



WORKING PAPER

A DSGE Model for a Small Open Economy with a CBDC Option

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October 2026

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October 7, 2026

Abstract

This paper develops a small open economy DSGE model for central bank policy analysis. The model's structure and calibration are based on the Moroccan economy, but with minor modifications it can be adapted to other economies. The framework features two household groups, banked households who have access to cash but also to credit and therefore use deposits as medium of exchange, and unbanked households who rely primarily on cash. Households interact with banks, financial investors, firms, unions, a fiscal authority, a central bank, and the external sector. The model can be simulated either with or without a retail CBDC, which is introduced as an additional payment instrument alongside cash and bank deposits. A key mechanism in the model is the interaction between real decisions and payment frictions. Consumption- and production-related payments are subject to money-in-advance constraints, where money or liquidity is a composite of cash, deposits, and—when introduced—CBDC. Any scarcity of money therefore affects spending, marginal costs and inflation, while credit frictions link collateral quality and default risk to the scarcity of money. The paper finds that, under the model's baseline assumptions, the introduction of CBDC causes modest steady state output gains and modest improvements in the economy's ability to deal with financial shocks.

JEL classification: E31, E37, E42, E44, E52, E58, F41, G21.

Keywords: DSGE; small open economy; CBDC; money-in-advance constraints; banking sector; monetary policy; fiscal policy; financial stability; Morocco.

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Acknowledgements

The authors gratefully acknowledge financial support from the UK Foreign, Commonwealth & Development Office (FCDO) and the collaboration between the Bank of England and Bank Al-Maghrib. The authors thank John Power and Ben Norman (Bank of England), and Abdessamad Saidi and Tarik Dkhissi (Bank Al-Maghrib), for their valuable guidance and support. All remaining errors are the authors' responsibility. Any views expressed in this paper are solely those of the authors and cannot be taken to represent those of the Bank of England or Bank Al-Maghrib, or to state the policy of either institution. This paper should therefore not be reported as representing the views of the Bank of England, Bank Al-Maghrib, or of members of the Monetary Policy Committee, Financial Policy Committee, or Prudential Regulation Committee.

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1 Introduction and Model Overview

This paper develops a small open economy dynamic stochastic general equilibrium (DSGE) model that is designed for central bank policy analysis in an economy exposed to a variety of real business cycle, financial business cycle, and external shocks. It follows the policy model tradition of the IMF’s Global Integrated Monetary and Fiscal Model (GIMF) of Kumhof et al. (2010), whose simulation properties are documented in Anderson et al. (2013). Building on the banking sector extensions proposed by Andrle et al. (2015) and Jakab and Kumhof (2019), the model adds a payments layer that emphasizes money-in-advance transactions constraints, a key prerequisite for the later introduction of CBDC into the model. The banking and macro-financial core also builds on an earlier Morocco-specific DSGE framework for macroprudential analysis, which emphasized nonlinearities, endogenous macro-financial feedback loops, and the explicit modeling of the aggregate bank balance sheet (Chafik et al., 2022).

The economy is populated by two household groups, firms, unions, banks, a fiscal authority, a central bank, and the external sector. **Banked households, which we will refer to as infinite-horizon households (INF)**, optimize intertemporally and have full access to the loans and deposits offered by the banking sector to smoothe consumption and investment. They also have access to cash (and potentially CBDC). **Unbanked households, which we will refer to as liquidity-constrained households (LIQ)**, also optimize intertemporally but have much more limited access to intertemporal smoothing, because they do not have access to banks and therefore exclusively rely on cash (and potentially CBDC) to smooth consumption. While this forces them to approximately spend their current disposable income, they are nevertheless quite distinct from the non-optimizing hand-to-mouth agents that are commonly found in policy models to capture non-Ricardian features.

The model’s shock and policy transmission can be understood through the interaction of two channels. The *real channel* runs from preferences to optimal consumption, labor supply and investment, and from there to production with capital, labor, and imported inputs, and finally to market clearing, inflation, and output. The *financial and payments channel* runs from central bank and commercial bank money creation to money-in-advance constraints whereby any real plan requires a sufficient quantity of the medium of exchange for its execution. As a result, the effective price of goods or inputs exceeds the purchase price by the convenience yield of money. This implies that credit and money, and therefore commercial and central bank policies, including CBDC policies, become an important additional wedge that influences demand and costs.

Starting with money, three money-in-advance constraints link different types of spending

to available monetary transactions balances, which are modeled as constant elasticity of substitution (CES) aggregates over bank deposits, cash and (when the CBDC regime is introduced) CBDC. For simplicity we will refer to these aggregates as “**money**”. For INF households, who in the model act both as households and as managers of industrial firms, two separate money-in-advance constraints apply to purchases of consumption goods and of industrial inputs, the latter including investment. For LIQ households the money-in-advance constraint applies only to purchases of consumption goods. The treatment of CBDC reflects the CBDC-as-additional-payment-option perspective in Barrdear and Kumhof (2016), while the open-economy implications of CBDC policy choices follow the logic developed by Kumhof et al. (2023). In this framework, when payment frictions worsen, such as following a collapse in bank lending, intended purchases become harder to carry out and thus more expensive. When payment frictions ease, such as through better payment technologies following the introduction of CBDC, constraints on payments are relaxed and spending responds quickly, especially for LIQ households¹.

Turning to credit, we consider the macro-financial link between collateral quality, default risk, spreads, and the quantity of loans (and therefore deposits) by adopting the financial accelerator framework of Bernanke et al. (1999) and Christiano et al. (2014), but with pre-committed lending rates that expose banks to loan default risk. In the presence of minimum capital adequacy regulations, this forces banks to maintain not only exogenous minimum capital levels but also endogenous precautionary capital buffers.

Household incomes include labor and capital incomes, asset returns, profits, transfers, and remittances, and household expenditures include consumption, investment, taxes, debt service, and asset accumulation. However, the feasibility of expenditure plans not only depends on sufficient incomes, as per budget constraints, but also on sufficient money, as per money-in-advance constraints. For LIQ households, any change in money balances requires gradual saving or dis-saving in cash (and potentially CBDC) while at the same time optimal cash balances are tied to saving rather than being chosen separately from saving. As a result, any reduction in LIQ households’ net income quickly increases their labor supply and reduces their consumption with little smoothing, and lower consumption optimally calls for lower cash holdings. Cash can therefore not be used to significantly smooth consumption. By contrast, INF households can buffer income shocks much more effectively through gross portfolio re-balancing. Specifically, because loans and deposits are not tied to saving, INF households who experience a reduction in net income maintain higher deposit balances to

¹This reflects the hypothesis that payment frictions constrain the execution of transactions by limiting access to transaction balances, so that tighter constraints raise effective costs and compress spending, while improvements in payment technologies relax these constraints and allow expenditures to adjust more rapidly.

help smooth the drop in consumption. The separation of the model’s household sector into INF and LIQ households, which has a clearly identifiable counterpart in the economic structure and data of emerging markets, therefore makes it possible to study both aggregate transmission and distributional consequences of shocks and of economic policies.

Firms are not modeled as a separate group of agents but rather as being managed by INF households. They produce differentiated varieties of output under monopolistic competition using labor, capital and imported energy inputs. Price and wage adjustment to changes in marginal cost is gradual due to nominal rigidities. This is a common feature of modern DSGE policy models. In this model, the tightness of the money-in-advance constraint enters marginal cost.

Financial investors hold domestic government debt and domestic wholesale deposits while issuing part of the economy’s foreign debt, with the remainder issued by the government.² They represent the model’s domestic wholesale money market and its interaction with the foreign bond market. This provides a clean mapping from the domestic policy stance and foreign financing conditions to domestic wholesale funding markets and to the exchange rate.

Monetary policy controls a short-term nominal policy rate and bank balance sheet re-financing operations. Through these tools it influences wholesale and retail interest rates, funding conditions, and the opportunity cost of money. Fiscal policy spends on goods and transfers, raises revenue through taxes, and issues debt under rules that ensure debt sustainability. CBDC is introduced as an additional retail payment option as in Barrdear and Kumhof (2016). The central bank is assumed to have some control over the technical characteristics and issuance mechanism of CBDC but not over its interest rate, which is assumed to equal zero. The technical efficiency of CBDC can change the tightness of money-in-advance constraints and through this the strength of policy transmission.

The external sector is associated with three channels that matter in a small open economy. First, global prices (industrial goods, agricultural goods, oil, phosphates) shift firms’ marginal costs and households’ wealth. Second, foreign interest rates and risk premia affect exchange rates and external financing conditions. Third, remittances enter household budgets directly and support consumption. This highlights the importance of incomplete international risk sharing in small open economies.

In equilibrium demand, driven by preferences, incomes and the availability of money, meets supply, driven by technologies, import costs, and again the availability of money. The interaction of households, firms, and banks with the fiscal and monetary authorities and external conditions determines real activity, inflation, and the external balance. This

²This captures the fact that foreign borrowing is not exclusively intermediated by private agents, but can also be undertaken directly by the government.

architecture, rooted in the policy model discipline of Anderson et al. (2013) and extended for banking and CBDC analysis in Andrle et al. (2015) and Jakab and Kumhof (2019), is designed for practical policy analysis. Beyond the usual analysis of domestic and foreign real demand, supply and fiscal shocks, it emphasizes the roles of financial shocks and of the central bank response to such shocks.

Figure 1 provides a compact overview of the model’s main agents and transmission channels. The central bank controls the policy rate and affects wholesale (through loans to banks) and retail (through cash and CBDC) money provision. Bank loans create credit money by creating two matching asset (loan) and liability (deposit) ledger entries, the counterpart of which is found in INF households’ budget constraint. In this way, changes in private sector borrower and lender risk, monetary policy, and regulatory policy all pass through to borrowing costs, money creation, and ultimately spending.

On the real side, INF and LIQ households supply labor and (in the case of INF households) capital. They receive wages and dividends in return. Their other incomes include lump-sum profits and transfers, commodity export revenues, and net returns to asset portfolios. They use their incomes to purchase goods from domestic firms and from the external sector. Nominal rigidities introduce inertia in price and wage setting decisions.

Fiscal policy interacts with both household types through taxes and transfers. This affects disposable incomes and, especially for LIQ households, near-term consumption given their limited smoothing capacity. Fiscal policy can therefore be especially effective if it can be financed through the issuance of money (Friedman (1948)), in our case cash and CBDC, because this simultaneously relaxes budget constraints and money-in-advance constraints. However, given the absence of an interest rate option on CBDC (and of course cash) under the assumptions of our model ³, the quantity of CBDC issuance is not a discretionary policy choice but rather accommodates demand conditions.

Finally, the external sector incorporates a variety of practically relevant trade flows and commodity prices, which affect domestic wealth and inflation, while remittances provide an additional income stream.

The color coding in Figure 1 highlights how real variables (black) are jointly determined with financial and payments variables (blue), how policy and fiscal instruments (red dashed) feed back into private decisions, and how external conditions (green) propagate through the economy via trade, commodity prices, and cross-border income flows.

In this paper we provide a description, focused on intuition, of model agents’ decision problems. This sometimes requires simplified notation. For example, unlike in the full list of

³In the literature on developing and emerging countries, CBDC instruments are generally considered cash-like and bear no interest rate.

model equations, our expressions for real variables omit normalization by constant exogenous technology growth ⁴. All shocks that are present in the model will be mentioned under the appropriate heading, and are normalized to have a mean of 1, if necessary by dividing the relevant variable by its steady state. We generally omit the agent-specific index j for decision variables except where necessary to make an economic point. Nominal and real aggregate variables are displayed in upper case letters, while real per capita values are displayed in lower case letters. The population shares of INF and LIQ households are $(1 - \iota)$ and ι . Superscripts ∞ and $\emptyset$ denote per capita variables pertaining to INF and LIQ households.

⁴Variables are presented in levels rather than detrended by the deterministic growth component; the full model is formulated in stationary form.

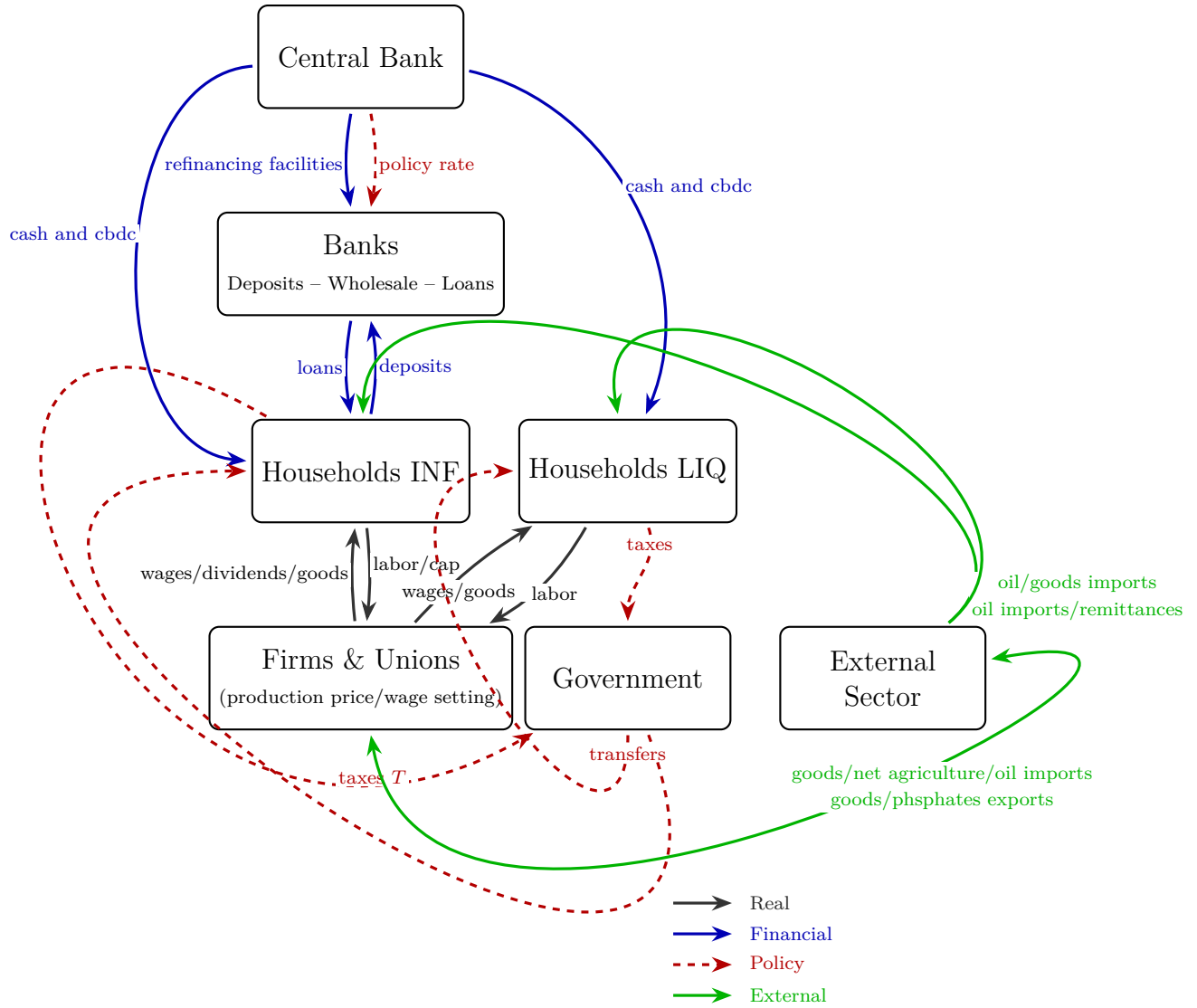


Figure 1: Overview of the small-open-economy DSGE model

2 Banking Sector

Banks create deposits through risky loans whose quantity is limited by the interaction of capital adequacy regulation, the riskiness of borrowers' income, and the riskiness of banks' own income. Deposits are needed to make consumption, investment and input purchases throughout the economy. For analytical simplicity, the banking system is segmented into three units, wholesale banks, retail lending banks, and retail deposit banks. Each serves a distinct role, enabling a clear understanding of bank balance sheet and pricing behavior. We can think of wholesale banks as the treasury department of the bank, which treats retail lending and retail deposit operations as separate profit centers of the overall operation.

Wholesale banks determine both the size and allocation of the bank's overall balance sheet. They decide on the volume of wholesale loans to retail lending banks and wholesale deposits from retail deposit banks, taking into account regulatory constraints, income risks, and market conditions. Wholesale banks do not directly interact with INF households while retail banks do. Retail lending banks determine the terms of retail loans, which are collateralized by the borrowers' capital stock, in the presence of borrower default risk. Retail deposit banks set deposit interest rates and thereby influence the allocation of gross transactions balances between deposits, cash, and CBDC.

2.1 Wholesale Banks

The core accounting identity for wholesale banks in nominal terms is

$$L_t = D_t + V_t + N_t^b, \quad (1)$$

where L_t denotes wholesale loans to retail lending banks, D_t wholesale deposits from retail deposit banks, V_t refinancing loans from the central bank, and N_t^b bank net worth.

Wholesale banks maximize expected net worth subject to Minimum Capital Adequacy Requirements (MCAR). MCAR ensure that banks maintain sufficient capital relative to their risk-weighted assets. When net worth falls below this regulatory threshold, banks face penalties designed to discourage risky behavior and to protect the broader economy from potential financial crises. Specifically, a penalty equal to a fraction χ of the stock of loans applies whenever next-period net worth (in nominal terms, at price level P_{t+1}) falls below a fraction of risk-weighted assets,

$$i_{\ell,t} L_t \omega_{t+1}^b - i_{w,t} D_t - i_{w,t} V_t + \Pi_{t+1}^R - \Lambda_{t+1}^b < \gamma S_t^{lev} i_{\ell,t} L_t \omega_{t+1}^b, \quad (2)$$

where Π_{t+1}^R are the expected profits of retail deposit banks and Λ_{t+1}^b are the expected losses of retail lending banks, both received in lump-sum fashion ⁵, $i_{\ell,t}$ is the nominal wholesale lending rate, $i_{w,t}$ is the nominal wholesale deposit rate, γ is the steady state minimum capital adequacy ratio and $S_t^{lev} = 1 + \rho_{lev}(S_{t-1}^{lev} - 1) + \epsilon_t^{lev}$ is a bank leverage shock that captures time-varying leverage tolerance (or alternatively countercyclical capital buffers)⁶. The return on the wholesale loan portfolio is stochastic, reflecting idiosyncratic risks in non-interest income across banks. The distribution of the shock ω^b is lognormal, $\ln(\omega_{t+1}^b) \sim \mathcal{N}(-0.5 \sigma_b^2, \sigma_b^2)$. Let $\bar{\omega}_{t+1}^b$ denote the cutoff between compliance and the penalty region in (2). This implies that the bank's expected profitability must be evaluated taking into account the probability of adverse realizations that push net worth into the penalty region. The wholesale bank optimization problem is

$$\text{Max}_{L_t} \mathbf{E}_t \left\{ i_{\ell,t} L_t \omega_{t+1}^b - i_{w,t} D_t - i_{w,t} V_t + \Pi_{t+1}^R - \Lambda_{t+1}^b - P_{t+1} \int_0^{\bar{\omega}_{t+1}^b} (\chi/P_t) L_t f^b(\omega) d\omega \right\}. \quad (3)$$

This equation states that wholesale banks trade off the expected marginal benefits of higher lending (higher interest income from loans) against the expected marginal costs of higher funding requirements (higher interest expenses on deposits and the central bank credit facility) and against the expected regulatory cost. The optimality condition requires that the wholesale lending rate $i_{\ell,t}$ exceed the wholesale deposit rate $i_{w,t}$ by a spread that increases with the quantity of loans, the tightness of MCAR γ , the penalty payable in case of a breach of MCAR χ , and the riskiness of banks σ_b . Regulation can therefore limit credit creation and thereby strengthen resilience. Next period net worth equals loan interest received minus deposit interest paid and central bank credit interest paid plus retail deposit bank net profits Π_t^R minus retail lending bank net losses Λ_t^b minus the ex-post penalty cost of violating MCAR $\mathcal{M}_t^b$ minus a share of net worth $\delta_b N_t^b$ that is paid out lump-sum to households.

2.2 Retail Deposit Banks

Retail deposit banks issue retail deposits to INF households and financial investors and hold wholesale deposits issued by wholesale banks. The interest rate on wholesale deposits $i_{w,t}$ is tied to the policy interest rate on reserves i_t by arbitrage, $i_{w,t} = i_t$.⁷ Financial investor deposits are issued under perfect competition, so that banks offer the wholesale deposit rate, $i_{d,t}^f = i_{w,t} = i_t$. Household deposits are issued under monopolistic competition, so that banks

⁵Lump-sum transfers are non-distortionary and do not affect marginal decisions.

⁶This shock represents exogenous shifts in leverage constraints, which can reflect regulatory adjustments such as countercyclical capital buffers or changes in banks' risk-taking behavior.

