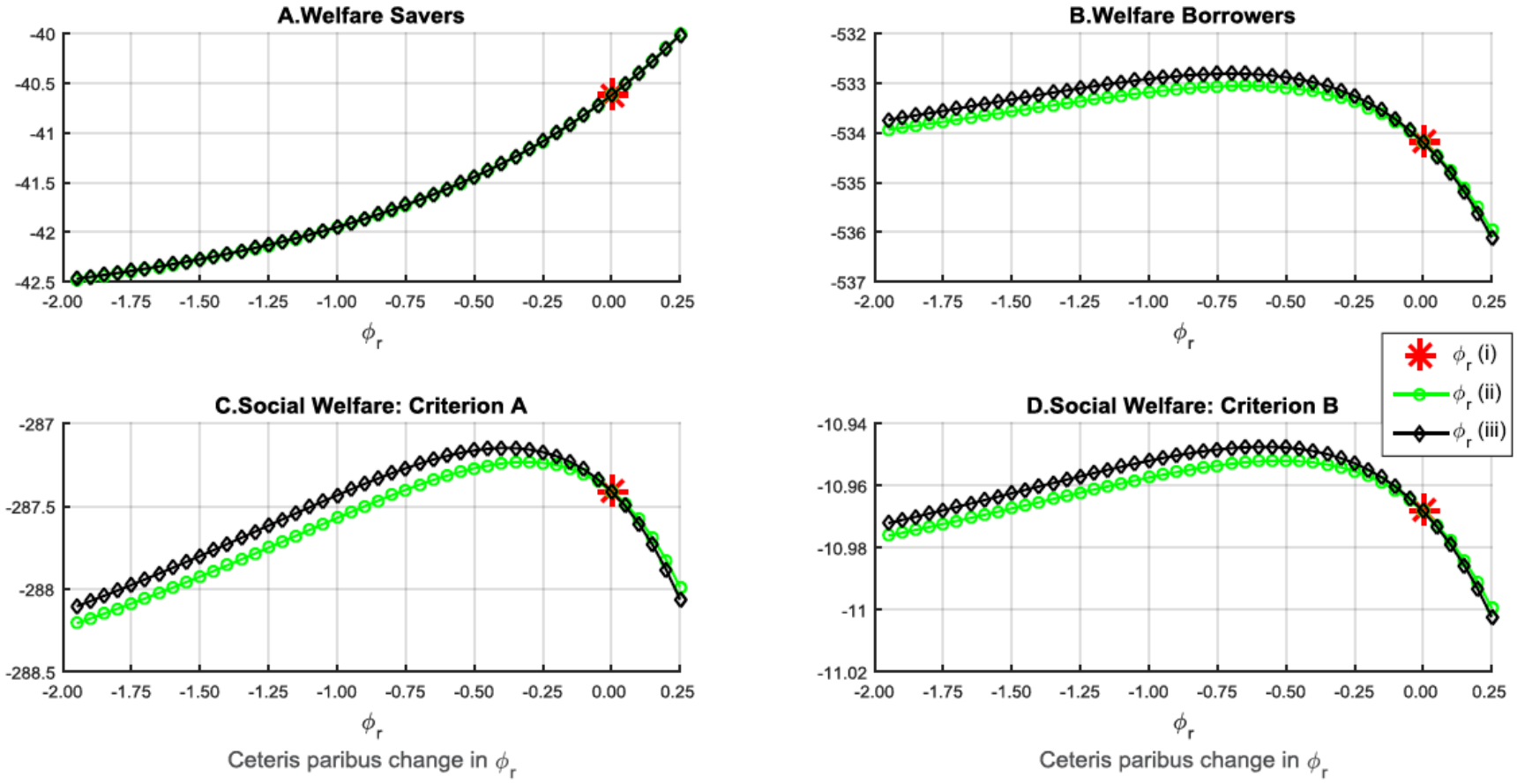
Business cycle impact of CBDC issuance

Figure 4: Transmission and cyclical effects. Impulse-responses to a positive CBDC supply shock