⁷For simplicity the market for reserves is not explicitly modeled.

offer a fixed markdown under the wholesale rate, $i_{d,t}^{hh} = i_{d,t} = \mu_d i_t$. Retail deposit bank profits Π_t^R equal the difference between the interest earned on wholesale deposits and the interest paid on retail deposits. These profits are lump-sum distributed to wholesale banks, where they interact with MCAR.

2.3 Retail Lending Banks

Retail lending banks issue retail loans to INF households at the nominal interest rate $i_{r,t}$, collateralized by INF households' capital $k_{coll,t}$, and obtain wholesale loans from wholesale banks at the nominal interest rate $i_{\ell,t}$. The return on INF households' capital $Ret_{k,t+1}\omega_{t+1}^k$ is stochastic, reflecting idiosyncratic income risks. The distribution of the shock ω^k is lognormal, $\ln(\omega_{t+1}^k) \sim \mathcal{N}(-0.5\sigma_k^2, \sigma_k^2)$. This implies that a borrower's expected profitability must be evaluated taking into account the probability of adverse realizations that would lead him to declare bankruptcy. Retail lending banks price loans so that expected repayments, net of collateral realizations minus bankruptcy costs $\mathcal{M}_t^k$, cover funding costs. The zero profit condition is

$$\mathbf{E}_t \left\{ \kappa S_t^{cred} Ret_{k,t+1} \omega_{t+1}^k Q_t k_{coll,t} (\Gamma_{t+1}^k - \xi G_{t+1}^k) - i_{\ell,t} L_t \right\} = 0, \quad (4)$$

where κ is the fraction (generally not equal to 100%) of the value of capital that banks will accept as collateral (we will refer to this as “pledged capital”), $S_t^{cred} = 1 + \rho_{cred}(S_{t-1}^{cred} - 1) + \epsilon_t^{cred}$ is a credit supply shock that captures changes in banks' willingness to lend, $Ret_{k,t+1} = ((1 - \Delta)Q_{t+1} + R_{k,t+1} - \tau_{k,t+1}(R_{k,t+1} - \Delta Q_{t+1}))/Q_t$ is the expected return to capital, Q_t is the market price of capital (Tobin's q), $R_{k,t}$ is the rental rate of capital, $\tau_{k,t}$ is the capital income tax rate, and Γ_t^k and ξG_t^k are the retail lending bank's share and the monitoring costs share in the expected gross earnings of pledged capital. This can be shown to imply that the retail lending rate $i_{r,t}$ must exceed the wholesale lending rate $i_{\ell,t}$ by a spread that increases with the riskiness of borrowers.

INF households only repay loans when the idiosyncratic productivity shock ω_t^k is sufficiently high. When they default, the bank recovers only the pledged fraction of collateral net of bankruptcy costs. The expected cutoff $\bar{\omega}_t^k$ that separates repayment from default is $\bar{\omega}_{t+1}^k = i_{r,t} L_t / (\kappa S_t^{cred} Ret_{k,t+1} Q_t k_{coll,t})$. Intuitively, higher required repayments (higher $i_{r,t}$ or larger L_t) raise the cutoff and increase default risk, while higher collateral values (higher κS_t^{cred} , higher $Ret_{k,t+1} Q_t$, higher $k_{coll,t}$) lower the cutoff and reduce default risk.

Costs of bankruptcy monitoring or loss-given-default are given by $\mathcal{M}_t^k$ ⁸. Ex-post loan

⁸This term captures bankruptcy monitoring costs and loss-given-default, representing the fraction of loan value that is not recovered in default.

losses Λ_t^b capture the gap between the promised wholesale return and expected collateral recoveries. These losses are lump-sum distributed to wholesale banks, where they interact with MCAR. Losses therefore tighten capital pressure and the quantity of lending, and increase the cost of lending.

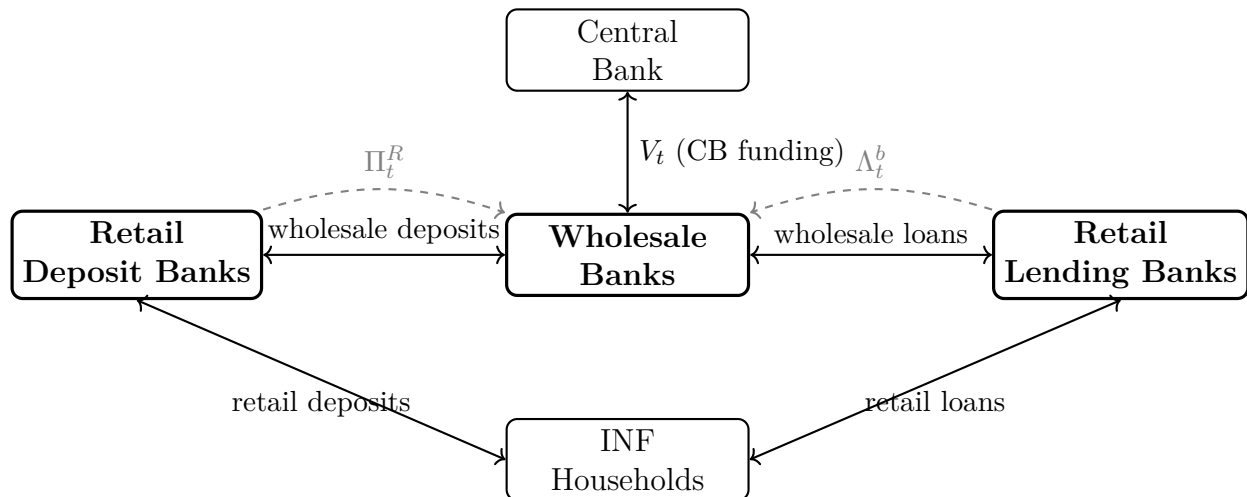


Figure 2: Components of the Banking Sector

Summary of the Banking Sector

The model features a banking sector composed of three sets of banks:

- **Wholesale Banks** issue wholesale deposits to retail deposit banks and issue wholesale loans to retail lending banks. Central bank funding V_t is a second wholesale bank liability. Wholesale banks manage the aggregate balance sheet to maximize net worth subject to MCAR. Expected returns to lending are traded off against funding costs and the probability-weighted regulatory penalty. Wholesale banks can be interpreted as the treasury department of the bank, which treats retail deposit banks and retail lending banks as separate profit centers. Wholesale loans are priced at a time-varying markup over the wholesale deposit (=policy) rate that reflects bank specific and regulatory risks.
- **Retail Deposit Banks** issue retail deposits to INF households and financial investors and purchase wholesale deposits from wholesale banks. Financial investor deposits are priced at the wholesale deposit rate. INF households' deposits are priced at a fixed markdown under the wholesale deposit (=policy) rate that reflects market power.
- **Retail Lending Banks** obtain wholesale loans from wholesale banks and issue retail loans to INF households. A default cutoff summarizes how repayment capacity depends on the pledged collateral value and the required loan repayment. Retail loans are priced at a time-varying markup over the wholesale loan rate that reflects borrower default risk and expected collateral recoveries.

3 INF (Banked) Households

In this section we study the optimization problem of INF or banked households. INF households' per capita variables are denoted by a superscript ∞ . Figure 3 shows the overview of this sector. INF households act both as households and as managers of industrial firms.

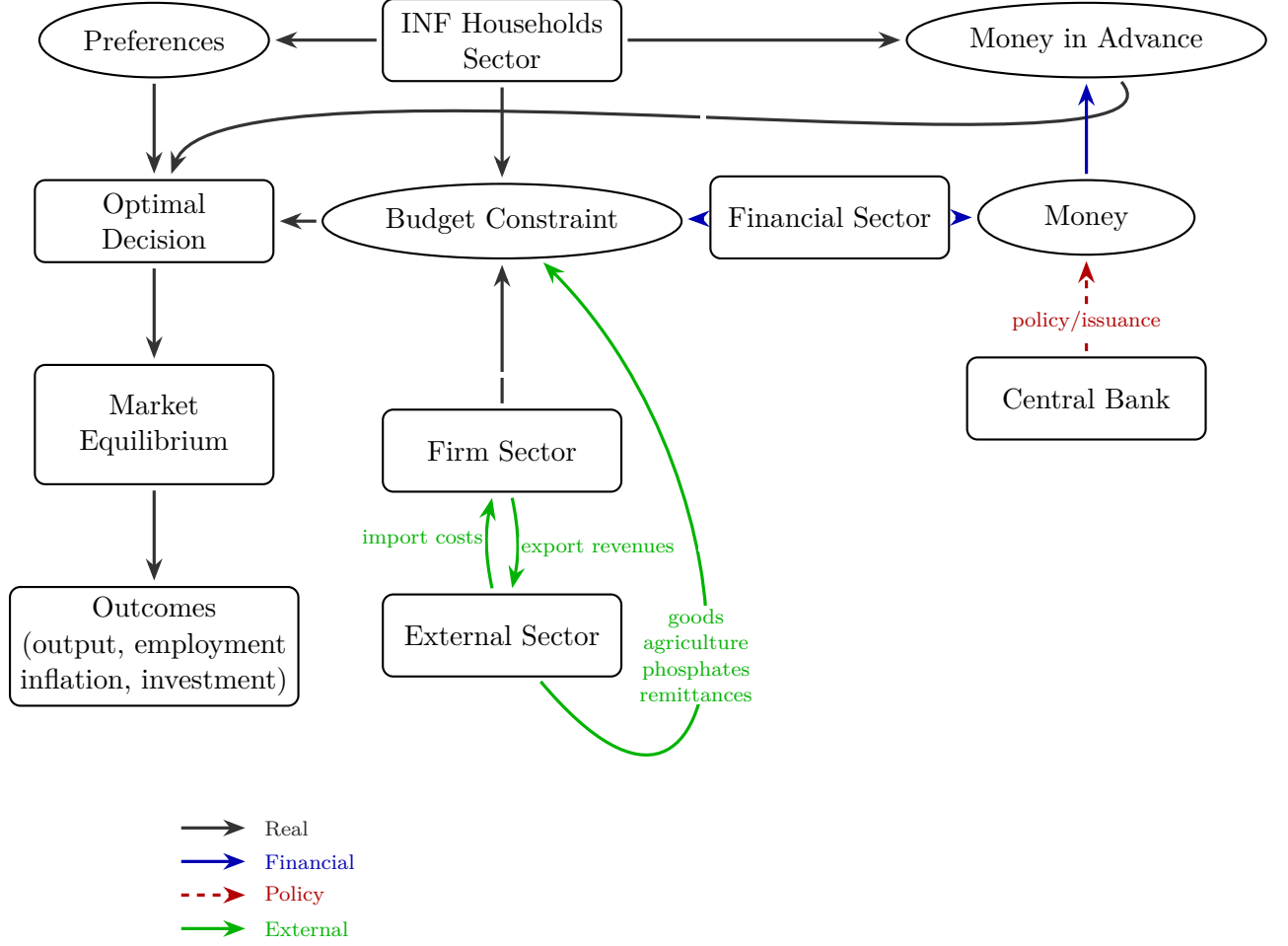


Figure 3: INF (Banked) Households

3.1 Preferences, Technologies, and Endowments

INF households' preferences increase in consumption (of industrial goods, agricultural goods and oil) and decrease in hours worked.

Household j maximizes expected lifetime utility:

$$\begin{aligned}
 \text{Max } \mathbf{E}_0 \sum_{t=0}^{\infty} \beta_{hh}^t S_t^c \left\{ (1 - \nu_{\infty}) \log(c_{ind,t}^{\infty}(j) - \nu_{\infty} c_{ind,t-1}^{\infty}) \right. \\
 \left. + \varrho_{\infty} (1 - \nu_{\infty}) \ln(c_{ag,t}^{\infty}(j) - \nu_{\infty} c_{ag,t-1}^{\infty}) - \psi_{\infty} / (1 + 1/\eta) (h_t^{\infty}(j))^{1+1/\eta} \right\}.
 \end{aligned} \tag{5}$$

Here $c_{ind,t}^{\infty}(j)$ and $c_{ag,t}^{\infty}(j)$ denote household j 's consumption of industrial and agricultural goods and $h_t^{\infty}(j)$ denotes hours worked.⁹ The discount factor β_{hh} is common across INF and

⁹In this case the household-specific index j is included to distinguish individual and aggregate consumption in the presence of external habit persistence.

LIQ households, and $S_t^c = 1 + \rho_c(S_{t-1}^c - 1) + \epsilon_t^c$ is a shock to savings preferences, with an increase in S_t^c increasing households' willingness to consume and reducing their willingness to work. The parameter ν_∞ governs the strength of external habits, and η is the labor supply elasticity with respect to the real wage, which is common across INF and LIQ households. The term $(1 - \nu_\infty)$ scales the habit component so that changes in ν_∞ do not mechanically change steady state consumption. The parameters ϱ_∞ and ψ_∞ fix the relative utility weights of agricultural goods consumption and hours worked.

Consumption is a nested CES aggregate. At the top level $c_{ind,t}^\infty$, households allocate expenditures between non-oil industrial goods $c_{y,t}^\infty$ and oil $o_{c,t}^\infty$, with elasticity of substitution θ_{oil}^c and oil share b_{oil}^∞ . The bottom level $c_{y,t}^\infty$ consists of domestic goods $c_{H,t}^\infty$ and foreign goods $c_{F,t}^\infty$, with elasticity of substitution θ_{chf} and home bias $b_{ch}^\infty S_t^m$, where $S_t^m = 1 + \rho_m(S_{t-1}^m - 1) + \epsilon_t^m$ is an import demand shock. Foreign demand for domestic goods is given by an export demand shock $y_{H,t}^*/\bar{y}_H^* = 1 + \rho_{y_H^*}(y_{H,t-1}^*/\bar{y}_H^* - 1) + \epsilon_t^{y_H^*}$. The model's numeraire is the price of $c_{y,t}^\infty$.

Agricultural consumption is separable in INF households' preferences. Agricultural production is linear in an exogenous agricultural labor supply (which can also be interpreted as agricultural technology), with a shock $h_{ag,t}^\infty/\bar{h}_{ag}^\infty = 1 + \rho_{h_{ag}}(h_{ag,t-1}^\infty/\bar{h}_{ag}^\infty - 1) + \epsilon_t^{h_{ag}}$ that is common across INF and LIQ households. Agricultural goods prices are determined by world prices, and are given by the stochastic process $p_{ag,t}^* = 1 + \rho_{pa}(p_{ag,t-1}^* - 1) + \epsilon_t^{pa}$. Phosphates output is represented by the stochastic endowment process $\Omega_{ph,t}/\bar{\Omega}_{ph} = 1 + \rho_{qp}(\Omega_{ph,t-1}/\bar{\Omega}_{ph} - 1) + \epsilon_t^{qp}$, while phosphates prices are determined by world prices, and are given by the stochastic process $p_{ph,t}^* = 1 + \rho_{pp}(p_{ph,t-1}^* - 1) + \epsilon_t^{pp}$. Foreign remittances are represented by the stochastic endowment process $j_t^*/\bar{j}^* = 1 + \rho_{fr}(j_{t-1}^*/\bar{j}^* - 1) + \epsilon_t^{fr}$.

Investment i_t^∞ and accumulation of capital k_t^∞ follow a standard law of motion with depreciation rate Δ and convex adjustment costs $\mathcal{G}_{I,t}$ whose magnitude depends on the parameter ϕ_i . A marginal-efficiency-of-investment shock $S_t^i = 1 + \rho_i(S_{t-1}^i - 1) + \epsilon_t^i$ changes the effectiveness of investment. Investment is a CES aggregate over domestic inputs $i_{H,t}^\infty$ and foreign inputs $i_{F,t}^\infty$, with elasticity of substitution θ_{ihf} and home bias $b_{ih} S_t^m$.

On the production side, each INF household-firm produces a differentiated variety of output under monopolistic competition. Output is a nested aggregate. At the top level CES aggregate $y_{ind,t}^\infty$, firms allocate expenditure between value added $y_{va,t}^\infty$ and oil $o_{y,t}^\infty$, with elasticity of substitution θ_{oil}^y and oil share b_{oil}^y . The bottom level Cobb-Douglas aggregate $y_{va,t}^\infty$ consists of labor and capital, with capital share αS_t^{ks} , where $S_t^{ks} = 1 + \rho_{ks}(S_{t-1}^{ks} - 1) + \epsilon_t^{ks}$ is an income distribution shock, and with a labor augmenting technology shock $S_t^a = 1 + \rho_a(S_{t-1}^a - 1) + \epsilon_t^a$. Capital inputs are supplied exclusively by INF households, while labor inputs are supplied by both household groups, with perfect substitutability in production across the two labor types. Firms face quadratic price adjustment costs $\mathcal{G}_{P,t}$ that penalize deviations of inflation from target inflation. Price setting is affected by a price markup shock $S_t^{mup} = 1 + \rho_{mup}(S_{t-1}^{mup} - 1) + \epsilon_t^{mup}$. For cross-border pricing we assume producer currency pricing.

3.2 Money Demand

For any economic activity to take place, households need not only sufficient income, as per a budget constraint, but also a sufficient quantity of the means of payment in order to make purchases, as per a money-in-advance constraint. The model distinguishes between money balances used for consumption purchases and money balances used for input purchases.

The consumption money-in-advance constraint is

$$\varkappa_{cc}^\infty A_{cc,t}^\infty \geq 4 S_t^{mon} \left(P_{H,t} c_{H,t}^\infty (1 + \tau_{c,t}) + E_t P_{F,t}^* c_{F,t}^\infty (1 + \tau_{c,t}) + E_t P_{o,t}^* o_{c,t}^\infty \right). \quad (6)$$

On the left-hand side, $A_{cc,t}^\infty$ is the stock of effective money available for consumption transactions, which we will discuss below, while the parameter $\varkappa_{cc}^\infty > 0$ governs how much spending can be supported by a given amount of money – it equals the steady state velocity of circulation for consumption transactions. On the right-hand side, the factor 4 converts quarterly spending flows into annualized spending. Total spending is scaled by a shock $S_t^{mon} = 1 + \rho_{mon}(S_{t-1}^{mon} - 1) + \epsilon_t^{mon}$ that represents flight-to-safety shocks, whereby an increase in S_t^{mon} leads to some combination of higher money balances and lower consumption. There are three components of consumption spending, consumption of domestic and foreign industrial goods $c_{H,t}^\infty$ and $c_{F,t}^\infty$ and consumption of oil $o_{c,t}^\infty$. $P_{H,t}$ is the domestic currency price of domestic goods, $P_{F,t}^*$ is the foreign currency price of imported goods, $P_{o,t}^*$ is the foreign-currency price of oil, E_t is the nominal exchange rate (domestic currency per unit of foreign currency), and $\tau_{c,t}$ is the consumption tax rate, so that $(1 + \tau_{c,t})$ converts producer prices into market prices. The global prices of foreign goods and of oil are exogenous stochastic processes $p_{F,t}^*/\bar{p}_F^* = 1 + \rho_{pf}(p_{F,t-1}^*/\bar{p}_F^* - 1) + \epsilon_t^{pf}$ and $p_{o,t}^* = 1 + \rho_{po}(p_{o,t-1}^* - 1) + \epsilon_t^{po}$.

Effective money for consumption $A_{cc,t}^\infty$ is represented by a nested CES aggregate. The top-level aggregate combines a deposits-cash aggregate $U_{cc,t}^\infty$ with CBDC $M_{cc,t}^\infty$, with elasticity of substitution θ_{cc}^{um} and deposits-cash share $b_{cc}^u S_t^{dc}$, where $S_t^{dc} = 1 + \rho_{dc}(S_{t-1}^{dc} - 1) + \epsilon_t^{dc}$ is a shock to CBDC demand. The bottom-level aggregate $U_{cc,t}^\infty$ combines deposits $D_{cc,t}^\infty$ and cash $N_{cc,t}^\infty$, with elasticity of substitution θ_{cc}^{dn} and deposits share b_{cc}^d :

$$A_{cc,t}^\infty = \left((b_{cc}^u S_t^{dc})^{\frac{1}{\theta_{cc}^{um}}} (U_{cc,t}^\infty)^{\frac{\theta_{cc}^{um}-1}{\theta_{cc}^{um}}} + (1 - b_{cc}^u S_t^{dc})^{\frac{1}{\theta_{cc}^{um}}} (P_t \mathfrak{k}_{cc}^\infty + \bar{\delta} M_{cc,t}^\infty)^{\frac{\theta_{cc}^{um}-1}{\theta_{cc}^{um}}} \right)^{\frac{\theta_{cc}^{um}}{\theta_{cc}^{um}-1}}, \quad (7)$$

$$U_{cc,t}^\infty = \left((b_{cc}^d)^{\frac{1}{\theta_{cc}^{dn}}} (D_{cc,t}^\infty)^{\frac{\theta_{cc}^{dn}-1}{\theta_{cc}^{dn}}} + (1 - b_{cc}^d)^{\frac{1}{\theta_{cc}^{dn}}} (N_{cc,t}^\infty)^{\frac{\theta_{cc}^{dn}-1}{\theta_{cc}^{dn}}} \right)^{\frac{\theta_{cc}^{dn}}{\theta_{cc}^{dn}-1}}.$$

The way CBDC enters this monetary aggregate requires some additional comments; they also apply to the two other monetary aggregates of the model (see below). First, the real constant $\mathfrak{k}_{cc}^\infty$ is calibrated at a small fraction of the pre-CBDC real monetary aggregate. This assumption is important for the transition simulation, which starts with CBDC at zero. In this case $\mathfrak{k}_{cc}^\infty = 0$ would imply an infinite marginal product of CBDC, while $\mathfrak{k}_{cc}^\infty > 0$ implies a finite marginal product. Our assumption therefore ensures positive but finite gains from CBDC introduction. Second, the CBDC efficiency parameter $\bar{\delta}$ is calibrated so that CBDC provides slightly more convenient payment services than cash. There is now an extensive literature on the advantages of CBDC (for an example, see Dionysopoulos et al. (2024)). Among other things, this literature stresses lower transaction costs through faster settlement times, a secure ledger that enhances auditability and reduces fraud, and programmability through smart contracts. Third, the liquidity share coefficients b_{cc}^u , b_{kl}^u and b_{cc}^d and the respective elasticity coefficients θ_{cc}^{um} , θ_{kl}^{um} and θ_{cc}^{nm} are set so that CBDC has a moderate potential as a medium of exchange while its substitutability with other forms of liquidity is low and similar to cash. See the calibration section for details.