Welfare Analysis: Interest rate rules

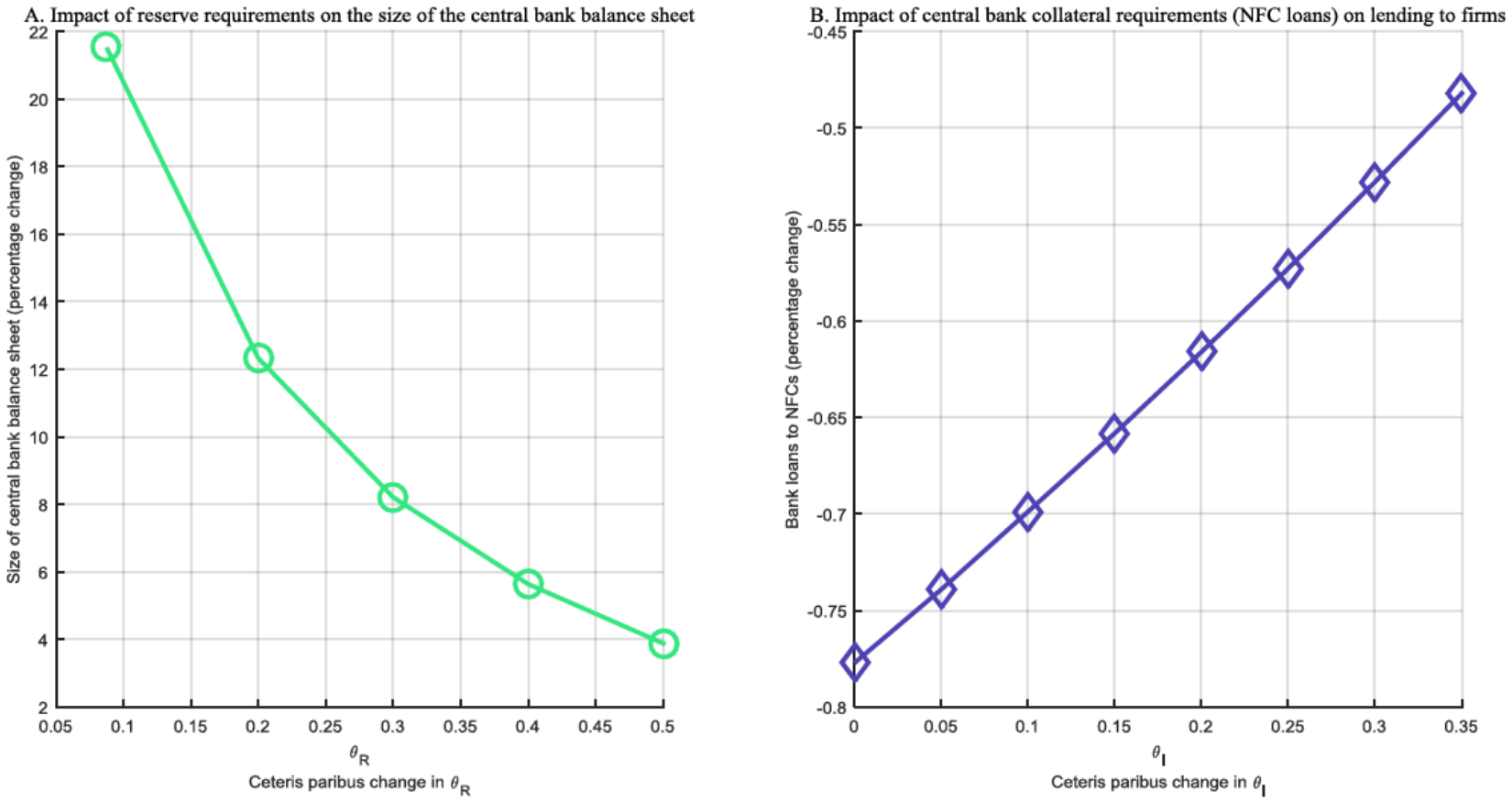
Figure 7: Welfare effects of CBDC interest rate rules (welfare effects of ceteris paribus changes in ϕ_r)



Steady State Effects of Related Policies

$$f_t \leq \theta_{b,t} E_t \left(\frac{b_{b,t}}{R_{f,t}} \pi_{t+1} \right) + \theta_{l,t} E_t \left(\frac{L_{e,t}}{R_{f,t}} \pi_{t+1} \right)$$