The production money-in-advance constraint is

$$\varkappa_{kl}^\infty A_{kl,t}^\infty \geq 4 S_t^{mon} \left(W_t^{pr} h_{ind,t}^\infty + R_{k,t} k_{ind,t}^\infty + E_t P_{o,t}^* o_{y,t}^\infty + P_{I,t} i_t^\infty \right). \quad (8)$$

On the left-hand side, $A_{kl,t}^\infty$ is the stock of effective money and $\varkappa_{kl}^\infty > 0$ equals the steady state velocity of circulation in production. On the right-hand side annualized nominal spending, scaled by the same shock S_t^{mon} as above, consists of spending on four production inputs, labor $h_{ind,t}^\infty$, capital $k_{ind,t}^\infty$, oil $o_{y,t}^\infty$, and investment i_t^∞ . W_t^{pr} is the producer wage, $R_{k,t}$ is the rental rate of capital, $E_t P_{o,t}^*$ is the domestic currency price of oil, and $P_{I,t}$ is the price of investment goods.

Effective money for production inputs $A_{kl,t}^\infty$ is represented by a nested CES aggregate. The top-level aggregate combines a deposits-cash aggregate $U_{kl,t}^\infty$ with CBDC $M_{kl,t}^\infty$, with elasticity of substitution θ_{kl}^{um} and deposits-cash share $b_{kl}^u S_t^{dc}$. The bottom-level aggregate $U_{kl,t}^\infty$ combines deposits $D_{kl,t}^\infty$ and cash $N_{kl,t}^\infty$, with elasticity of substitution θ_{kl}^{dn} and deposits share b_{kl}^d :

$$A_{kl,t}^\infty = \left(b_{kl}^u S_t^{dc} \frac{1}{\theta_{kl}^{um}} (U_{kl,t}^\infty)^{\frac{\theta_{kl}^{um}-1}{\theta_{kl}^{um}}} + (1 - b_{kl}^u S_t^{dc}) \frac{1}{\theta_{kl}^{um}} (P_t \mathfrak{E}_{tl}^\infty + \mathfrak{D} M_{kl,t}^\infty)^{\frac{\theta_{kl}^{um}-1}{\theta_{kl}^{um}}} \right)^{\frac{\theta_{kl}^{um}}{\theta_{kl}^{um}-1}}, \quad (9)$$

$$U_{kl,t}^\infty = \left((b_{kl}^d)^{\frac{1}{\theta_{kl}^{dn}}} (D_{kl,t}^\infty)^{\frac{\theta_{kl}^{dn}-1}{\theta_{kl}^{dn}}} + (1 - b_{kl}^d)^{\frac{1}{\theta_{kl}^{dn}}} (N_{kl,t}^\infty)^{\frac{\theta_{kl}^{dn}-1}{\theta_{kl}^{dn}}} \right)^{\frac{\theta_{kl}^{dn}}{\theta_{kl}^{dn}-1}}.$$

Finally, INF households face small loan adjustment costs $\mathcal{G}_{L,t}$, whose size depends on the coefficient ϕ_ℓ , and which penalize sharp changes in their bank borrowing L_t^∞ .

3.3 Credit Demand

Bank credit creates deposit money, but unlike cash or CBDC this money is subject to borrower and regulatory risks that affect wholesale and retail lending spreads. As shown in equation (4), a fraction $\kappa S_t^{cred} \Gamma_{t+1}^k$ of gross capital returns $Ret_{k,t+1} Q_t k_{coll,t}$ is available for repayment to lenders. This has an exogenous component κS_t^{cred} and an endogenous component Γ_{t+1}^k . When one of these falls, e.g. due to higher collateral haircuts, higher lending risk, or weaker collateral, loan volumes decrease and loan spreads increase.

3.4 Budget Constraint

INF households' end-of-period net worth NW_t^∞ is equal to the value of its money balances plus the value of capital minus outstanding loans,

$$NW_t^\infty = (D_{ci,t}^\infty + D_{kl,t}^\infty + N_{ci,t}^\infty + N_{kl,t}^\infty + M_{ci,t}^\infty + M_{kl,t}^\infty)(1 + \phi_{bv}(b_t^{rat} - v_t^{rat} - b_{ss}^{rat} + v_{ss}^{rat})) + Q_t k_t^\infty - L_t^\infty (1 - (\phi_\ell/2)(\ell_t^\infty - \ell_{t-1}^\infty)^2) - \Psi_t^\infty. \quad (10)$$

The term $(\phi_\ell/2)(\ell_t^\infty - \ell_{t-1}^\infty)^2$ represents loan adjustment costs. The expression $\phi_{bv}(b_t^{rat} - v_t^{rat} - b_{ss}^{rat} + v_{ss}^{rat})$ represents transactions costs related to holdings of financial assets, where $x_t^{rat} = X_t/(4GDP_t)$ for any nominal financial asset or liability X_t , b_t^{rat} is the government debt-to-GDP ratio, v_t^{rat} is the government credit-to-GDP ratio, and b_{ss}^{rat} and v_{ss}^{rat} are the corresponding steady state values. This cost is treated as exogenous by households, and the term Ψ_t^∞ represents its lump-sum distribution back to households. The budgetary effect is

therefore neutral, while marginal conditions are affected. This feature allows the model to replicate the small but positive elasticity of equilibrium real interest rates r^* with respect to government debt found in the empirical literature and in IMF debt sustainability analysis. Interest rates on all financial assets are assumed to be affected in the same fashion, so that a change in the net domestic currency government debt-to-GDP ratio, *ceteris paribus*, will affect the level of interest rates but not the structure of spreads.

With this, INF households' budget constraint can be written in stylized form as

$$NW_t^\infty = \mathcal{R}_t^\infty + \mathcal{Y}_t^\infty + \mathcal{X}_t^\infty - \mathcal{E}_t^\infty. \quad (11)$$

The right-hand side consists of four components: $\mathcal{R}_t^\infty$ represents gross returns on assets (deposits, cash, CBDC, capital) minus gross costs of liabilities (loans). $\mathcal{Y}_t^\infty$ includes after-tax wages and INF households' share of after-tax income from capital rentals, firm profits (firms, unions, financial investors) and after-tax endowments (agriculture, phosphates). $\mathcal{X}_t^\infty$ is INF households' share of net fiscal transfers, foreign remittances, and the share $1 - \tau$ of transactions and adjustment costs that do not represent real resource costs. $\mathcal{E}_t^\infty$ is total after-tax expenditure on consumption (domestic goods, foreign goods, oil, agricultural goods) and investment. Lump-sum distributions of firm profits, fiscal net transfers, transactions and adjustment costs, foreign remittances and phosphates endowments are distributed on an equal per capita basis to all INF and LIQ households.

INF households choose consumption, hours, investment, and gross portfolio positions (loans, deposits, cash, CBDC, and capital) to maximize lifetime utility (5) subject to budget constraints (11), bank participation constraints (4), and money-in-advance constraints (6) and (8). The multiplier of the budget constraint is the stochastic discount factor that is used to discount future cash flows, the multiplier of the bank participation constraint measures the tightness of credit, and the multipliers on the two money-in-advance constraints measure the tightness of money.

3.5 Optimality Conditions

The consumption optimality conditions (for domestic, foreign and agricultural goods and for oil) state that households increase consumption until the marginal benefit gained from one additional unit consumed, taking into account habit persistence, equals its marginal cost. The latter includes the price of consumption, where we distinguish between the *producer price*, the tax-inclusive *market price*, and the monetary-friction-inclusive *effective price*. The monetary friction $4 S_t^{mon} m_{cc,t}^\infty$ is determined by the multiplier of the consumption money-in-advance constraint but also by the money demand shock. This friction determines not

only the **effective prices** of consumption and production inputs, but also the **convenience yields** in asset Euler equations. The key observation is that when money is scarce, buying becomes more expensive, so that consumption is reduced even if market prices are stable. We will refer to the monetary friction as the **money tax rate**, because it enters Euler equations in an analogous fashion to ordinary tax rates. There are three money tax rates, corresponding to the three money-in-advance constraints.

The labor supply condition is standard since it does not feature a monetary friction while labor demand does (see below). The investment optimality condition features investment adjustment costs and the effective price of investment, which depends on the multiplier of the production money-in-advance constraint. Additional conditions determine the shares of domestic and foreign goods in overall investment goods.

In the Euler equations for deposits, cash, and CBDC, each instrument must offer the same expected marginal benefit taking into account three factors, financial returns, convenience yields, and the effects of government net debt on r^* ¹⁰. The Euler equations therefore show that households do not value interest rates alone, they also value financial instruments that make payments easier. In the case of CBDC, its convenience yield is influenced by the technical characteristics of CBDC implementation. The Euler equation for loans features loan adjustment costs and an effective cost of borrowing that includes not only the wholesale lending rate but also the multiplier of the bank participation constraint, which quantifies the tightness of credit conditions. The Euler equation for capital includes not only the return to capital but also expressions that relate to the use of capital as loan collateral.

Firms choose labor, capital services, and oil inputs to minimize costs. Marginal productivities are equated to effective factor prices, which include the multiplier of the production money-in-advance constraint. Therefore, when money is tight, effective marginal cost rises, which feeds into inflation dynamics.

Firms set prices subject to monopolistic competition and quadratic price adjustment costs. As a result, inflation reflects three forces. First, it reacts to *current marginal costs*: when wages or capital rentals or oil prices increase, or transactions become harder because money is tight, or markup shocks increase, firms raise prices. Second, pricing decisions are *forward-looking*: firms take into account how costs and demand are likely to evolve in the future, so that expectations about the future matter for today's inflation. Third, prices display *inertia*: firms avoid large changes in prices, depending on the magnitude of the parameter ϕ_p , thereby making inflation persistent over time. Domestic producer-price inflation $\pi_{H,t}^p$, which we will take to represent **core inflation** in the model, therefore tends to move back toward its target level $\bar{\pi}$ in a gradual fashion.

¹⁰The latter is only quantitatively relevant for the simulation of the transition to CBDC.

4 LIQ (Unbanked) Households

In this section we study the optimization problem of LIQ or unbanked households. LIQ households' per capita variables are denoted by a superscript $\emptyset$. The overview of the LIQ household sector is very similar to that of INF households in Figure 3, but with two important exceptions. First, LIQ households do not manage industrial firms. Second, the financial sector and its impact on the budget constraint and on money is absent.

The main difference is therefore that LIQ households do not have access to bank deposits. This matters because banks can create deposits very elastically to finance intertemporal smoothing, simply by creating ledger entries and therefore independently of real resources. Because LIQ households do not have access to this highly elastic form of money, their spending is much more tightly constrained by current disposable income, including labor income, commodity income, transfers and remittances, and by less elastic monetary instruments such as cash and CBDC, which they can accumulate only through saving out of current income (Anderson et al., 2013; Kumhof et al., 2010).¹¹ As a result, income and expenditure shocks affect LIQ consumption and LIQ labor supply more directly, with larger implications for the volatility of output and inflation. By contrast, changes in interest rates and intertemporal substitution play a more limited role for these households.

4.1 Preferences and Endowments

The form of LIQ households' preferences is identical to that of INF households. Formally, household j maximizes expected lifetime utility:

$$\begin{aligned} \text{Max } \mathbf{E}_0 \sum_{t=0}^{\infty} \beta_{hh}^t S_t^c \left\{ (1 - \nu_{\emptyset}) \log(c_{ind,t}^{\emptyset}(j) - \nu_{\emptyset} c_{ind,t-1}^{\emptyset}) \right. \\ \left. + \varrho_{\emptyset} (1 - \nu_{\emptyset}) \ln(c_{ag,t}^{\emptyset}(j) - \nu_{\emptyset} c_{ag,t-1}^{\emptyset}) - \psi_{\emptyset} / (1 + 1/\eta) \left(h_t^{\emptyset}(j)\right)^{1+1/\eta} \right\}. \end{aligned} \quad (12)$$

Consumption is represented by the same nested CES aggregator as for INF households, including a top level goods-oil aggregate $c_{ind,t}^{\emptyset}$ consisting of $c_{y,t}^{\emptyset}$ and $c_{o,t}^{\emptyset}$, with elasticity and share parameters θ_{oil}^c and $b_{oil}^{\emptyset}$, and a bottom level domestic-foreign goods aggregate $c_{y,t}^{\emptyset}$ consisting of $c_{H,t}^{\emptyset}$ and $c_{F,t}^{\emptyset}$, with elasticity and share parameters θ_{chf} and $b_{ch}^{\emptyset} S_t^m$. All but one of the main behavioral parameters are common across household groups, including the discount factor β_{hh} and the associated saving shock S_t^c , the labor supply elasticity η , and the two consumption elasticities of substitution θ_{oil}^c and θ_{chf} . The preference weights $\varrho_{\emptyset}$ and $\psi_{\emptyset}$,

¹¹INF households can even accumulate cash and CBDC instantaneously, because they can exchange them against existing or newly created bank deposits.

and the oil and home bias weights $b_{oil}^\emptyset$ and $b_{ch}^\emptyset$, may differ across household groups. The key behavioral parameter that is not common is habit persistence, with $\nu_\emptyset$ set to be significantly lower than ν_∞ . This is a common feature in models with liquidity-constrained households. The price of LIQ agents' consumption of non-oil goods is $P_t^\emptyset$.

For technologies, the main difference between LIQ and INF households is that LIQ households do not invest and accumulate capital, do not make production input choices, and do not set goods prices. However, agricultural production takes the same form as for INF households, with an identical shock to their endowment of agricultural labor. Stochastic phosphates endowments, priced at stochastic world prices, and stochastic remittances, are also treated in the same way as for INF households.

4.2 Money Demand

LIQ households only need money to pay for consumption goods, not for production inputs. The consumption money-in-advance constraint takes the same form as for INF households:

$$\varkappa_{cc}^\emptyset A_{cc,t}^\emptyset \geq 4 S_t^{mon} \left(P_{H,t} c_{H,t}^\emptyset (1 + \tau_{c,t}) + E_t P_{F,t}^* c_{F,t}^\emptyset (1 + \tau_{c,t}) + E_t P_{o,t}^* o_{c,t}^\emptyset \right). \quad (13)$$

The notation, except for superscripts, is the same as for INF households. Because of the absence of bank deposits, effective money for LIQ consumption $A_{cc,t}^\emptyset$ is represented by a single CES aggregate in cash and CBDC, with elasticity of substitution θ_{cc}^{nm} and cash share $b_{cc}^n S_t^{dc}$:

$$A_{cc,t}^\emptyset = \left((b_{cc}^n S_t^{dc})^{\frac{1}{\theta_{cc}^{nm}}} (N_{cc,t}^\emptyset)^{\frac{\theta_{cc}^{nm}-1}{\theta_{cc}^{nm}}} + (1 - b_{cc}^n S_t^{dc})^{\frac{1}{\theta_{cc}^{nm}}} (P_t \mathfrak{t}_{cc}^\emptyset + \mathfrak{d} M_{cc,t}^\emptyset)^{\frac{\theta_{cc}^{nm}-1}{\theta_{cc}^{nm}}} \right)^{\frac{\theta_{cc}^{nm}}{\theta_{cc}^{nm}-1}}. \quad (14)$$

The attractiveness of CBDC design, or the quality of these money balances, directly affects the tightness of the money-in-advance constraint. For LIQ households this matters far more than for INF households because they are unable to quickly augment the quantity of their money balances by obtaining loans from banks.

4.3 Budget Constraint

LIQ households choose consumption, hours and portfolio positions (cash and CBDC) to maximize (12) subject to an intertemporal budget constraint. LIQ households' end-of-period net worth $NW_t^\emptyset$ is equal to the value of its cash and CBDC balances,

$$NW_t^\emptyset = (N_{cc,t}^\emptyset + M_{cc,t}^\emptyset)(1 + \phi_{bv}(b_t^{rat} - v_t^{rat} - b_{ss}^{rat} + v_{ss}^{rat})) - \Psi_t^\emptyset. \quad (15)$$

Then LIQ households' budget constraint can be written in stylized form as

$$NW_t^\emptyset = \mathcal{R}_t^\emptyset + \mathcal{Y}_t^\emptyset + \mathcal{X}_t^\emptyset - \mathcal{E}_t^\emptyset. \quad (16)$$

The right-hand side consists of four components: $\mathcal{R}_t^\emptyset$ represents gross returns on cash and CBDC. $\mathcal{Y}_t^\emptyset$ includes after-tax wages and equal per capita shares of firm profits and after-tax endowments. $\mathcal{X}_t^\emptyset$ represents equal per capita shares of net fiscal transfers, foreign remittances, and the share $1 - \tau$ of transactions and adjustment costs that do not represent real resource costs. $\mathcal{E}_t^\emptyset$ is total after-tax expenditure on consumption. The difference between incomes and expenditures can only be saved in the form of cash or CBDC.

LIQ Households maximize lifetime utility (12) subject to budget constraints (16) and money-in-advance constraints (13).

4.4 Optimality Conditions

The consumption and labor optimality conditions, and the Euler equations for cash and CBDC, take the same form as for INF households. The optimality conditions for loans, deposits, investment and capital are absent.

5 Wage Setting

Wages are set by unions that set wages under conditions of monopolistic competition and nominal rigidities. Households supply homogeneous labor to unions at a nominal worker wage W_t^{wo} , and unions sell differentiated labor varieties to firms at a nominal producer wage $W_t^{pr}(j)$. Unions face quadratic wage adjustment costs $\mathcal{G}_{W,t}$ that penalize deviations of wage inflation from target. This generates wage inertia and helps the model to match the observed persistence of wages and prices. Wage setting is affected by a wage markup shock $S_t^{muw} = 1 + \rho_{muw}(S_{t-1}^{muw} - 1) + \epsilon_t^{muw}$. The wedge between producer wages and worker wages generates union profits, which are distributed lump-sum to households. The aggregate producer wage W_t^{pr} is a key input into firms' marginal costs and thereby affects goods price inflation.