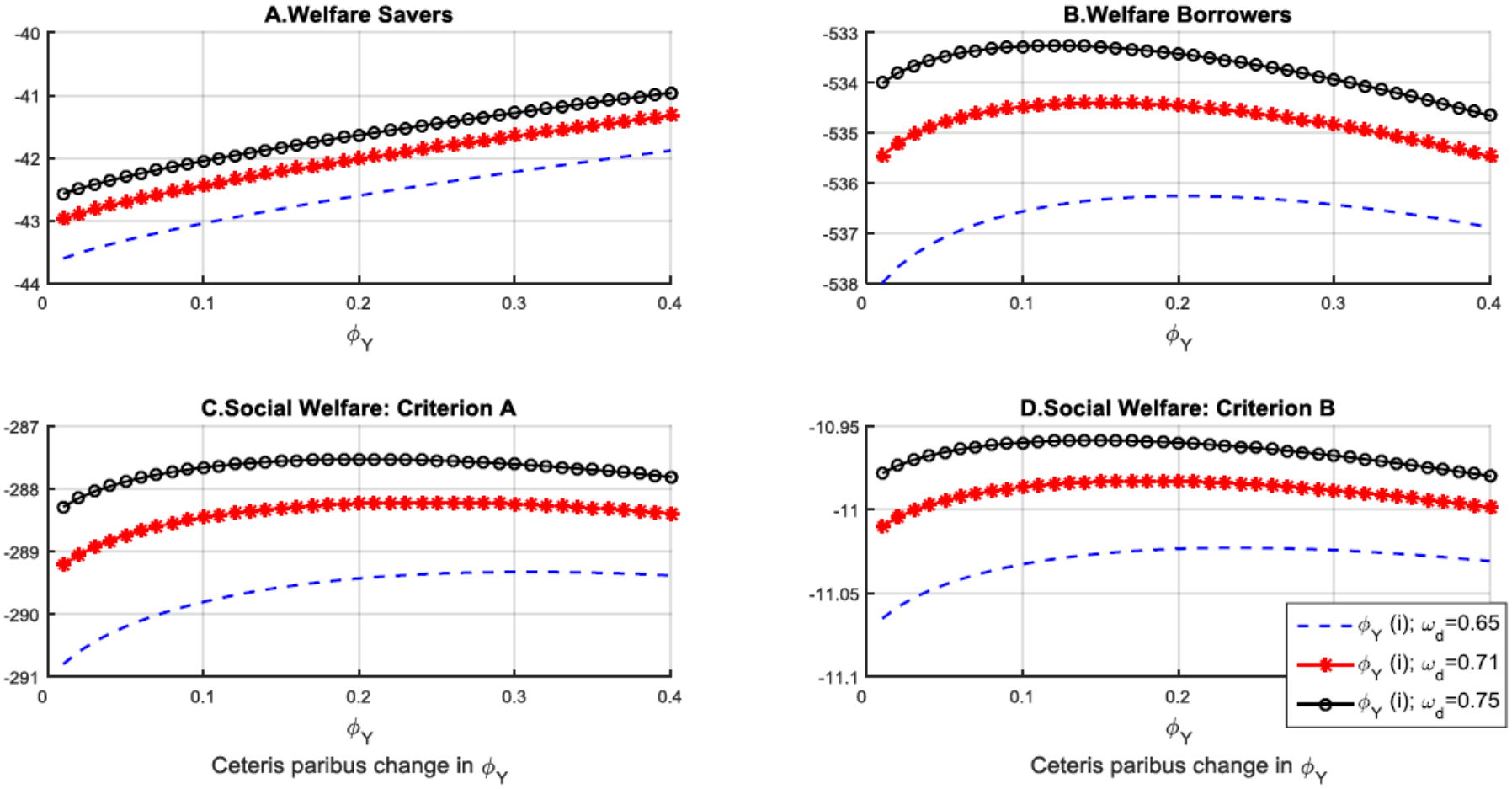
Figure 10: Steady state effects of related policies under optimal CBDC quantity rule (ii)