6 Financial Investors

Financial investors represent the wholesale money markets. They hold domestic government bonds B_t that pay the nominal interest rate $i_{b,t}$ and wholesale bank deposits D_t^{fi} that pay the nominal interest rate i_t , and they issue foreign bonds F_t^{fi} . Foreign bonds issued by foreigners pay the stochastic foreign nominal interest rate $i_{f,t}^*/\bar{i}_f^* = 1 + \rho_{if}(i_{f,t-1}^*/\bar{i}_f^* - 1) + \epsilon_t^{if}$. However, foreign bonds issued by domestic borrowers pay $i_{f,t}^*(1 + \phi_f(f_t^{rat} - f_{ss}^{rat}))$, where $\phi_f(f_t^{rat} - f_{ss}^{rat})$ is a foreign exchange risk premium that depends on the deviation of the external-debt ratio f_t^{rat} from its steady-state benchmark f_{ss}^{rat} , with $\phi_f > 0$ governing the extent to which external borrowing costs rise when foreign liabilities increase. This follows Schmitt-Grohé and Uribe (Schmitt-Grohé and Uribe, 2003) by introducing a mechanism that removes the unit root in net foreign assets; in other words, it ensures that net foreign liabilities do not drift without bound. While in most models this is simply a device that ensures dynamic stability, in our case we will calibrate ϕ_f to be consistent with empirical evidence for Morocco. The foreign exchange risk premium is separate from the financial asset transaction cost, which applies equally to INF households, LIQ households, and financial investors. Financial investors do not hold CBDC because they have no need for a low-interest high-liquidity medium of exchange. They pay out their net interest earnings as dividends Π_t^{fi} that enter their utility function, with the same habit persistence as households:

$$\text{Max } \mathbf{E}_0 \sum_{t=0}^{\infty} \beta_{fi}^t S_t^c \left\{ S_t^c (1 - \nu_{\infty}) \log(\Pi_t^{fi}(j) - \nu_{\infty} \Pi_{t-1}^{fi}) \right\}. \quad (17)$$

Their end-of-period net worth NW_t^{fi} is equal to the net value of their financial balances,

$$NW_t^{fi} = (B_t + D_t^{fi} - E_t F_t^{fi})(1 + \phi_{bv}(b_t^{rat} - v_t^{rat} - b_{ss}^{rat} + v_{ss}^{rat})) - \Psi_t^{fi}. \quad (18)$$

In their budget constraint, income is derived from gross returns on assets minus gross costs of liabilities, while expenditure equals dividends. We obtain optimality conditions for dividends and for the three financial instruments. The latter determine the steady state real interest rate r^* of the economy, and they result in two arbitrage conditions. First, the interest rate on government debt equals the policy interest rate, $i_{b,t} = i_t$. Second, a modified UIP condition

$$i_t = i_{f,t} \mathbf{E}_t \varepsilon_{t+1} \left(1 + \phi_f^*(f_t^{rat} - f_{ss}^{rat}) \right). \quad (19)$$

7 Central Bank and Government

7.1 Monetary Policy

Monetary policy sets the nominal interest rate on reserves, i_t , according to a Taylor-type rule. The rule is centered on a domestic inflation objective: the policy rate responds to deviations of expected domestic producer-price inflation, $\pi_{H,t+1}^p$, from the inflation target $\bar{\pi}$. At the same time, the rule is augmented with an open-economy component, since the central bank may also react systematically to expected nominal exchange-rate depreciation, ε_{t+1} . Thus, the inflation target itself is domestic, while the overall reaction function is hybrid in the sense that it combines domestic inflation stabilization with a response to external conditions. This flexible framework can be adapted to reflect a transition towards an inflation-targeting regime. The central bank adjusts i_t with inertia around a steady-state level consistent with both the inflation target $\bar{\pi}$ and the model-consistent steady-state real interest rate r^* , where the latter incorporates the effects of a higher net government debt-to-GDP ratio. Discretionary or unexpected movements in the nominal policy rate are captured by a monetary-policy shock $S_t^{int} = 1 + \epsilon_t^{int}$:

$$i_t = (i_{t-1})^{i_i} \left(\frac{\pi x(1 + \phi_{bv}(b_t^{rat} - v_t^{rat} - b_{ss}^{rat} + v_{ss}^{rat}))}{\beta_{fi}} \right)^{1-i_i} \left(\frac{\pi_{H,t+1}^p}{\bar{\pi}} \right)^{(1-i_i)i_\pi} (\varepsilon_{t+1})^{(1-i_i)i_\varepsilon} S_t^{int}. \quad (20)$$

7.2 Fiscal Policy

Public spending on goods G_t is equal to a fixed fraction of steady state GDP multiplied by a government spending shock $G_t/\bar{G} = 1 + \rho_g(G_{t-1}/\bar{G} - 1) + \epsilon_t^g$. Public spending on transfers is equal to a fixed fraction of steady state GDP. Spending furthermore includes a cost of cash issuance $\mathcal{G}_{N,t} = s_{caco}N_t$. Spending and transfers are financed by tax revenues and by government financing instruments. Tax rates include consumption taxes (including VAT), labor income taxes, capital income taxes, and lump-sum taxes. Financing instruments include domestic currency debt B_t , foreign currency debt F_t^{gov} (with total foreign debt F_t equal to the sum of the foreign debts of the government and financial investors), cash N_t , and CBDC M_t , minus government credit to banks V_t .

Because the allocation of the economy's foreign debt between financial investors and the government is not otherwise determinate, we assume that the government maintains a constant foreign debt-to-GDP ratio,

$$100((E_t F_t^{gov})/(4 GDP_t)) = f_{ss}^{govrat}, \quad (21)$$

which implies that all variations in the economy's overall foreign debt-to-GDP ratio are due to variations in the foreign debt of financial investors.

The fiscal rule specifies a short-run target for the deficit-to-GDP ratio gd_t^{rat} that is consistent with a long-run target gd_{ss}^{rat} (which is in turn consistent with a long-run target net government debt-to-GDP ratio), and that in addition allows for systematic responses to the business cycle (the output gap $\ln(gdp_t/gdp_{ss})$), with a response coefficient of $100d^{gdp}$, and to short-run deviations of net government debt from its long-run target (the net debt gap $befnmv_t^{rat} - befnmv_{ss}^{rat}$), with a response coefficient of d^b :

$$\begin{aligned} gd_t^{rat} &= gd_{ss}^{rat} - 100d^{gdp} \ln(gdp_t/gdp_{ss}) - d^b(befnmv_t^{rat} - befnmv_{ss}^{rat}), \\ befnmv_t^{rat} &= 100(((B_t + E_t F_t^{gov} + N_t + M_t - V_t)/(4 GDP_t))), \\ gd_t^{rat} &= gd_{b,t}^{rat} + gd_{f,t}^{rat} + gd_{n,t}^{rat} + gd_{m,t}^{rat} - gd_{v,t}^{rat}, \\ gd_{x,t}^{rat} &= 100(X_t - X_{t-1})/GDP_t, \quad X \in \{B, EF, N, M, V\}. \end{aligned} \tag{22}$$

The deficit that is called for by this rule can be implemented through different combinations of fiscal instruments that may require the specification of auxiliary fiscal rules. For the simulations of the model's 22 shocks we mostly abstract from fiscal policy considerations by assuming that lump-sum taxes are adjusted, which implies that auxiliary rules are not required. For the simulation of the transition to CBDC, which has an important fiscal policy dimension, we will instead assume that consumption, labor income and capital income taxes are adjusted while lump-sum taxes are kept constant. In this case the deficit rule is assumed to endogenize the labor income tax rate while two auxiliary rules ensure that the consumption and capital income tax rates move in proportion to the labor income tax rate:

$$\begin{aligned} (\tau_{c,t} - \bar{\tau}_c)/\bar{\tau}_c &= (\tau_{L,t} - \bar{\tau}_L)/\bar{\tau}_L, \\ (\tau_{k,t} - \bar{\tau}_k)/\bar{\tau}_k &= (\tau_{L,t} - \bar{\tau}_L)/\bar{\tau}_L. \end{aligned} \tag{23}$$

7.3 CBDC Policy

The central bank policy rule for CBDC is identical to that for cash. Namely, it pays a nominal interest rate of zero, and at that rate satisfies any household demand for CBDC. The two principal means of issuing CBDC are buying government debt and granting central bank credit to banks. In our model, reflecting the preferences of the Moroccan central bank, we assume that CBDC is issued one-for-one against central bank credit to banks,

$$V_t = P_t \bar{v} + M_t, \tag{24}$$

where $\bar{v}$ is the pre-CBDC level of real credit to banks.

8 Aggregation and Market Clearing

The INF and LIQ household sections of the model are written in terms of sector-specific per capita variables identified by superscripts ∞ and $\emptyset$. On the other hand, the banking, financial investor, external, and central bank and government sections are written in terms of aggregate variables. To relate these to each other, and also for the purpose of defining some aggregate reporting variables, this section presents not only market clearing conditions but also equations that define aggregate variables in terms of sector-specific variables.

8.1 Financial Variables

The following market clearing conditions relate the aggregate financial variables pertaining to the banking and central bank and government sectors to the per capita variables of INF and LIQ households.

$$L_t = (1 - \iota)L_t^\infty, \quad (\text{Loan Market Clearing}) \quad (25)$$

$$D_t = D_t^{fi} + (1 - \iota)(D_{cc,t}^\infty + D_{kl,t}^\infty), \quad (\text{Deposit Market Clearing}) \quad (26)$$

$$N_t = (1 - \iota)(N_{cc,t}^\infty + N_{kl,t}^\infty) + \iota N_{cc,t}^\emptyset, \quad (\text{Cash Market Clearing}) \quad (27)$$

$$M_t = (1 - \iota)(M_{cc,t}^\infty + M_{kl,t}^\infty) + \iota M_{cc,t}^\emptyset, \quad (\text{CBDC Market Clearing}) \quad (28)$$

$$F_t = F_t^{gov} + F_t^{fi}. \quad (\text{Foreign Debt Market Clearing}) \quad (29)$$

8.2 Real Variables

Consumption: Equations (30) and (31) relate aggregate domestic goods consumption, which is needed for the industrial output market clearing condition, and aggregate foreign goods consumption, which is needed for the current account equation, to the quantities of consumption that are chosen by INF and LIQ households. Equations (32) and (33) relate INF and LIQ households' aggregate non-oil goods consumption, which is needed for the definition of GDP, to their per capita non-oil goods consumption.

$$C_{H,t} = (1 - \iota)c_{H,t}^\infty + \iota c_{H,t}^\emptyset, \quad (\text{Aggregate Domestic Goods}) \quad (30)$$

$$C_{F,t} = (1 - \iota)c_{F,t}^\infty + \iota c_{F,t}^\emptyset, \quad (\text{Aggregate Foreign Goods}) \quad (31)$$

$$C_{y,t}^\infty = (1 - \iota)c_{y,t}^\infty, \quad (\text{Aggregate INF Households' Non-Oil Goods}) \quad (32)$$

$$C_{y,t}^\emptyset = \iota c_{y,t}^\emptyset. \quad (\text{Aggregate LIQ Households' Non-Oil Goods}) \quad (33)$$

Hours: The market clearing condition for hours (34) equates the demand for inputs of labor hours by INF households in their function as managers of firms to the supply of labor hours by INF households in their function as households and the supply of labor (weighted by population shares) of LIQ households. Aggregate hours in the second equation (35) is needed as one of the reporting variables.

$$h_{ind,t}^{\infty} = h_t^{\infty} + (\iota/(1 - \iota))h_t^{\emptyset}, \quad (\text{Hours Market Clearing}) \quad (34)$$

$$H_t = (1 - \iota)h_t^{\infty} + \iota h_t^{\emptyset}. \quad (\text{Aggregate Hours}) \quad (35)$$

Capital and Investment: The capital market clearing condition (36) equates the demand for capital inputs by INF households in their function as managers of firms to the supply of capital by INF households in their function as households. The next two equations (37) and (38) relate aggregate domestic goods investment, which is needed for the industrial output market clearing condition, and aggregate foreign goods investment, which is needed for the current account equation, to the quantities of investment that are chosen by INF and LIQ households. Aggregate capital and investment in the final two equations (39) and (40) are needed as reporting variables.

$$k_{ind,t}^{\infty} = k_{t-1}^{\infty}/x, \quad (\text{Capital Market Clearing}) \quad (36)$$

$$I_{H,t} = (1 - \iota)i_{H,t}^{\infty}, \quad (\text{Aggregate Domestic Investment Inputs}) \quad (37)$$

$$I_{F,t} = (1 - \iota)i_{F,t}^{\infty}, \quad (\text{Aggregate Foreign Investment Inputs}) \quad (38)$$

$$K_t = (1 - \iota)(k_{t-1}^{\infty}/x), \quad (\text{Aggregate Capital}) \quad (39)$$

$$I_t = (1 - \iota)i_t^{\infty}. \quad (\text{Aggregate Investment}) \quad (40)$$

Agriculture: Equations (41) and (42) relate aggregate agricultural goods production and consumption, which are needed for the current account equation and for the definition of GDP, to the quantities produced and consumed by INF and LIQ households.

$$Y_{ag,t} = (1 - \iota)y_{ag,t}^{\infty} + \iota y_{ag,t}^{\emptyset}, \quad (\text{Aggregate Agricultural Goods Output}) \quad (41)$$

$$C_{ag,t} = (1 - \iota)c_{ag,t}^{\infty} + \iota c_{ag,t}^{\emptyset}. \quad (\text{Aggregate Agricultural Goods Consumption}) \quad (42)$$

Oil: Equation (43) relates aggregate oil purchases, which are needed for the current account equation and for the definition of GDP, to the quantities consumed by INF and LIQ households. Aggregate INF and LIQ oil consumption in equations (44) and (45) are needed in the definition of GDP.

$$O_t = (1 - \iota)(o_{c,t}^\infty + o_{y,t}^\infty) + \iota o_{c,t}^\emptyset, \quad (\text{Aggregate Oil Purchases}) \quad (43)$$

$$O_{c,t}^\infty = (1 - \iota)o_{c,t}^\infty, \quad (\text{Aggregate INF Oil Consumption}) \quad (44)$$

$$O_{c,t}^\emptyset = \iota o_{c,t}^\emptyset. \quad (\text{Aggregate LIQ Oil Consumption}) \quad (45)$$

Industrial Output: Equation (46) equates aggregate industrial output to INF household per capita industrial output multiplied by the population share of INF households. Equation (47) equates the aggregate supply of industrial output to the different components of its demand, including aggregate domestic goods consumption purchases $C_{H,t}$ and investment purchases $I_{H,t}$, government spending on goods G_t (which is assumed to be spent exclusively on domestic goods), a stochastic foreign demand for domestic goods $Y_{H,t}^*/\bar{Y}_H^* = 1 + \rho_{y_H^*}(Y_{H,t-1}^*/\bar{Y}_H^* - 1) + \epsilon_t^{y_H^*}$, and finally the share $\mathfrak{r}$ of monitoring and transactions costs that represents resource costs.

$$Y_{ind,t} = (1 - \iota)y_{ind,t}^\infty, \quad (\text{Aggregate Industrial Output}) \quad (46)$$

$$Y_{ind,t} = C_{H,t} + I_{H,t} + G_t + Y_{H,t}^* + \mathfrak{r}P_t(\mathcal{M}_t^b + \mathcal{M}_t^k + \mathcal{G}_{N,t} + \mathcal{G}_{L,t} + \mathcal{G}_{P,t} + \mathcal{G}_{W,t})/P_{H,t}. \quad (\text{Industrial Output Market Clearing}) \quad (47)$$

8.3 GDP

GDP: Nominal GDP at market prices is the sum of INF and LIQ households' aggregate non-oil industrial goods, oil and agricultural goods consumption, aggregate investment spending, and aggregate government spending, plus exports minus imports.

$$\begin{aligned} GDP_t = & P_t C_{y,t}^\infty (1 + \tau_{c,t}) + P_t^\emptyset C_{y,t}^\emptyset (1 + \tau_{c,t}) + E_t P_{o,t}^* (O_{c,t}^\infty + O_{c,t}^\emptyset) \\ & + E_t P_{ag,t}^* C_{ag,t} + P_{I,t} I_t + P_{H,t} G_t + EXP_t - IMP_t. \end{aligned} \quad (48)$$

Exports: Exports are the sum of non-oil industrial goods exports, net agricultural exports, and phosphates exports.

$$EXP_t = P_{H,t} Y_{H,t}^* + E_t P_{ag,t}^* (Y_{ag,t} - C_{ag,t}) + E_t P_{ph,t}^* \Omega_{ph,t}^*. \quad (49)$$

Imports: Imports are the sum of purchases of foreign goods for consumption and investment purposes and of total oil purchases.

$$IMP_t = E_t P_{F,t}^* C_{F,t} + E_t P_{F,t}^* I_{F,t} + E_t P_{o,t}^* O_t. \quad (50)$$

When reporting impulse responses, GDP is constructed as a Fisher-weighted quantity index. This ensures that real GDP movements reflect changes in quantities rather than relative price movements among the components of GDP. This is especially important when foreign goods and commodity prices are volatile and when exchange rate movements change the local-currency value of trade flows.

8.4 Inflation and Interest Rates

Inflation measures are derived from the model's price indices. Core or producer price inflation is identified with the rate of change of the producer price of domestic goods $\pi_{H,t}$, while CPI inflation is identified with the rate of change of the consumer price of non-oil industrial goods π_t . CPI inflation therefore excludes the prices of oil and of agricultural goods, while core inflation in addition excludes the price of foreign non-oil industrial goods.

For reporting purposes, for inflation and depreciation rates we will generally present forward-looking measures, for example $\pi_{H,t}^{report} = \pi_{H,t+1}$, while any initial price level jumps in response to shocks can be inferred from jumps in the respective relative prices. For real interest rates, because monetary policy will be assumed to target core inflation, real interest rates are reported as nominal rates deflated by the expected core inflation rate. Therefore, any real interest rate on instrument x is reported for time t as $r_{x,t}^{report} = i_{x,t} / \pi_{H,t+1}$.

8.5 Current Account

This subsection closes the small open economy by linking the economy's net foreign liability position $E_t F_t$ to the interest expenses on foreign debt and to the trade balance. This aspect of the model is particularly important for the Moroccan economy, which is exposed to volatile world prices for goods and commodities, and where remittances are a large and volatile source of external income. Net foreign liabilities are given by

$$E_t F_t = i_{f,t-1}^* E_t F_{t-1} \left(1 + \phi_f (f_{t-1}^{rat} - f_{ss}^{rat}) \right) + E_t P_{F,t}^* C_{F,t} + E_t P_{F,t}^* I_{F,t} + E_t P_{o,t}^* O_t - P_{H,t} Y_{H,t}^* - E_t P_{ph,t}^* \Omega_{ph,t}^* - E_t P_t^* J_t^* - E_t P_{ag,t}^* (Y_{ag,t} - C_{ag,t}). \quad (51)$$

We have commented on the foreign interest rate and the foreign exchange risk premium in Section 6. Imports of foreign consumption and investment goods $E_t P_{F,t}^* (C_{F,t} + I_{F,t})$ and of oil $E_t P_{o,t}^* O_t$ increase external debt, while exports of domestic goods $P_{H,t} Y_{H,t}^*$, phosphates exports $E_t P_{ph,t}^* \Omega_{ph,t}^*$, foreign remittances $E_t P_t^* J_t^*$ and net agricultural exports $E_t P_{ag,t}^* (Y_{ag,t} - C_{ag,t})$ reduce external debt.

9 Calibration

In this section we discuss the calibration of the model economy's steady state, divided into the real and financial sectors, in Sections 9.1-9.2, followed by the calibration of the model's dynamic parameters in Section 9.3. All references to sample averages refer to approximate Moroccan averages over the last 2-3 years.

9.1 Real Sector Steady State

Basics: Trend productivity growth x is set to equal 2% in annual terms.¹² The real interest rate $\bar{r}$ is set to 3% in annualized terms by adjusting the discount factor of financial investors β_{fi} . The target for domestic core inflation $\bar{\pi}$ is set to 1% per annum, roughly equal to average Moroccan inflation for 2024. The foreign inflation rate π^* is held fixed at 1%. We match the 54% share of the Moroccan population that has access to a bank account, as reported in Bank Al-Maghrib (2024), by setting $\iota = 0.46$. Parameters that determine LIQ households' shares of different lump-sum incomes are all set equal to $\iota = 0.46$, so that all households receive identical per capita amounts of these incomes.

¹²This parameter was for simplicity omitted from the above presentation.

Preferences: Following Christiano et al. (2014) we fix the elasticity of labor supply at $\eta = 1$ and we normalize labor supplies at 1 by adjusting the preference weights ψ_∞ and $\psi_\emptyset$. We fix habit persistence at $\nu_\infty = 0.75$ and $\nu_\emptyset = 0.25$ – the assumption of a lower value for liquidity-constrained households is common in the literature. The elasticities of substitution between domestic and foreign consumption and investment goods are set to $\theta_{chf} = \theta_{ihf} = 1.5$, a common value in the business cycle literature.

Technologies: Steady state price and wage gross markups are fixed at $\mu_p = \mu_w = 1.1$, in line with much of the literature. The share of transactions and adjustment costs that represent real resource costs is set to $\tau=0.5$. The collateral haircut parameter κ and the capital share parameter α are fixed to match the sample averages for the Moroccan capital-to-GDP ratio of 233% (IMF ICSD data) and the ratio of compensation of employees to GDP (Moroccan national accounts). The model equivalent of compensation of employees is total labor income derived from industrial goods production plus 100% of the endowment incomes earned in agricultural goods and phosphates production.¹³ We set the ratio of investment to GDP to its sample average of 26.0% by adjusting the depreciation rate Δ .

Oil/Energy: We adjust the three CES oil/energy share parameters b_{oil}^∞ , $b_{oil}^\emptyset$ and b_{oil}^y to fix three ratios pertaining to the oil sector. The oil imports-to-GDP ratio is fixed at its Moroccan sample average of 8.3%. We fix the share of oil use in production in total oil use (consumption plus production) at 50%. We fix share of oil consumption of LIQ households in total oil consumption (INF plus LIQ households) at the share ι of LIQ households in the population. Finally, the elasticities of substitution between oil and other consumption goods θ_{oil}^c and other production inputs θ_{oil}^y are set to a low 0.05, to represent the fact that energy is an indispensable factor in both production and consumption, and needs to grow approximately in line with economic activity almost regardless of the price.

Agriculture: We adjust the four agricultural sector preference and endowment parameters ϱ_∞ , $\varrho_\emptyset$, $\bar{h}_{ag}^\infty$ and $\bar{h}_{ag}^\emptyset$ to fix four ratios pertaining to the agricultural sector. The ratios of aggregate agricultural production and consumption to GDP are fixed at their sample averages of 10.6% and 11.0%, while the shares of LIQ households in agricultural production and consumption are fixed at their population share ι .

External Sector: The ratios to GDP of industrial goods exports, phosphates exports and foreign remittances are set to their sample averages of 16.0%, 6.0% and 8.1% by adjusting

¹³We have found that, unless endowment incomes are fully assigned to labor incomes, rates of return to capital and many variables in banks' lending technology, which depend on capital collateral, become distorted. With our assignment, the calibration outcome is very plausible. Intuitively, we can think of the capital stock of the industrial sector as providing services to the phosphates and agriculture sectors. This capital stock has a share greater than 50% in the industrial goods production function, but not in overall production.

the exogenous variables $\bar{Y}_H^*$, $\bar{\Omega}_{ph}$ and $\bar{j}^*$. We adjust the three CES share parameters b_{ch}^∞ , $b_{ch}^\emptyset$ and b_{ih} to fix three ratios. First, the real exchange rate is normalized to 1. Second, the ratio of INF to LIQ households' per capita consumption of imports is set to 2, to reflect the fact that these households are on average wealthier. Third, the share of imported investment goods in total investment goods is fixed at its sample average of 40%. The price of foreign goods $\bar{p}_F^*$ is normalized to 1. The total and government foreign debt-to-GDP ratios are fixed at their sample averages of 48.8% and 17.3% by adjusting the parameters f_{ss}^{rat} and f_{ss}^{govrat} , leaving financial investors to hold the remainder of 31.5%.

Fiscal Sector: The government spending-to-GDP ratio is set to its sample average of 18.1% by adjusting s_g . The sample average of the overall government debt-to-GDP ratio equals 68.6% (IMF World Economic Outlook). Given our above calibration of the foreign currency portion of that debt, this leaves a domestic currency government debt-to-GDP ratio of 51.3%, which we fix by adjusting gd_{ss}^{rat} . The ratio of central bank credit to banks is fixed at its recent sample average of 8.8% (Bank Al-Maghrib, 2024) by adjusting the coefficient $\bar{v}$. We set the marginal tax rates τ_L , τ_k and τ_c to match the recent averages for the ratios of labor income, capital income and consumption taxes to GDP of 3.5%, 4.3% and 10.9%. Net lump-sum transfers are adjusted to balance the budget.

9.2 Financial Sector Steady State

Bank Capital Ratios: The minimum capital adequacy ratio (MCAR) is set to $\gamma = 0.09$ to match the Category 1 regulatory ratio applicable to Moroccan banks. Banks generally hold capital considerably above the regulatory minimum. Based on the data in Bank Al-Maghrib (2024), we therefore set the actual capital ratio to 12.4%, for an endogenous capital buffer of 3.4%, by adjusting banks' dividend payout parameter δ_b .

Non-compliance and Bankruptcy Rates: Based on assessments of BAM experts we set the cumulative share of banks that violate the Basel minimum in any quarter F^b to 1.0%, by adjusting the bank riskiness parameter σ^b , and the bankruptcy rate of bank borrowers F^k to 2.5% by adjusting the loss-given-default parameter ξ .

Interest Rates and Spreads: Interest rates are anchored by calibrating the domestic and foreign real interest rates r and r_f^* at 3% and 2% by adjusting the discount factor of financial investors β_{fi} and the exogenous variable $\bar{i}_f^*$. We relied on BAM expert assessments to calibrate the real wholesale lending rate r_ℓ at 3.5% by adjusting the MCAR parameter χ . We calibrate the real retail lending and deposit rates r_r and r_d at 5.5% and 1.0%, based on recent mortgage rates and deposit rates reported at the website of Bank al-Maghrib, by adjusting the borrower risk and deposit markdown parameters σ^k and μ_d .

Balance Sheets: Based on data in Bank Al-Maghrib (2024), we fix the ratios to GDP of bank loans and of INF households' total (consumption and production) transactions deposits at 108.3% and 56.5%, by adjusting the household discount factor β_{hh} and the consumption velocity constant κ_{cc}^∞ . We then make the assumption that 80%/20% of the transactions deposits are used for consumption/production purposes, by adjusting the production velocity constant κ_{kl}^∞ . The foregoing calibrations of steady state asset and liability positions, together with the steady state net worth position implied by the calibration of bank capital ratios, leaves the financial investor wholesale deposits to GDP ratio as a residual, at 29.6% of GDP.

Interest Elasticities: The elasticity of the real policy interest rate with respect to changes in the government debt-to-GDP ratio is the subject of Laubach (2009), Engen and Hubbard (2004) and Gale and Orszag (2004), who report, for the US, that each percentage point increase in the debt ratio increases the real interest rate by between 1 and 6 basis points. This concept has more recently also been incorporated into the IMF's framework for debt sustainability analysis (International Monetary Fund (2021, 2022)), which uses a baseline elasticity of 4 basis points. Our calibration adopts the same value, by adjusting the parameter ϕ_{bv} . The elasticity of the real foreign interest rate with respect to changes in the foreign debt-to-GDP ratio is fixed at the same 4 basis points by adjusting the parameter ϕ_f .

Cash: Based on the data reported in Bank Al-Maghrib (2023), we fix the ratios to GDP of INF households' consumption and production cash balances and LIQ households' consumption cash balances at 7.6%, 7.6% and 13.0%, by adjusting the parameters b_{cc}^d , b_{kl}^d and $\kappa_{cc}^\emptyset$. We set the semi elasticities (in consumption and production) of INF households' cash demand with respect to the policy interest rate to 5% for a 1 percentage point increase in the policy rate, following the estimate in Ball (2001). According to an ongoing study by BAM, cash management costs are calibrated at 0.3% of GDP through the parameter s_{caco} .

CBDC: Calibrating the CBDC sector is challenging because neither the Moroccan nor any other significant economy has so far had much practical experience with CBDC. We are therefore forced to make a number of assumptions that appear plausible, but that may have to be revised later in light of experience. See Section 3.2 for a discussion.

First, the real constants $\mathfrak{k}_{cc}^\infty$, $\mathfrak{k}_{kl}^\infty$ and $\mathfrak{k}_{cc}^\emptyset$ are calibrated at 10% of the pre-CBDC real monetary aggregate. Second, the CBDC efficiency parameter is calibrated at $\bar{\delta} = 1.1$. Third, the liquidity aggregate share coefficients b_{cc}^u , b_{kl}^u and b_{cc}^d are set to 0.8, and the respective elasticity coefficients θ_{cc}^{um} , θ_{kl}^{um} and θ_{cc}^{nm} to 0.6. This implies an interest semi-elasticity of CBDC demand of about 3.5% for a 1 percentage point increase in the policy rate.

We have no empirical data, and certainly no Morocco-specific data, to directly validate our substitutability assumptions. But we do have bank-level empirical studies on the stickiness, or lack of responsiveness to interest rate differentials, of deposits held at different

financial institutions. Using data from major UK and US banks, Chiu and Hill (2018), Adams et al. (2007), Dick (2008), Ho and Ishii (2011), and Kuehn (2018) find that a 1 percentage point increase in an individual institution’s deposit rate is associated with an increase in the total stock of deposits of that institution of 0.3%, 2.44%, 1.77%-2.99%, 1.36%, and 2.32%, while our calibration implies a very similar and in fact slightly higher value of 3.5% for CBDC. This literature strongly suggests that a very high substitutability would be an inappropriate assumption.

These calibration choices should nevertheless be interpreted as assumptions for scenario analysis rather than as empirical estimates of CBDC adoption in Morocco. In particular, the elasticity of substitution and the relative transactional efficiency of CBDC are key determinants of its demand and of the resulting reallocation of monetary balances. Alternative parameterizations could therefore be considered to assess the sensitivity of the results to different CBDC design and adoption scenarios.

9.3 Dynamic Parameters

Policy Rule Parameters, Transition Simulation: For the interest rate on reserves we assume a conventional Taylor rule without interest rate smoothing $i_i = 0$, an inflation coefficient of $i_\pi = 2.4$, and an exchange rate coefficient of $i_\varepsilon = 0$. For CBDC and cash, the rules are to pay a zero interest rate. For the fiscal rule, we assume that $d^{gdp} = 0.75$ and $d^b = 0.2$, with distortionary taxes used to meet deficit targets. These rules ensure that the central bank and the government help to speed up the transition to the new steady state. The central bank does so through an immediate and strong response to any initial spikes in inflation, while the government does so by activating automatic stabilizers which ensure that the budget and debt reach their new steady states more quickly, and that households benefit from any additional fiscal space through lower distortionary taxes.

Policy Rule Parameters, Shock Simulations: For the interest rate on reserves we assume a conventional Taylor rule with interest rate smoothing $i_i = 0.7$, an inflation coefficient of $i_\pi = 2.0$, and an exchange rate coefficient of $i_\varepsilon = 1.5$. For CBDC and cash, the rules are to pay a zero interest rate. For the fiscal rule, following Anderson et al. (2013), we assume that $d^{gdp} = 0.48$ and $d^b = 0.08$, with lump-sum taxes used to meet deficit targets, and with distortionary tax rates held constant. These rules isolate the role of monetary policy while minimizing the role of fiscal policy.

Adjustment Cost Parameters and Shocks, All Simulations: The price and wage rigidity coefficients are calibrated at $\phi_p = \phi_w = 300$. Investment adjustment costs are set to $\phi_i = 0.8$ and loan adjustment costs to $\phi_\ell = 0$. For the purpose of illustrative shock simu-

lations, most first-order shock autocorrelation coefficients are set to 0.9, with the exception of investment demand shocks ($\rho_i = 0.7$) and monetary policy shocks ($\rho_{int} = 0$). The sizes of shocks in the shock simulations are $\epsilon_t^{lev} = +0.1$, $\epsilon_t^{cred} = -0.1$, $\epsilon_t^{mon} = +0.03$, $\epsilon_t^{dc} = -0.05$, $\epsilon_t^c = -0.02$, $\epsilon_t^m = -0.02$, $\epsilon_t^i = -0.02$, $\epsilon_t^g = -0.005$, $\epsilon_t^{int} = +0.0025$, $\epsilon_t^a = -0.01$, $\epsilon_t^{hag} = -0.05$, $\epsilon_t^{mup} = +0.01$, $\epsilon_t^{muw} = 0.01$, $\epsilon_t^{ks} = -0.003$, $\epsilon_t^{y_H^*} = -0.05$, $\epsilon_t^{qp} = -0.05$, $\epsilon_t^{pp} = -0.1$, $\epsilon_t^{fr} = -0.1$, $\epsilon_t^{pa} = -0.05$, $\epsilon_t^{po} = +0.05$, $\epsilon_t^{pf} = +0.02$, $\epsilon_t^{if} = 0.0025$.

10 Impulse Responses (IRFs)

This section reports impulse responses for the transition from the pre-CBDC economy to the CBDC economy and for the 22 shocks that are present in the model. All IRFs are reported after the bibliography, in Figures 4 – 34.

In the shock simulations, black lines report IRFs for the pre-CBDC economy while green lines report IRFs, for the same shock, for the CBDC economy. Because the introduction of CBDC changes the steady state of the model economy, the short-run fluctuations shown in the shock simulations are around different steady states.

The horizontal axis in each subplot represents quarters. For the transition simulation we report 60 quarters or 15 years, while for the shocks we report 20 quarters or 5 years. Real variables are reported in percent deviations from steady state, inflation rates and interest rates in annualized percentage point deviations from steady state, and balance sheet variables in percentage point deviations from steady state. All balance sheet variables are reported as ratios relative to steady state GDP. This helps interpretation, because in this way the reported variables represent changes in balance sheets that are not “contaminated” by changes in GDP. The figures that report balance sheets show four rows, for households, banks, government, and financial investors. Some subplots repeat when one agent group’s asset is another agent group’s liability. The variable “Money Tax Rate” refers to the money tax rate associated with the consumption money-in-advance constraint of INF households. The variable “Real CBDC Rate” refers to the variable $r_{m,t} = 1/\pi_{H,t+1}$. The sign of each shock is chosen to generate a contractionary scenario.

10.1 Transition Towards an Economy with CBDC

The transition scenario studies the effects of introducing CBDC instantaneously at time 0. Given the zero interest rate on CBDC, its quantity is demand-determined. We assume that CBDC’s productivity in generating liquidity services takes time to be fully realized, with $\bar{\theta}$ slowly growing from 0.5 to 1.1 over a period of 6 years. The solid line represents the actual transition path while the dotted step function shows the long-run change in the steady state. Due to the real effects of this shock, in particular to capital and government debt accumulation, this new steady state takes a number of years to be reached. We begin by looking at the balance sheet effects in Figure 4, and then turn to the real economy in Figure 5.

The balance sheets in Figure 4 show some transitional effects, particularly to the net foreign liabilities position, but the bulk of the domestic balance sheet effects is realized very quickly. We will therefore focus our comments on steady state changes.

Households respond to the availability of a new medium of exchange by demanding CBDC equal to 6.6% of GDP. This allows them to reduce their holdings of cash and retail deposits by 5.6% and 10.6% of GDP while increasing their effective liquidity by well over 1%. In the long run, *banks* more than make up for the reduction in retail deposits (-10.6% of GDP) through higher wholesale deposits from financial investors (+4.9% of GDP) and higher credit from the central bank (+6.6% of GDP), which reflects a slightly higher long-run stock of loans (+1.0% of GDP). The *government* issues the CBDC of 6.6% of GDP through credit to banks of 6.6% of GDP. It compensates for the loss in cash holdings of 5.5% of GDP by issuing additional interest bearing debt of 5.5% of GDP. By assumption the ratio of government foreign debt is constant relative to GDP.

These results depend on the assumed CBDC issuance mechanism and on the availability of central bank refinancing. In particular, the ability of banks to replace lost retail deposits with central bank credit and wholesale funding limits the potential contraction in bank lending. Alternative arrangements involving more costly or constrained access to refinancing could lead to different outcomes, including stronger pressures on bank funding costs and credit supply.

The real economic implications of these balance sheet changes operate mostly through real interest rates. A key observation is that while interest-bearing government bonds are a debt of the consolidated government, cash and CBDC are not debts and are in fact equity-like hybrid instruments. The main but not the only reason is that, unlike for bonds, holders of cash or CBDC cannot call on the government to redeem these instruments in anything other than more cash or more CBDC, and can therefore never trigger default. See Kumhof et al. (2020) for more details.

Furthermore, in the case of Morocco the relevant magnitude is the debt of the consolidated government net of central bank credit to banks $B_t - V_t$. This decreases by a modest 1.1% of GDP and, with our assumptions about the elasticity of real interest rates with respect to net debt, this triggers a long-run decline in real interest rates of just over 4 basis points. While not insignificant, this is nevertheless much smaller than for large OECD economies, see Barrdear and Kumhof (2022). The reason is that in those economies reduced holdings of bank deposits are likely to be the main counterpart of higher CBDC holdings, while the effects on cash holdings, which start out small, are likely to be much smaller.

As shown in Figure 5, the introduction of CBDC moderately stimulates the real economy, with additional year-on-year output growth of between 0.1% and 0.2% over the years following the introduction of CBDC, and with long-run output 0.7% higher relative to trend. The main reason is a more than 1% increase in effective liquidity, especially for LIQ households and firms where the increase is around 1.5%. This in turn allows money tax rates to drop

by 15% on impact and by almost 30% after a few years, which immediately stimulates both consumption and production. It also generates inflationary pressure because consumption responds more immediately than production. Specifically, core inflation, exchange rate depreciation, and CPI inflation increase by 0.4, 0.9, and 0.55 percentage points on impact.¹⁴ The real policy rate responds to higher inflation and depreciation through a 0.3 percentage point increase, and thereafter takes many years to reach its 4 basis points lower long-run level, thereby increasing government debt servicing costs in the short run. This in turn means that two important beneficial effects of the CBDC introduction, lower real interest rates and lower distortionary tax rates due to greater fiscal space, are only realized after a number of years. Over the first 3 to 4 years all tax rates have to rise to finance the higher interest charges on the debt, while in the longer run reduced financing costs permit a reduction in the consumption and capital income tax rates by around 0.6 percentage points.

The adjustment differs across household types. LIQ households experience a larger and more volatile adjustment in liquidity since they cannot smooth by changing indebtedness. Their adjustment therefore occurs through real saving decisions. INF households, by contrast, can re-optimize their liquidity positions much more rapidly, by changing their deposits instantaneously through changes in loans, without any need for saving. This allows them to smooth liquidity and through this consumption more effectively. This asymmetry highlights that while CBDC can quickly improve the *quality* of transaction liquidity, it does not by itself eliminate vulnerabilities associated with financial exclusion because it cannot quickly increase the *quantity* of transaction liquidity.

10.2 Financial Shocks

This subsection examines shocks that primarily originate in or affect the financial sector and its balance sheets. Unlike for real demand shocks, such as shocks to consumption or investment demand, the primary driver here is banks adjusting balance sheet quantities and spreads. The experiments are especially informative about the interaction between bank credit supply frictions and payments frictions, and about the extent to which CBDC can help to stabilize monetary aggregates and thereby the real economy. We will in each case first discuss the balance sheet implications and then the real macroeconomic implications.

10.2.1 Bank Leverage Shock

The leverage shock in Figures 6–7 is specified as an increase in the bank capital adequacy requirement S_t^{lev} that could be due to a regulatory intervention or alternatively to a business

¹⁴The exchange rate depreciation follows an initial 1% real appreciation.

decision of banks to deleverage. It raises the Tier 1 capital adequacy target.

Figure 6 reports the balance sheet implications. Banks respond to the shock by restricting lending and increasing lending spreads. On the bank liability side, deposits fall as the balance sheet contracts. This includes both retail and wholesale deposits. Households react to the reduced availability of retail deposits by reallocating transaction balances towards cash and, when available (the green lines) CBDC. The increases in cash and CBDC are smaller than the decline in deposits. This partly reflects imperfect substitutability in transaction services. But it also reflects the fact that in the short run households need to draw down their retail bank deposits even further in order to obtain additional cash or CBDC. The central bank accommodates the CBDC issuance by increasing lending to banks, thereby replacing the lost deposits. We observe that the availability of CBDC significantly dampens the effects of this shock on bank loans and bank deposits, by reducing monetary frictions and thereby maintaining a stronger demand for deposits.

Figure 7 reports the real effects. Output declines as credit supply tightens and borrowing costs rise. Inflation, exchange rate depreciation, and real interest rates drop. The availability of CBDC helps only modestly to reduce the real effects of bank deleveraging.

10.2.2 Bank Credit Supply Shock

The credit supply shock in Figures 8–9 is specified as a decrease in banks' credit collateral valuation S_t^{cred} that reduces banks' willingness to lend against available collateral.

Figure 8 shows that the shock generates a cumulative decline in bank lending of around 1.5% of steady state GDP over three years, and through this a similar decline in bank deposits, with retail deposits accounting for more than half of the adjustment over the medium run but most of the adjustment in the short run. The latter reflects feedback effects from lower supply of transactions balances to lower real activity and through this to even lower demand for transactions balances.

Without CBDC, households partially offset lower retail deposit balances by increasing cash holdings to meet transaction needs. However, because substitution across transactions balances is imperfect, the contraction in deposits translates into a large decline in aggregate money balances and therefore into a tightening of the monetary friction. With CBDC, households increase both CBDC and cash. CBDC issuance is accommodated through central bank lending to the banking sector. Similar to the previous shock, the availability of CBDC significantly dampens the effects of the shock on bank loans and bank deposits, by reducing monetary frictions and thereby maintaining a stronger demand for deposits.

Figure 9 shows that output declines, driven by weaker consumption and investment which are in turn due to tighter credit and monetary conditions. Inflation, exchange rate

depreciation, and real interest rates drop. However, in this case the availability of CBDC mitigates the output loss more significantly by allowing households to partly compensate for the loss of transactions balances – notice the much reduced increase in the money tax rate. This in turn has positive feedback effects, because higher real activity encourages banks to limit the contraction in lending and therefore in deposit creation.

10.2.3 Money Demand Shock

The money demand shock in Figures 10–11 is specified an increase S_t^{mon} that reduces the desired velocity of money. In other words, households increase the desired ratio of money balances to real activity, and this leads to a combination of higher money balances, a higher money tax rate, and lower real activity.