Robustness checks: Share of deposit funding

Larger share of deposit funding implies lower optimal CBDC

Figure 12: Robustness Checks: ω_d (welfare effects of ceteris paribus changes in ϕ_Y)



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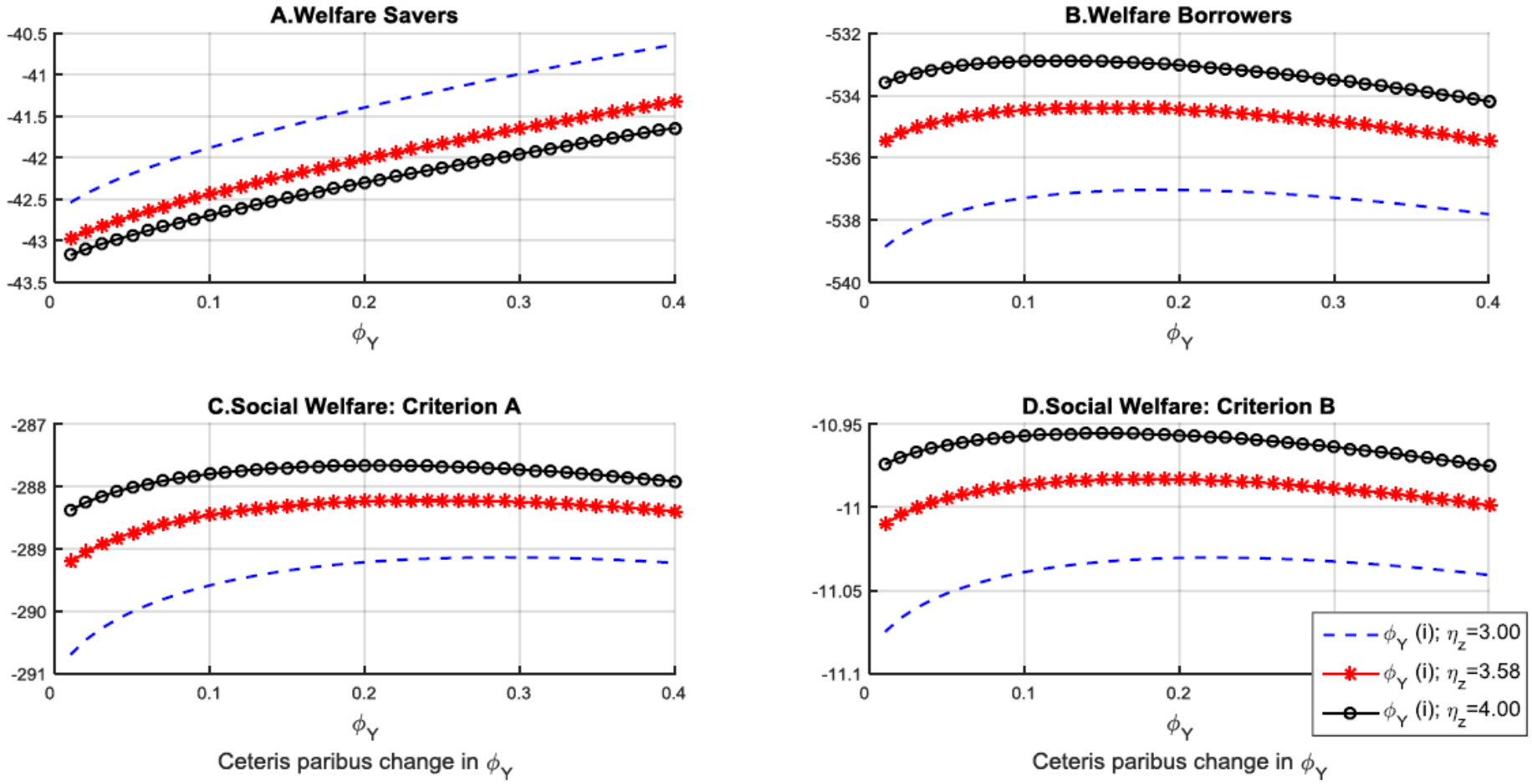
Robustness checks: Substitutability

Greater substitutability implies lower optimal CBDC

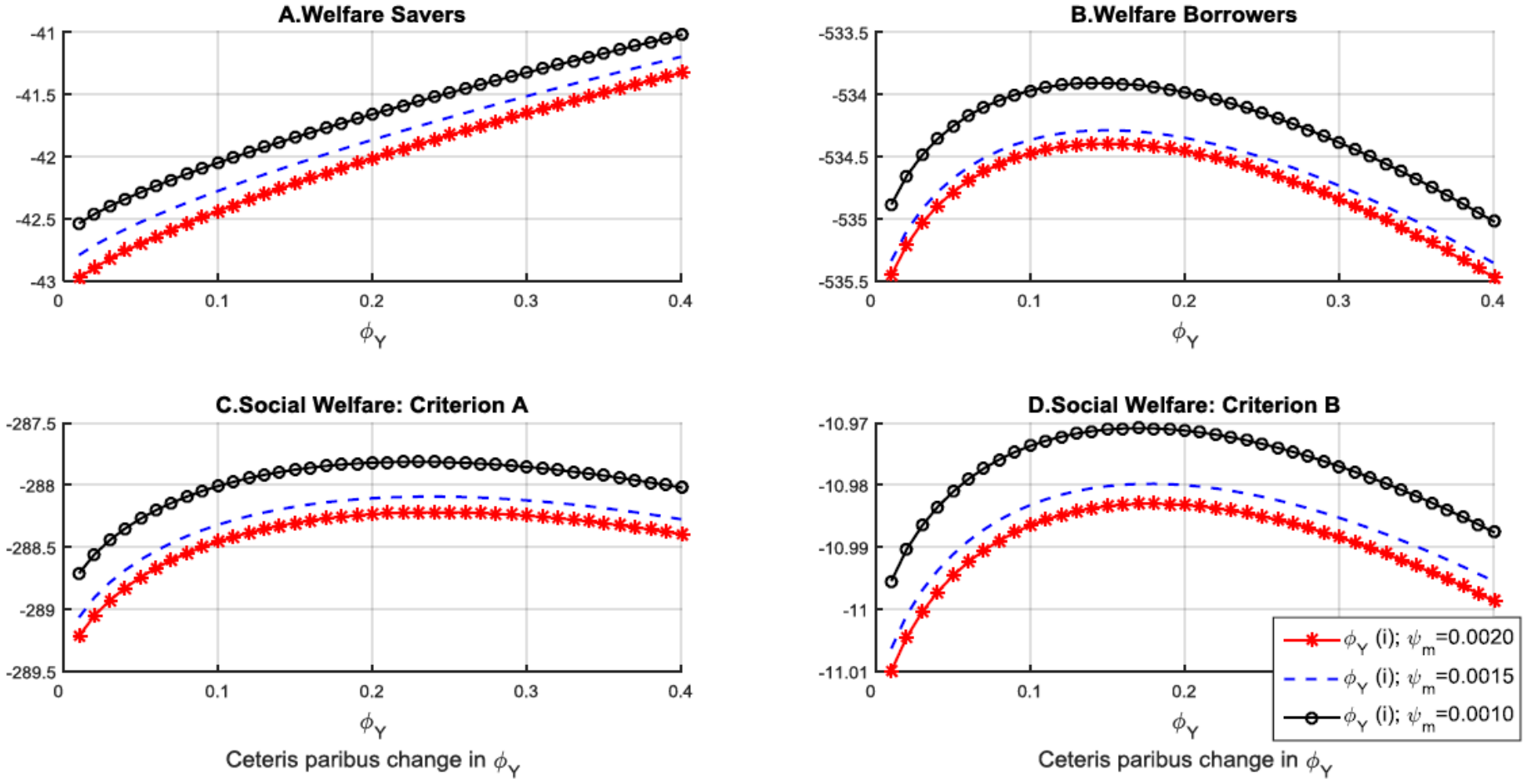
Figure 13: Robustness Checks: η_z (welfare effects of ceteris paribus changes in ϕ_Y)



Robustness checks: Cash storage costs

Lower cash storage costs imply lower optimal CBDC

Figure 14: Robustness Checks: ψ_m (welfare effects of ceteris paribus changes in ϕ_Y)