Figure 10 shows that without CBDC the increase in demand for money relative to real activity is met through higher holdings of deposits, obtained through additional bank loans, and cash, obtained either through drawdowns of bank deposits (INF households) or through saving (LIQ households), while Figure 11 shows the corresponding reduction in the demands for consumption and investment. Relative to GDP the amplitude of fluctuations of deposits is greater than that of cash because the steady state quantity of deposits is larger. When CBDC is available, part of the increase in money demand can be accommodated through higher CBDC holdings, so that deposits and cash increase by significantly less. Again, and more significantly than before, CBDC dampens the effects of the shock on bank loans and bank deposits. On the government’s balance sheet, under the assumptions of our model, the increase in demand for CBDC is met through an increase in central bank lending to banks, while the increase in demand for cash is met through a reduction in government debt. Both reduce the free float of government debt and thereby improve fiscal sustainability.

Figure 11 shows the contractionary real effects of the shock. The availability of CBDC provides more ample money, which is reflected in a much smaller increase in the money tax rate. This reduces the need for a sharp contraction in spending, with consumption and especially investment contracting significantly less. Inflation, the exchange rate, and interest rates are also less volatile. In this case the availability of CBDC mitigates the output loss even more significantly than for the credit supply shock, by allowing households to more easily satisfy the desired increase in money balances.

10.2.4 CBDC Demand Shock

The CBDC-demand shock in Figures 12–13 is specified as an increase in households’ CBDC preference weight S_t^{dc} in the three money aggregators. This shock is only relevant for the

CBDC economy, which is why the black lines are absent in the figures.

Figure 12 shows that this shock primarily affects the composition rather than the overall quantity of money. Household CBDC balances increase while their cash and deposit balances decrease, with limited implications for the total quantity of money and therefore (see Figure 13) the money tax rate. Although households shift a large quantity of deposits into CBDC, total bank lending changes by much less, while the central bank accommodates CBDC issuance by replacing bank deposits with loans to banks. Figure 13 shows that output, consumption, and investment responses are small, as are the effects on inflation and interest rates.

10.3 Demand Shocks

This subsection groups shocks to different agents' spending plans. With such shocks payment balances are mostly demand determined, and the presence of CBDC generally has only small effects on aggregate outcomes. We therefore reverse the ordering of the figures to show the real effects first, and we only show balance sheet effects for a few shocks where they are significant. The same holds for supply shocks and external shocks in the subsequent subsections.

10.3.1 Saving Shock

The saving shock is specified as a decrease in saving preference S_t^c that leads to a decrease in desired consumption and an increase in desired working hours, in other words an increase in desired saving. Figure 14 shows that higher saving is reflected in higher investment and, over time, a higher capital stock that is the main reason behind a gradual but modest increase in GDP. Inflation and monetary policy remain largely unchanged.

Figure 15 shows that the effects on money demand are very modest. In general, following aggregate demand shocks, the direction of the change in money demand is ambiguous. This is because it depends on the relative effects of these shocks on consumption, investment, and input demand, as well as on the extent to which these real demand components translate into demand for money. In this case the shock primarily reduces consumption money demand, and because this demand is very large in steady state, overall demand for money and thus the money tax rate decreases slightly. Furthermore, the reduction in consumption money demand permits an expansion of production money balances (this is not shown here), which reduces marginal cost and increases production. But these effects are very modest and are not the main reason for the increase in GDP. This is a very general result for all demand shocks.

10.3.2 Import Demand Shock

The import demand shock is specified as a decrease in consumption and investment home bias S_t^m that leads to an increase in the demand for imported goods. Figure 16 shows that this reduces the demand for domestic goods, domestic incomes, and GDP. The real exchange rate depreciates as the trade balance deteriorates. Inflation rates, depreciation rates, and interest rates decline. This disturbance operates mainly through real reallocations and relative price changes. Financial variables and monetary aggregates are demand determined and are not the primary transmission channel. CBDC therefore has only limited ability to help the economy to deal with this shock.

10.3.3 Investment Demand Shock

The investment demand shock is specified as a decrease in the marginal efficiency of investment S_t^i that leads to an decrease in the demand for investment. Figure 17 shows that investment falls on impact, which in turn slows capital accumulation and causes a persistent decline in GDP. Inflation rates, depreciation rates, and interest rates decline. Consumption rises slightly, reflecting some household reallocation of spending towards consumption in response to weaker investment opportunities, but this increase is not large. The money tax rate falls because of lower demand for money balances. Externally, due to the very high import content of investment, this shock acts like a negative import demand shock, and therefore has the opposite effects to the import demand shock discussed above, namely a real appreciation and an improvement in the current account. On the financial side (not shown), this shock significantly reduces the market price of capital Q_t , which in turn reduces the value of loan collateral. As a result, loans and deposits fall. Households therefore satisfy some of their liquidity needs through cash and CBDC instead of bank deposits.

10.3.4 Government Spending Shock

The government spending shock is specified as a decrease in public expenditure $G_t/\bar{G}$. Figure 18 shows that this reduces output (despite a modest crowding-in of consumption and investment), inflation, and interest rates. The real exchange rate depreciates. The effects on balance sheets are very small.

10.3.5 Monetary Policy Shock

The monetary policy shock is specified as a contractionary increase in the nominal policy interest rate S_t^{int} that raises the nominal policy rate by 1 percentage point. The shock itself is not persistent, but it has persistent effects due to interest rate smoothing.

Figure 19 shows that the real effects of the shock are contractionary. Output, consumption, and investment decline as higher real interest rates reduce aggregate demand. Bank lending contracts as higher borrowing costs reduce credit demand. Inflation declines and this contributes to a further increase in the real policy rate. All nominal interest rates rise in line with the policy rate, and therefore rise relative to the zero interest rates on cash and CBDC.

Figure 20 shows that this triggers a reallocation of household portfolios towards interest-bearing retail deposits and away from cash and CBDC. When CBDC is available this reallocation is stronger because CBDC can decline alongside cash. This dampens the effects of the shock on bank balance sheets.

10.4 Supply Shocks

This subsection groups shocks to different agents' production plans.

10.4.1 Industrial Goods Supply Shock

The industrial goods supply shock or technology shock is specified as a 1% decrease in industrial productivity S_t^a . Figure 21 shows that the shock triggers a reduction in domestic GDP, consumption and especially investment. The recovery is gradual due to the effects of the shock on the capital stock. We also observe a modest increase in inflation, exchange rate depreciation (the latter following an initial appreciation), and interest rates. The increase in the real policy rate is mainly due to the presence of nominal depreciation in the Taylor rule. Balance sheet responses are again demand-driven, contractionary, and limited in size.

10.4.2 Agricultural Goods Supply Shock

The agricultural goods supply shock is specified as a 5% decrease in agricultural output, with both INF production, through $h_{ag,t}^\infty$, and LIQ production, through $h_{ag,t}^\emptyset$, equally affected in percentage terms. Figure 22 shows that GDP declines by about 10% of the shock to agricultural production, reflecting agriculture's approximately 10% share in steady state GDP. Consumption and investment also decline, due to the negative wealth effects of the shock and the real exchange rate depreciation. The current account deteriorates as the economy replaces domestic with foreign agricultural production. The effects on inflation and interest rates are very small. The same is true for balance sheet responses.

10.4.3 Price Markup Shock

The price markup shock is specified as a 1% increase in firms' price markups S_t^{mup} that increases the wedge between prices and marginal costs and thereby increases inflation and reduces output. Figure 23 shows that the effects of the shock are very similar to those of an industrial goods supply shock. It triggers a reduction in domestic GDP, consumption and especially investment. The recovery is gradual due to the effects of the shock on the capital stock. We also observe a modest increase in inflation, exchange rate depreciation (the latter following an initial appreciation), and interest rates. The increase in the real policy rate is mainly due to the presence of nominal depreciation in the Taylor rule. Balance sheet responses are again demand-driven, contractionary, and limited in size.

10.4.4 Wage Markup Shock

The wage markup shock is specified as a 1% increase in unions' wage markups S_t^{muw} that increases the wedge between the labor cost faced by firms and the real wage received by households. Figure 24 shows that the effects of this shock are qualitatively very similar to the effects of a price markup shock. However, they are quantitatively much smaller because the shock only affects the labor margin of production rather than both labor and capital. The contraction in output is driven primarily by a decline in labor input.

10.4.5 Capital Share Shock

The capital share shock is specified as a decline in the capital share S_t^{ks} in the industrial goods production function. Figure 25 shows that this shock, because it reduces the productivity of the installed capital stock, induces a sharp contraction in investment and, because of the resulting negative wealth effects, a smaller contraction in consumption. The effects on output are very persistent due to long-lived effects on the capital stock. Because this shock acts like a negative industrial goods supply shock, it shares several features with that shock, including a real appreciation followed by subsequent depreciation, subdued core inflation but temporarily high CPI inflation, and an increase in policy and market interest rates. Balance sheet responses are again demand-driven, contractionary, and modest in size.

10.5 External Shocks

This subsection groups shocks to foreign variables.

10.5.1 Industrial Goods Export Demand Shock

The industrial goods export demand shock is specified as a 5% decline in foreign demand for domestically produced industrial goods $Y_{H,t}^*/\bar{Y}_H^*$. Figure 26 shows that the shock reduces GDP, while the size of the effect reflects the 16% share of foreign demand for domestically produced industrial goods in GDP. The real exchange rate depreciates and the current account deteriorates due to lower export revenues. The effects on inflation and interest rates are modest. The same is true for balance sheets.

10.5.2 Phosphates Output Shock

The phosphates output shock is specified as a 5% decline in phosphates production $\Omega_{ph,t}/\bar{\Omega}_{ph}$. Figure 27 shows that the shock reduces GDP, while the size of the effect reflects the 6% share of phosphates production in GDP. Consumption and investment both decrease due to the negative wealth effects of the shock. Core and CPI inflation display only small movements and the policy rate remains broadly unchanged. The main adjustments are in external variables – the real exchange rate depreciates and the current account deteriorates due to lower export revenues. In the current version of the model government revenues are not linked to phosphates production, so that government spending does not adjust endogenously to amplify the output contraction. Future versions of the model may consider a framework with resource-based fiscal revenues. Balance sheet responses are small in size.

10.5.3 Industrial Goods Import Price Shock

The industrial goods import price shock is specified as a 2% increase in the world price of imported industrial goods $p_{F,t}^*$. Figure 28 shows that the shock's main contractionary effect is on investment due to the very high (40%) import content of investment spending. The effects on consumption and GDP are much more modest. However, because of the long-lasting effects on the capital stock the decline in GDP is very persistent. Inflation rates and interest rates decline, but the magnitudes are small. The main adjustments are in external variables – the real exchange rate appreciates and the current account improves due to lower imports. As for balance sheets, the demand for money decreases mainly due to lower investment demand, while the supply of credit decreases due to lower collateral values in the wake of the drop in investment.

10.5.4 Phosphates Price Shock

The phosphates price shock is specified as a 10% drop in the world price of phosphates $p_{ph,t}^*$. Figure 29 shows that the shock has a small direct effect on GDP, but the contraction is exacerbated by a decrease in consumption and investment triggered by negative wealth effects. The main effects of the shock are external – the current account deteriorates, mainly due to lower export revenues, and the real exchange rate depreciates. The effects on inflation and interest rates are modest. Balance sheet effects are very small.

10.5.5 Oil Price Shock

The oil price shock is specified as a 5% increase in the world price of oil $p_{o,t}^*$. The shock has a small direct effect on GDP, but Figure 30 shows that the contraction is exacerbated by sizable decreases in consumption and investment triggered by negative wealth effects. The shock also has a negative effect on production, where oil is a hard-to-replace input that suddenly becomes much more expensive. The current account deteriorates, mainly due to more expensive imports, and the real exchange rate depreciates. The effects on inflation and interest rates are very modest. Balance sheet effects are negligible.

10.5.6 Agricultural Goods Price Shock

The agricultural goods price shock is specified as a 5% decline in the world price of agricultural goods $p_{ag,t}^*$. Figure 31 shows that there is a modest contraction in GDP that reflects two countervailing effects, an increase in the consumption of agricultural goods due to the drop in their price, and larger decreases in non-agricultural consumption and investment. The current account deteriorates, mainly due to a loss of net export revenue in the agricultural sector, and the real exchange rate depreciates. The effects on inflation and interest rates are very modest. The same is true for balance sheet effects.

10.5.7 Foreign Remittances Shock

The foreign remittances shock is specified as a 10% decrease in foreign remittances $j_t^*/\bar{j}^*$. Given that remittances account for around 8% of Moroccan GDP, the shock corresponds to an income loss of approximately 0.8% of GDP. Figure 32 shows that this shock, due to its negative effects on incomes and wealth, significantly reduces consumption and investment. However, domestic production falls much less, as an improvement in the trade balance, due to a depreciation of the real exchange rate, partially offsets the contraction in domestic demand. However, the current account deteriorates significantly because it is dominated by

the effects of lower foreign remittances. The responses of inflation and interest rates are modest. Balance sheet effects are small.

10.5.8 Foreign Interest Rate Shock

The foreign interest rate shock is specified as a 1 percentage point increase in the foreign nominal interest rate $i_{f,t}^*/\bar{i}_f^*$. Figure 33 shows that the shock is transmitted to the economy through the uncovered interest parity condition. It induces an immediate and sizable 2% depreciation of the real exchange rate, which is brought about through a 3.2% nominal depreciation and 1.2% increase in the domestic CPI. This is followed by a period of domestic inflation and nominal exchange rate appreciation as the real exchange rate returns to its long-run value.

The price jump reduces the real value of cash and CBDC balances by around 1.5%, which immediately reduces the real spending power of LIQ households. Their saving is the main reason behind the initial drop in consumption. At the same time, the real depreciation immediately increases the cost of imported inputs, which is the main reason behind the drop in investment that has a very high import content.

Monetary policy does not respond strongly to domestic inflation due to the presence of the exchange rate in the policy rule, and as a result the real interest rate drops. This drop, together with the real exchange rate depreciation, stimulates the economy through the trade balance, so that GDP rises in the short run despite the significant drop in consumption and investment demand.

Figure 34 shows that balance sheet responses reflect tighter credit conditions alongside changes in demand for different types of money. Bank credit declines substantially due to lower collateral valuations in the face of a shock that reduces incentives to invest. At the same time bank deposit money increases, because the increase in foreign nominal interest rates leads to at least a modest increase in domestic nominal interest rates. This increases the opportunity cost of holding cash or CBDC instead of bank deposits, and as a result we observe an increased use of retail bank deposits and a decreased use of cash and CBDC. However, this does not have strong implications for macroeconomic transmission, as the money tax rate does not exhibit very large fluctuations. Finally, the availability of CBDC does not materially affect the transmission of this shock to the real economy.

11 Summary

This paper has developed a policy-oriented DSGE framework that is tailored to the Moroccan economy. The modeling framework contains detailed interactions between the real, monetary, fiscal, banking, and external sectors under realistic adjustment frictions. The model can be used to study a variety of common domestic and external shocks that can affect the Moroccan economy, and in addition it can be used to assess the implications of a variety of monetary, fiscal, and macroprudential policies. Adjustment frictions on the real side include habit persistence in consumption, investment adjustment costs, and price and wage adjustment costs. Adjustment frictions on the financial side include risky collateralized lending, regulatory capital adequacy requirements, and money-in-advance constraints that link real activity to the availability of monetary transactions balances.

A central feature of the framework is the explicit modeling of different payment instruments. The central bank sets the policy rate on commercial bank reserves and in addition supplies cash and CBDC transactions liquidity elastically at a zero interest rate, with quantities determined by private demand rather than by exogenous monetary targets. CBDC is issued by banks converting bank deposits into CBDC on demand and the central bank refinancing these deposits through credit to banks. The remaining transactions liquidity is created by banks through loans, with the central bank having some influence over credit creation through the policy rate and macroprudential regulation, but with banks retaining significant autonomy. This setup mirrors the operational reality of modern central banks.

Households are heterogeneous along a dimension that is practically highly relevant for Morocco. Infinitely-lived or banked households (INF) smooth consumption intertemporally and arbitrage across liquid assets that include not only cash and CBDC but crucially also bank deposits that can be created at short notice through loans, as long as the borrower offers sufficient collateral and the bank offers credit at an acceptable cost. Liquidity-constrained or unbanked households (LIQ) transact using only cash and CBDC and do not have access to banks. They therefore suffer from a limited financial inclusion that is particularly severe when they only have access to cash and less severe when they also have access to CBDC. However, even with CBDC their financial inclusion is far from perfect, because the key criterion for financial inclusion is not primarily the technical characteristics of the available payment instruments but rather the access to an institution that can create these payment instruments elastically and on demand. CBDC as currently envisaged does not satisfy this criterion. This difference between INF and LIQ households, which each make up around half of the Moroccan population, generates empirically plausible distributional asymmetries in the responses to shocks.

In addition to monetary and CBDC policies, the model incorporates a detailed representation of fiscal policy. The government levies taxes on consumption, capital income, labor income, and lump-sum taxes, and it follows a deficit and debt stabilization rule. This allows fiscal policy to operate countercyclically to stabilize the economy while preserving medium-run sustainability. In the presence of LIQ households this is a valuable tool because it can in principle be used to help these agents to smooth consumption.

Finally, the external sector captures Morocco as a small open economy that imports industrial goods, agricultural goods and oil (all at exogenous world prices), that exports industrial goods (at domestic producer prices converted using the exchange rate) and phosphates (at world prices), that receives large and volatile remittances from Moroccans residing abroad, and that is exposed to foreign interest rate shocks.

12 Lessons for CBDC

The first and most important insight is that **the policy-rate rule, possibly complemented by macroprudential policies, remains the main active stabilization instrument**. Cash is not an active stabilization instrument in this model, since it is a non-interest-bearing medium of exchange whose quantity is mainly demand determined. A non-interest-bearing CBDC resembles cash in this respect, and also differs from bank deposits, which can be created endogenously by banks when extending credit (Barrdear and Kumhof, 2016, 2022; Jakab and Kumhof, 2019). We have seen that, in response to certain shocks, CBDC can nevertheless have stabilizing effects. However, this does not represent an active stabilization policy, but rather a passive response: the availability of an additional medium of exchange makes the adjustment to shocks more flexible.

The second insight is that **CBDC can enhance efficiency with limited macroeconomic risk when issuance is well designed**. The main distinctive feature of CBDC in the model is indeed technological, in that it can qualitatively enhance and quantitatively increase effective money balances. In our simulations, a CBDC adoption corresponding to a steady-state CBDC stock of around 6.6% of annual GDP yields modest but broadly positive effects on long-run levels. This includes a modest increase in GDP, a modest decrease in real interest rates and distortionary tax rates, and increased effective real money balances. At the same time the presence of CBDC does not impair demand for bank credit, because bank credit allows banked households to flexibly obtain not only retail deposits but also cash and CBDC when, as assumed here, the central bank issues cash and CBDC against bank deposits. This supports the view that a well-calibrated CBDC can raise payment-system efficiency without jeopardizing macroeconomic stability. This conclusion is also consistent

with recent evidence for African economies, which shows that the effects of CBDC adoption on bank funding, lending conditions, and financial stability depend critically on the design of the issuance and intermediation framework (Mikou, 2025).

The third insight is that **the role of CBDC in improving financial inclusion is not simple and one-dimensional**. A CBDC that improves payment system technology can certainly help to give financially excluded households access to a modern and highly convenient form of money. In other words, it can increase the *quality* of money. But financially excluded households still need to save in order to accumulate sufficient CBDC, in other words CBDC cannot elastically increase the *quantity* of money when it is needed. In the current model, only banks can do that, by creating retail deposit money through ledger entries, without any need for saving. Monetary policy can support elastic money creation in two ways, either through a refinancing policy for banks' deposit losses that remains credible even in the face of large outflows, thereby ensuring that banks can always fulfill this vital function, or perhaps more controversially through public financial institutions that can create CBDC in the same way that banks can create deposits.

An important distinction is that the model captures financial inclusion primarily through access to transaction liquidity, rather than through changes in access to banking services. The introduction of CBDC does not endogenously change households' banking status or provide unbanked households with access to credit.

Furthermore, CBDC adoption is assessed from a macroeconomic perspective, through CBDC holdings and the reallocation of monetary balances between cash, bank deposits and CBDC. The model does not explicitly distinguish between payment methods such as bank cards and transfers, whose underlying monetary balances are captured through bank deposits. It therefore does not directly measure the number of CBDC users, transaction volumes or substitution between CBDC and individual payment methods.

Overall, the analytical framework that we have developed in this paper delivers a coherent mapping from CBDC design to macro-financial outcomes that is highly relevant to the Moroccan environment. Furthermore, the model can simulate several macroeconomic and financial shocks relevant for Moroccan policymakers, whether or not CBDC is introduced. This makes the framework useful beyond the specific question of CBDC adoption.