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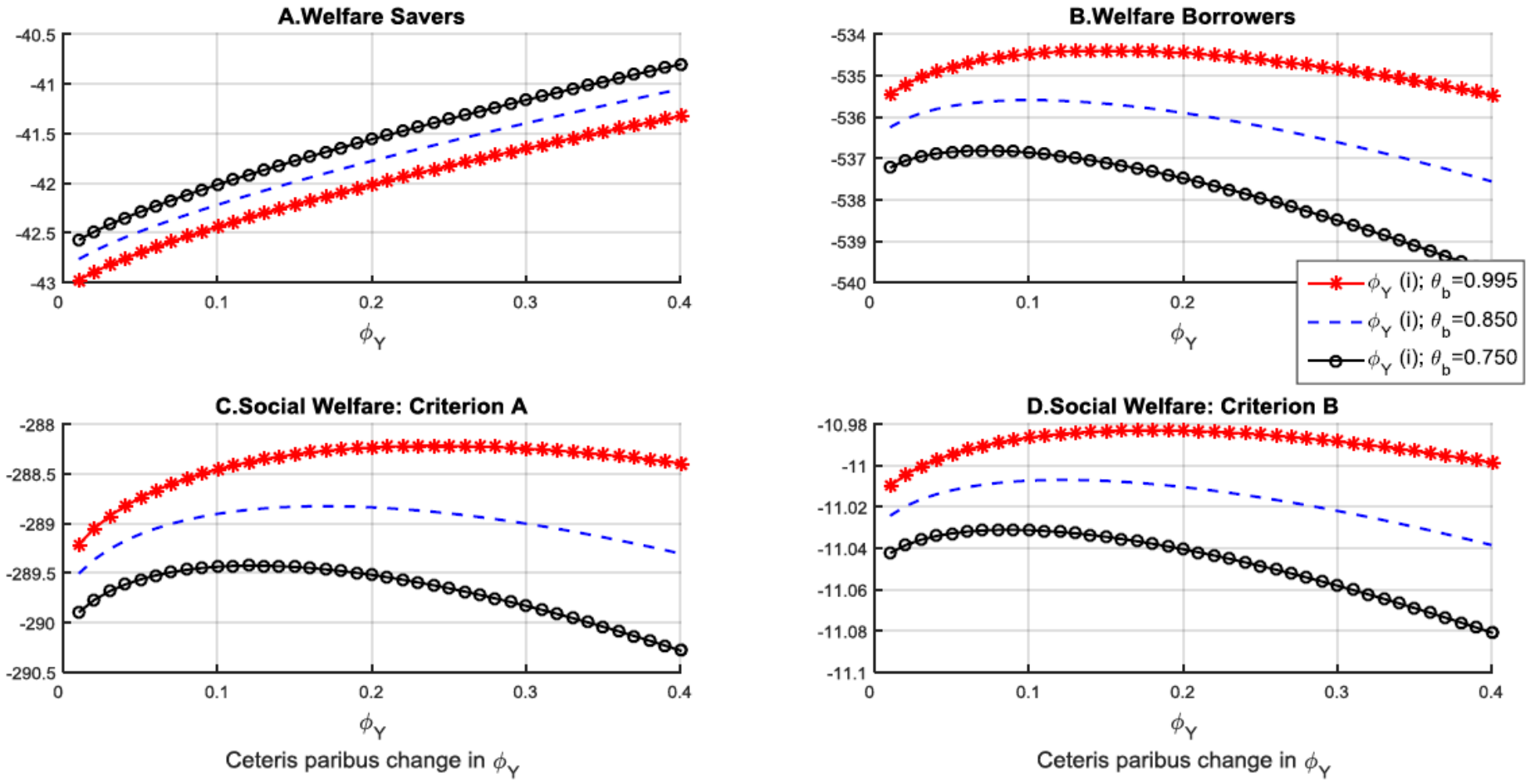
Robustness checks: Collateral constraint

Tighter CB collateral constraint implies lower optimal CBDC

Figure 15: Robustness Checks: θ_b (welfare effects of ceteris paribus changes in ϕ_Y)



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