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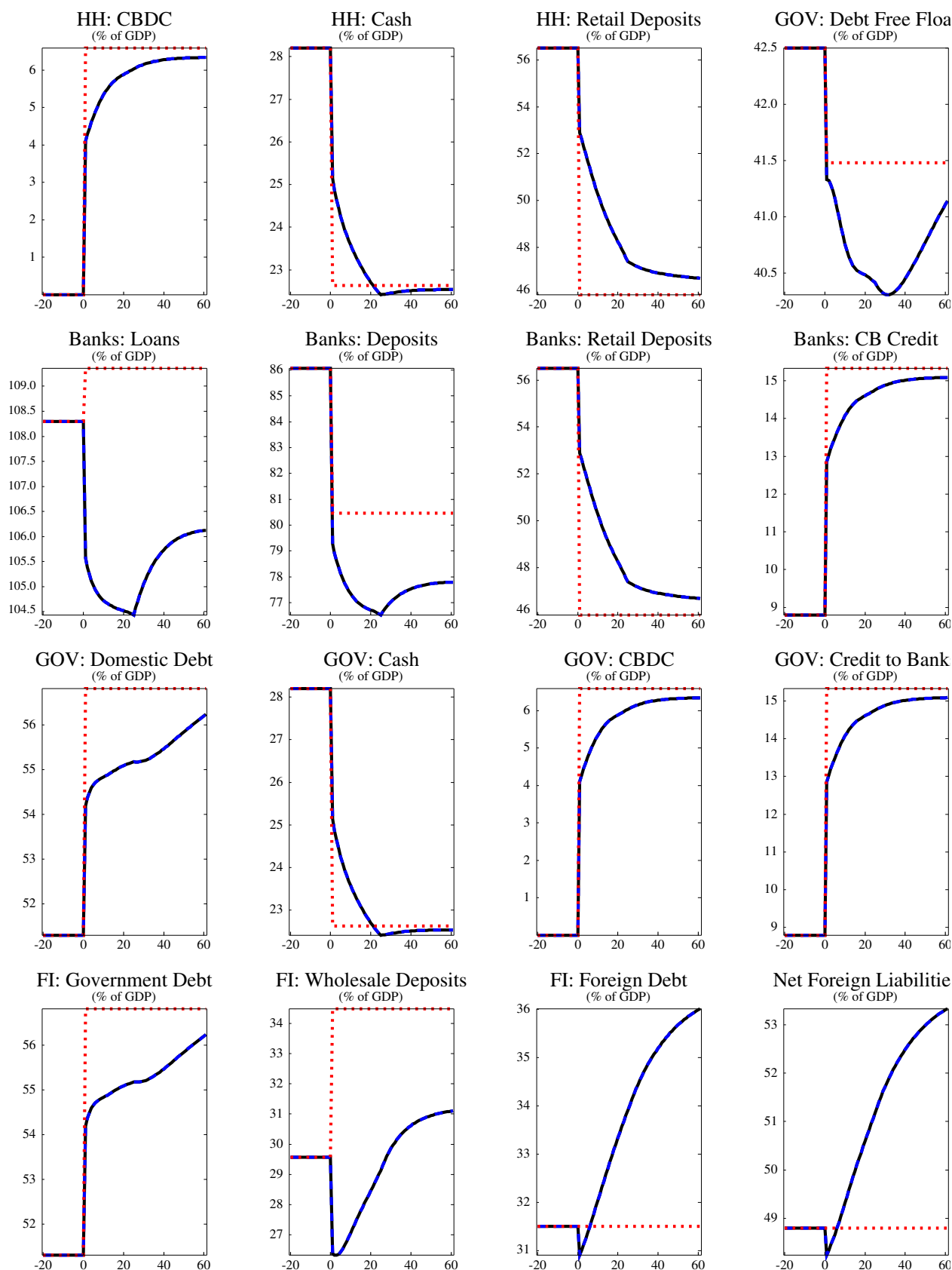


Figure 4: CBDC Transition - Balance Sheets

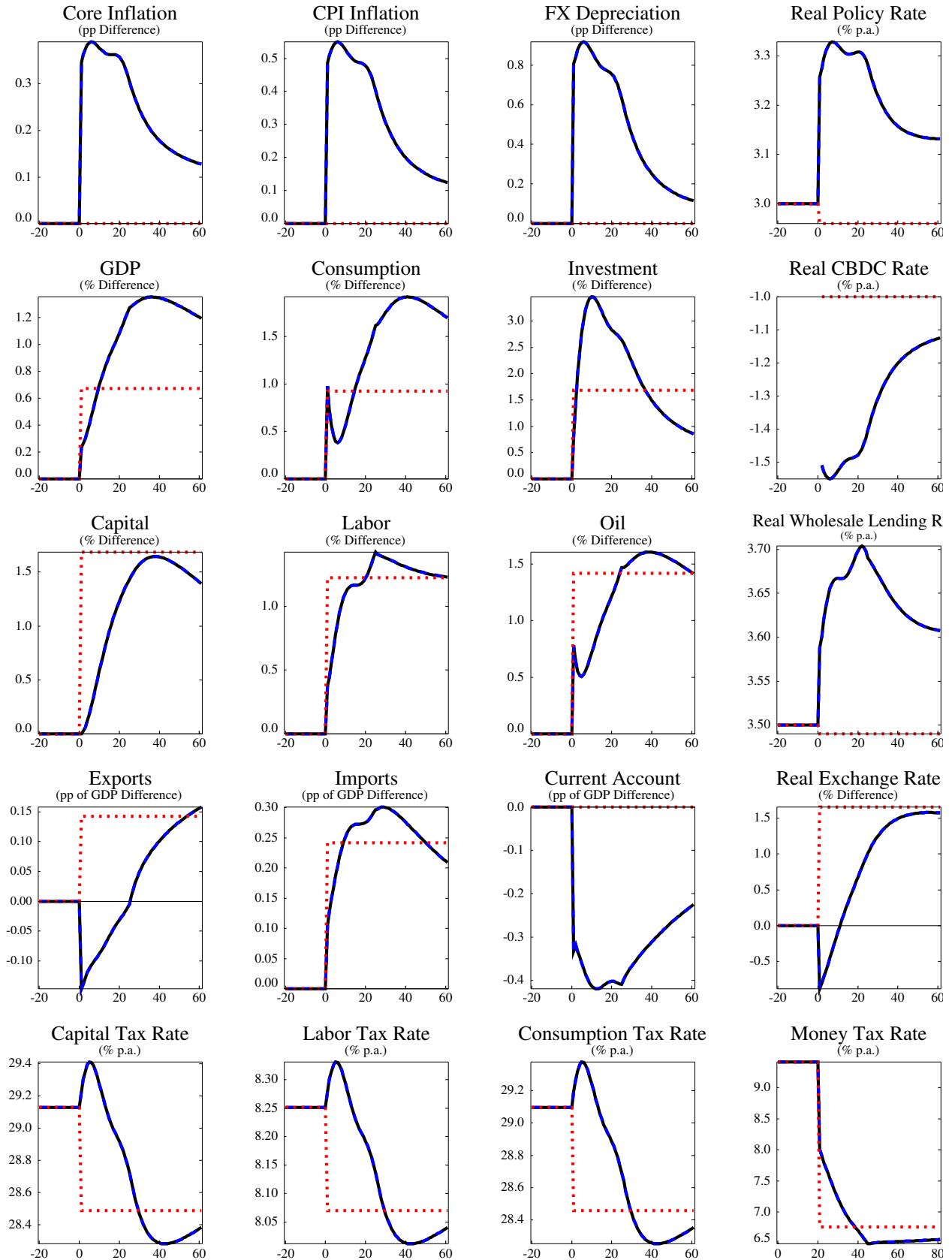


Figure 5: CBDC Transition - Macroeconomic Implications

— Full Dynamic Transition - - - Steady State before and after CBDC Introduction

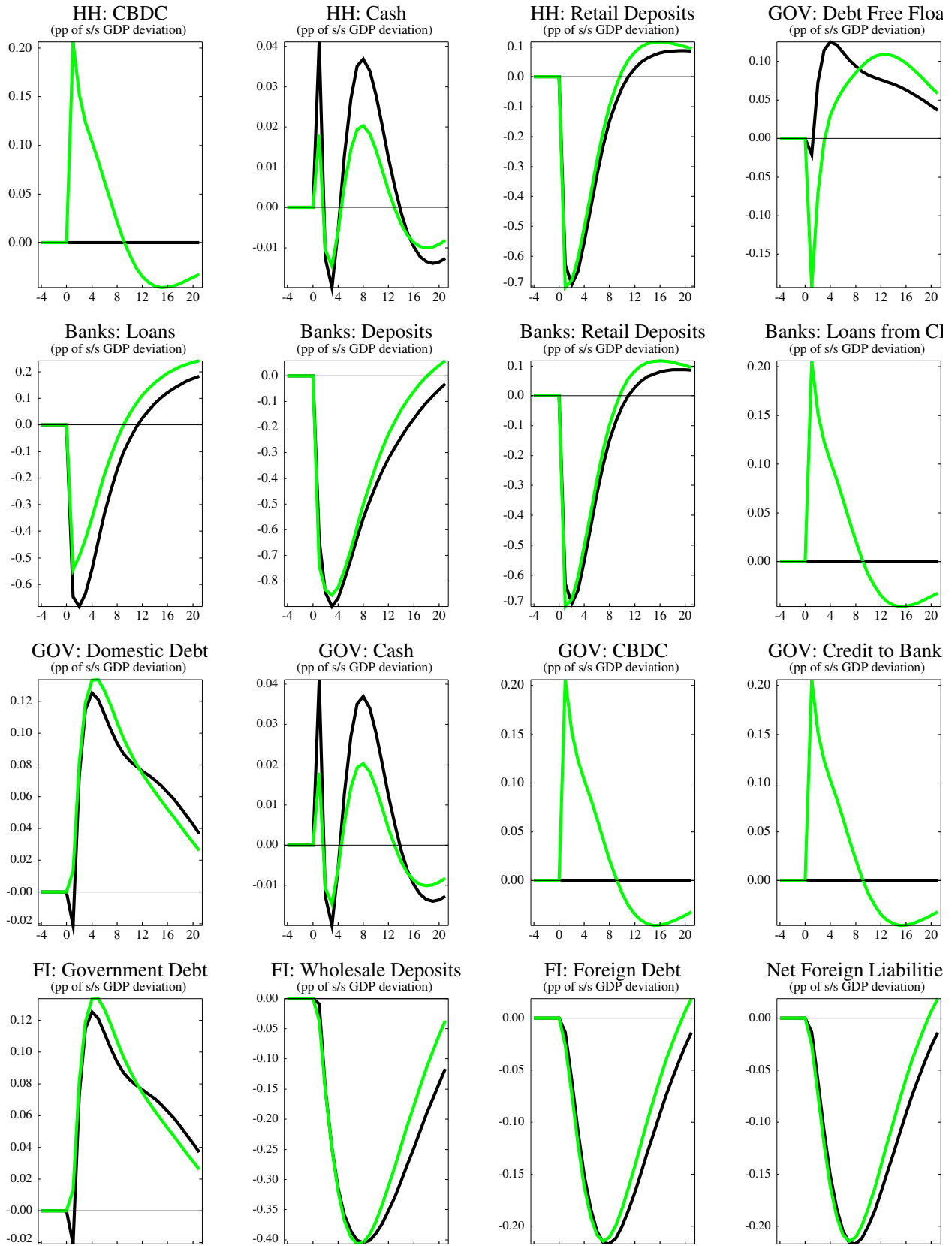


Figure 6: Bank Leverage Shock: Balance Sheets

— Without CBDC — With CBDC

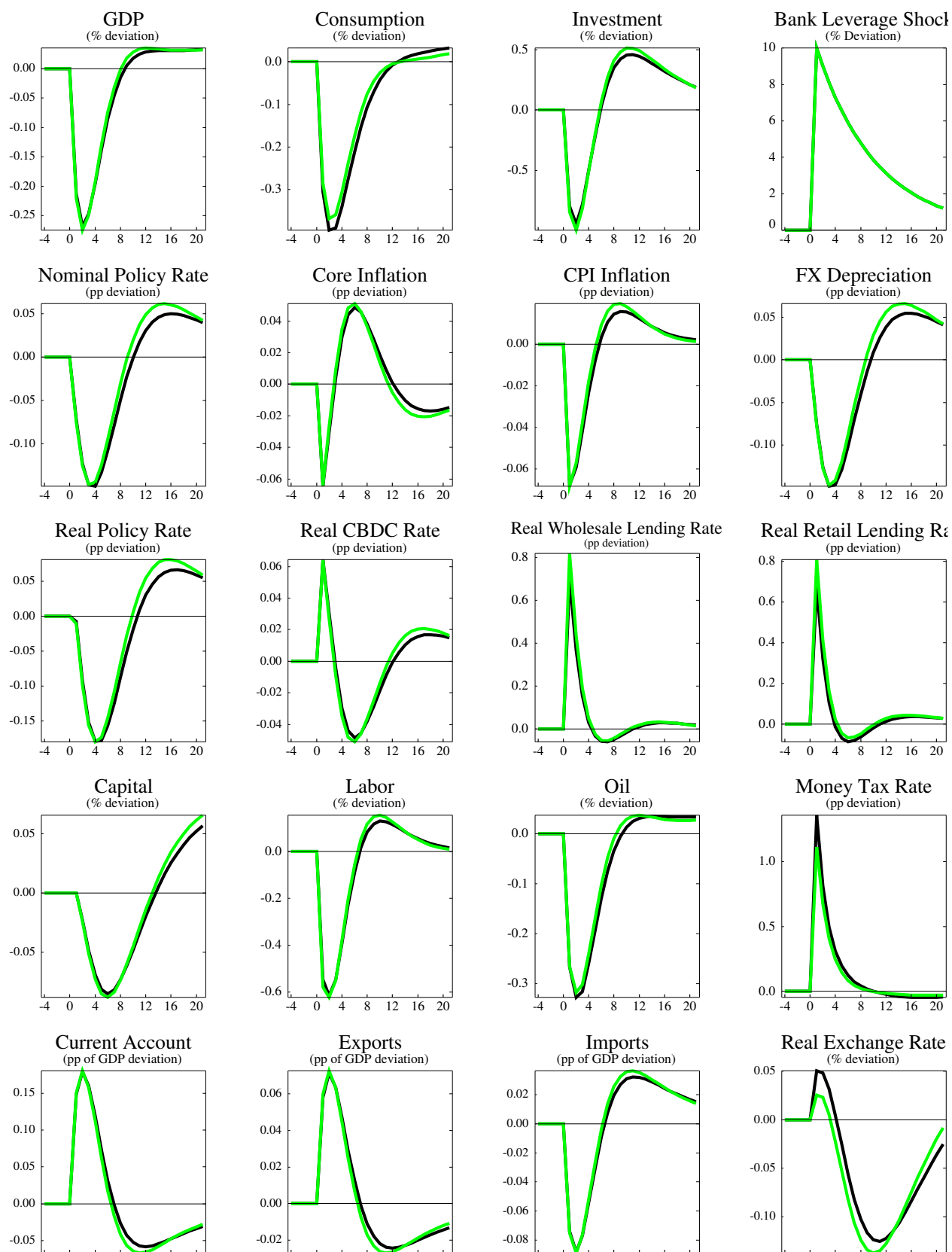


Figure 7: Bank Leverage Shock: Macroeconomic Implications

— Without CBDC — With CBDC

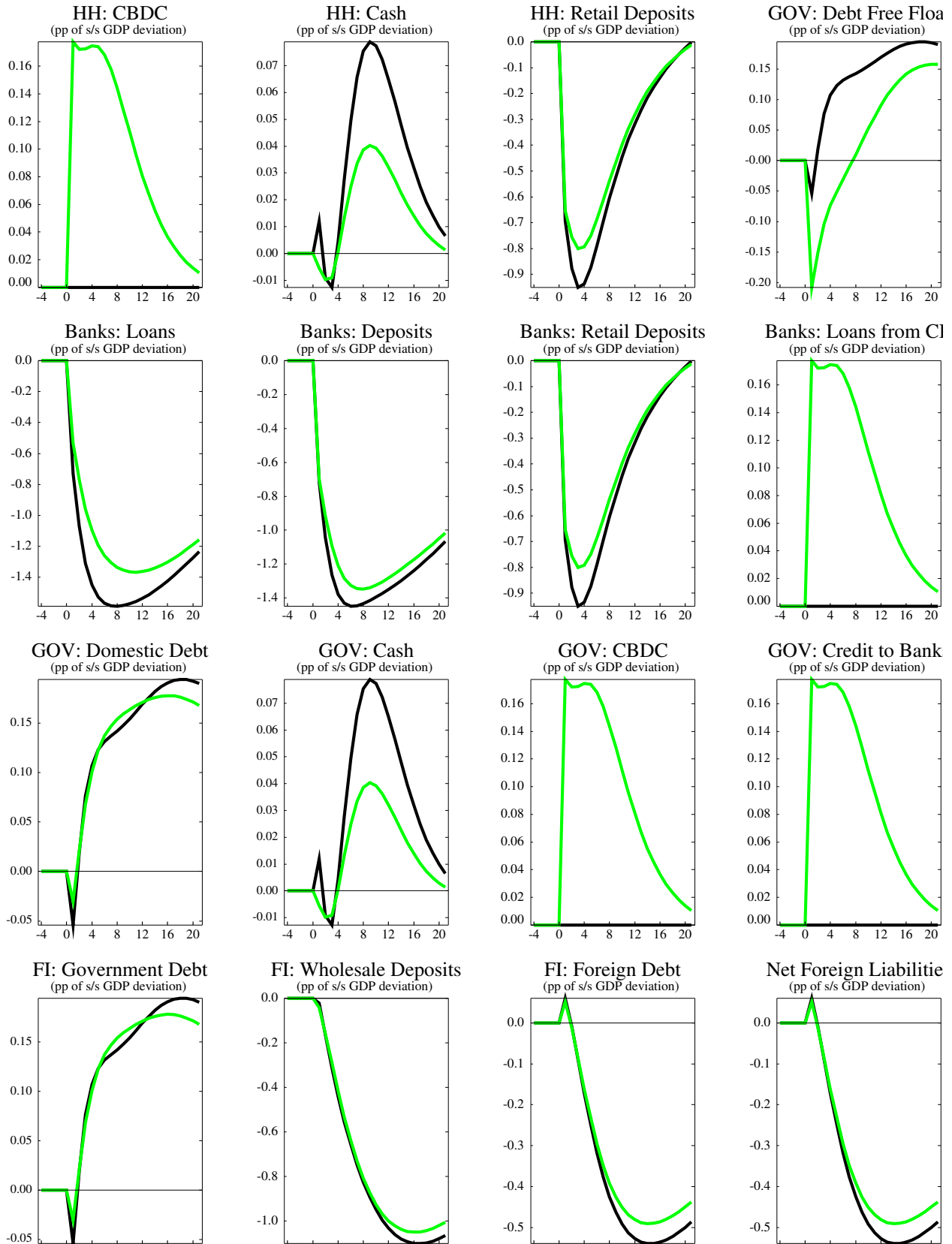


Figure 8: Bank Credit Supply Shock: Balance Sheets

— Without CBDC — With CBDC

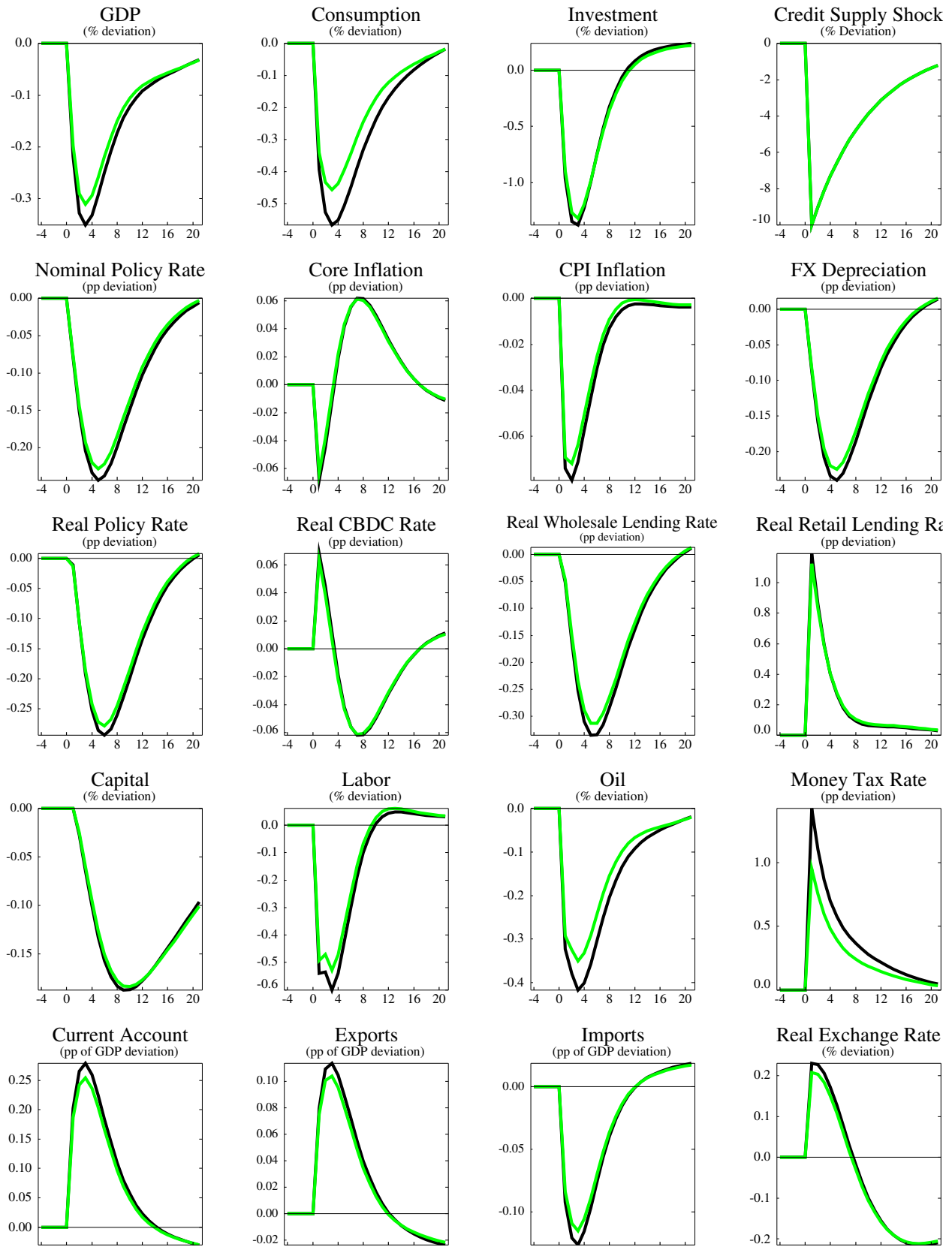


Figure 9: Bank Credit Supply Shock: Macroeconomic Implications

— Without CBDC — With CBDC

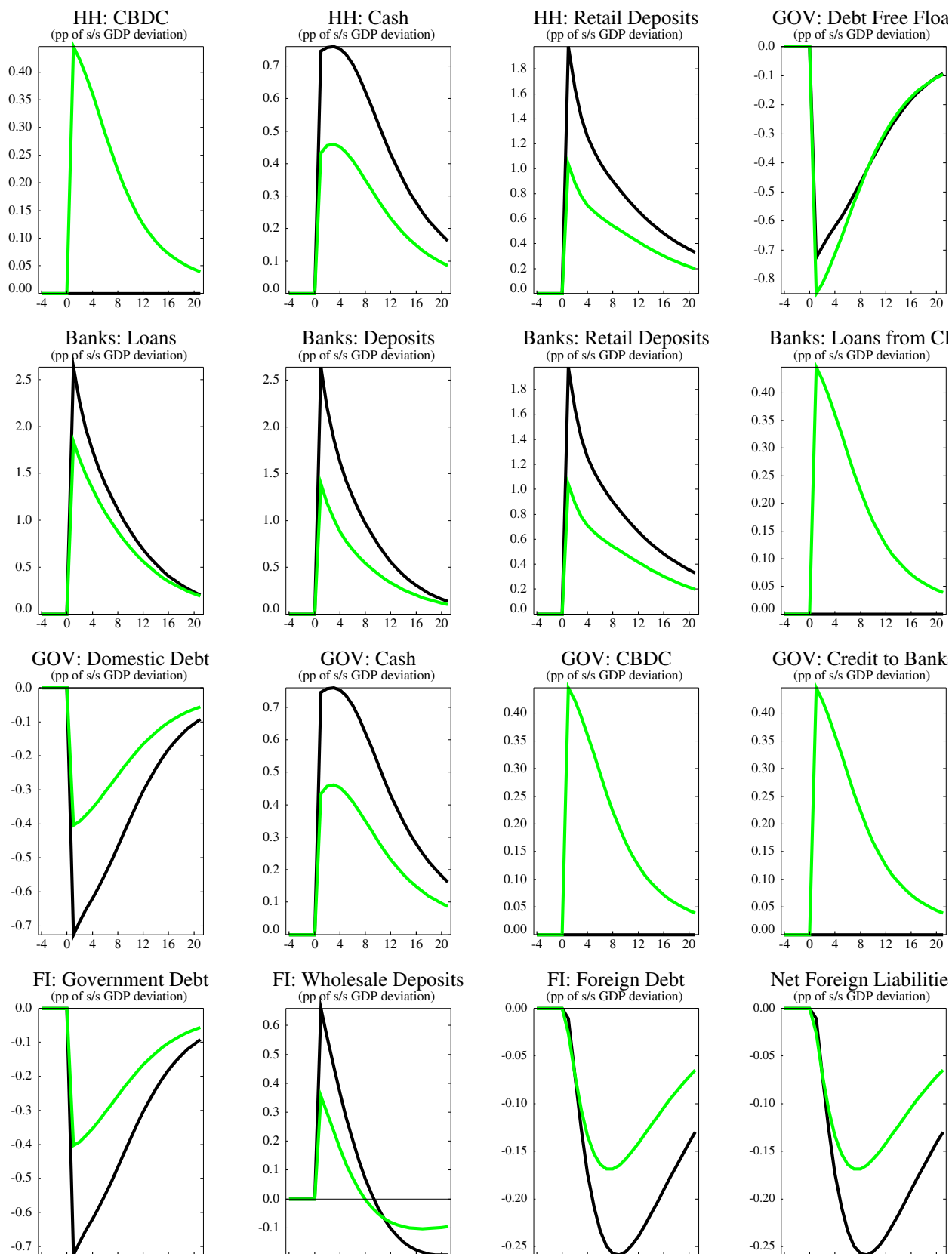


Figure 10: Money Demand Shock: Balance Sheets

— Without CBDC — With CBDC

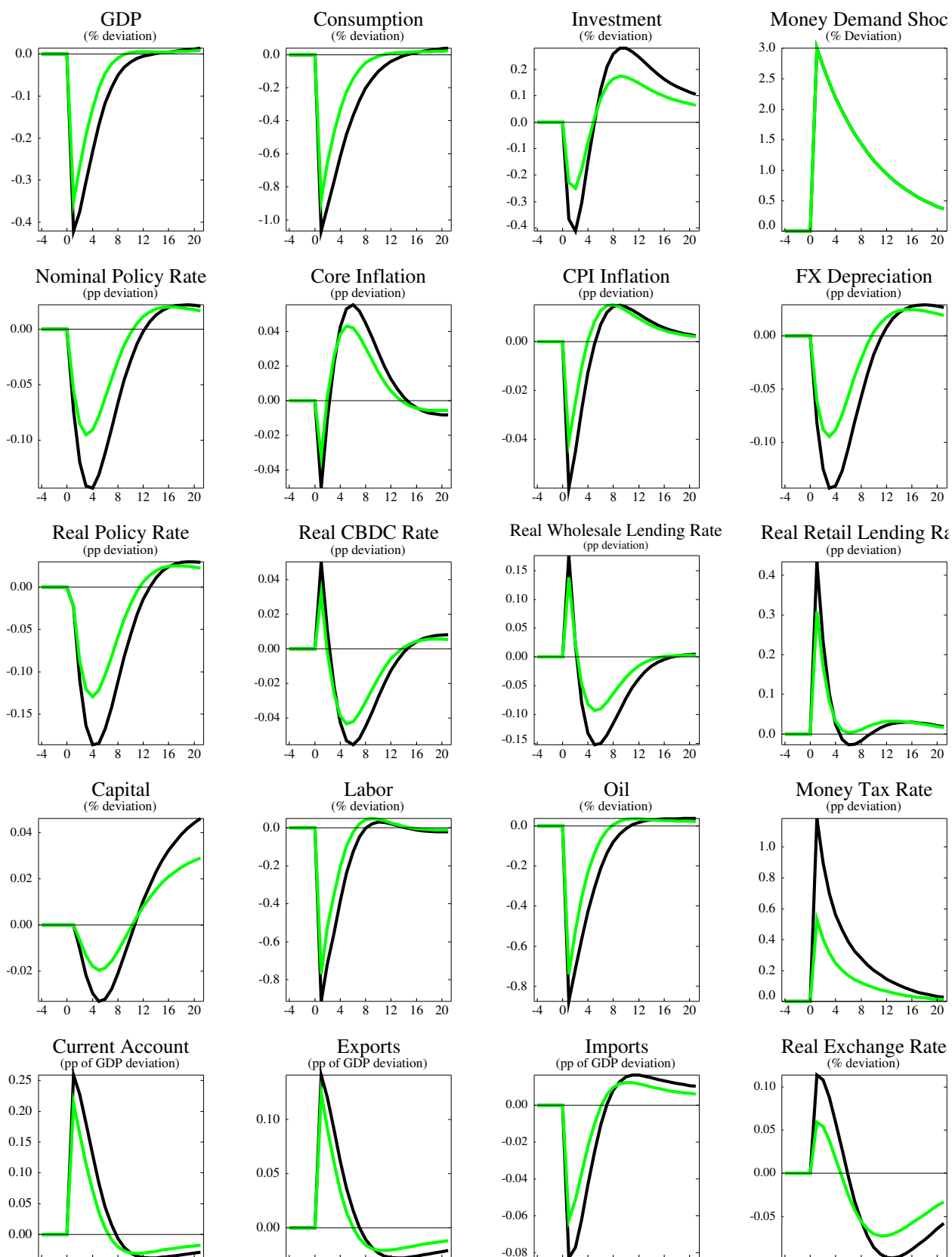


Figure 11: Money Demand Shock: Macroeconomic Implications

— Without CBDC — With CBDC

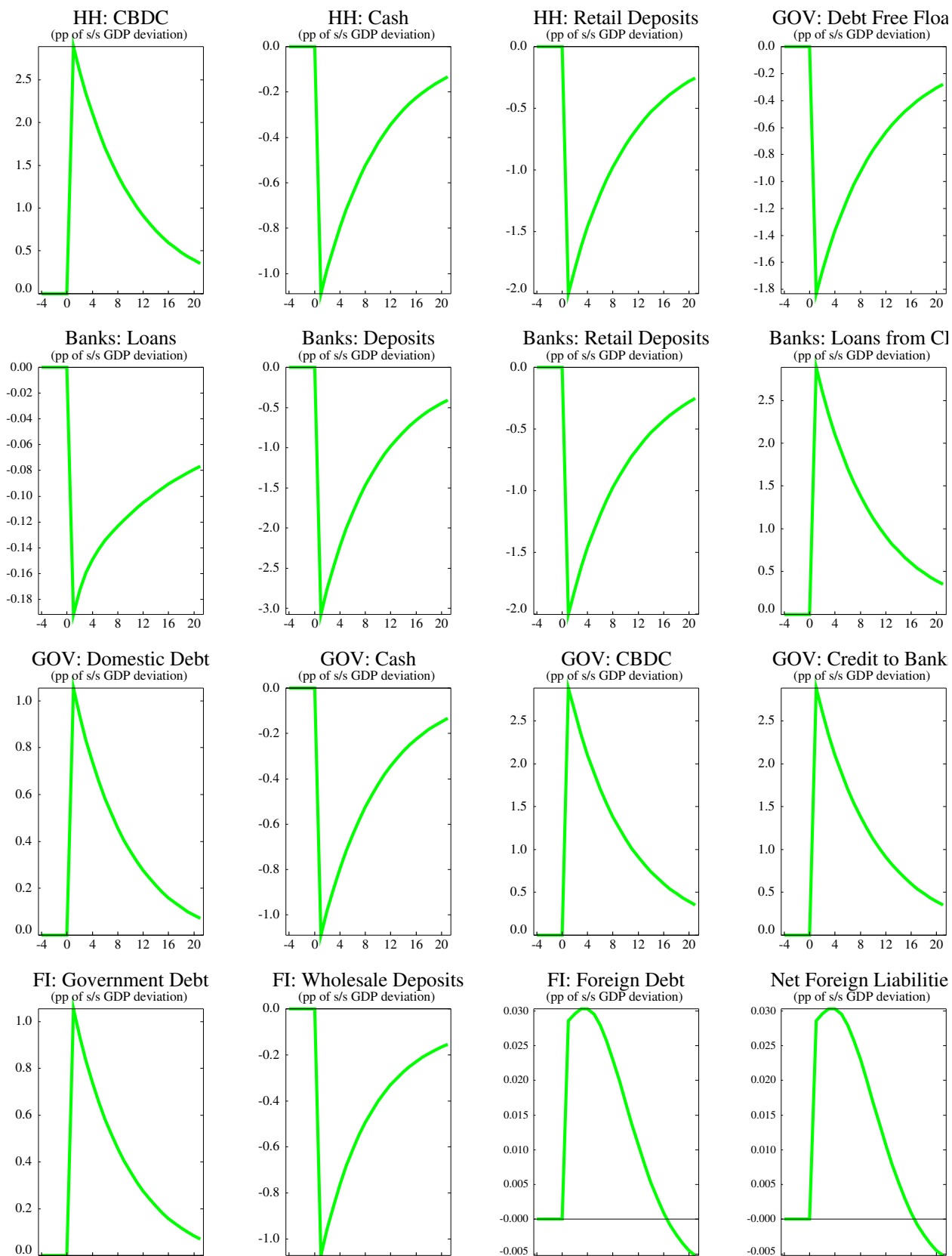


Figure 12: CBDC Preference Shock: Balance Sheets

— Without CBDC — With CBDC

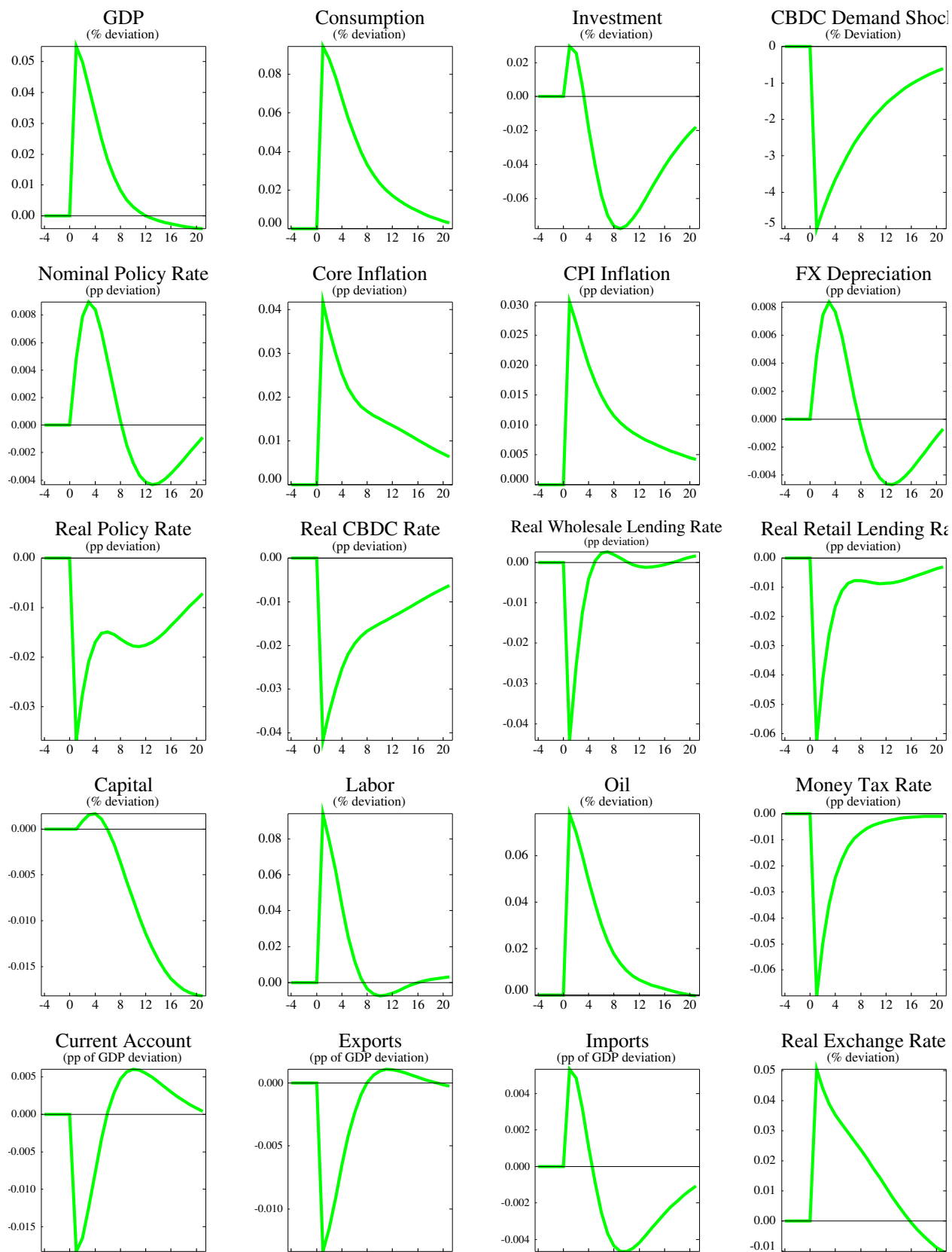


Figure 13: CBDC Preference Shock: Macroeconomic Implications

— Without CBDC — With CBDC

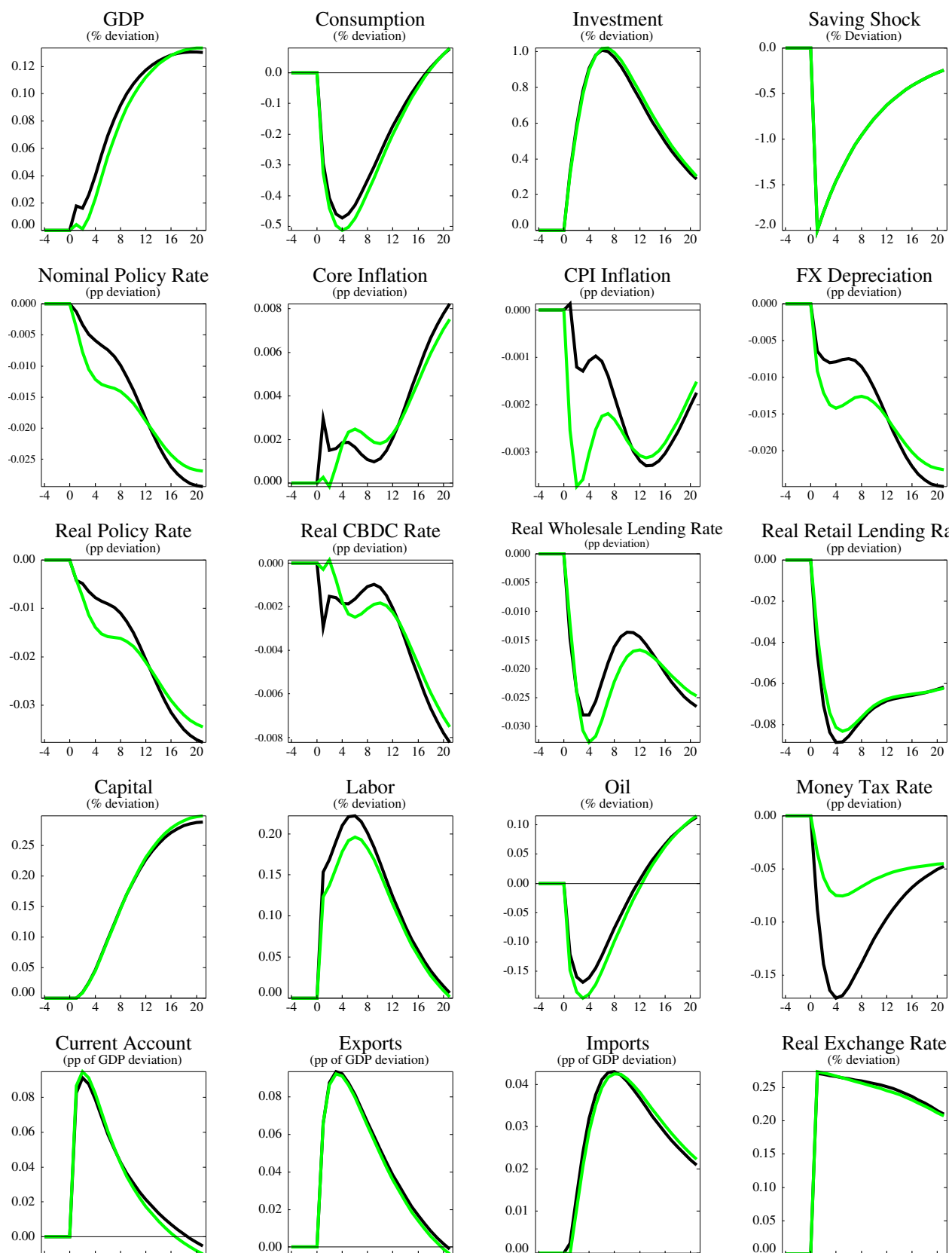


Figure 14: Saving Shock: Macroeconomic Implications

— Without CBDC — With CBDC

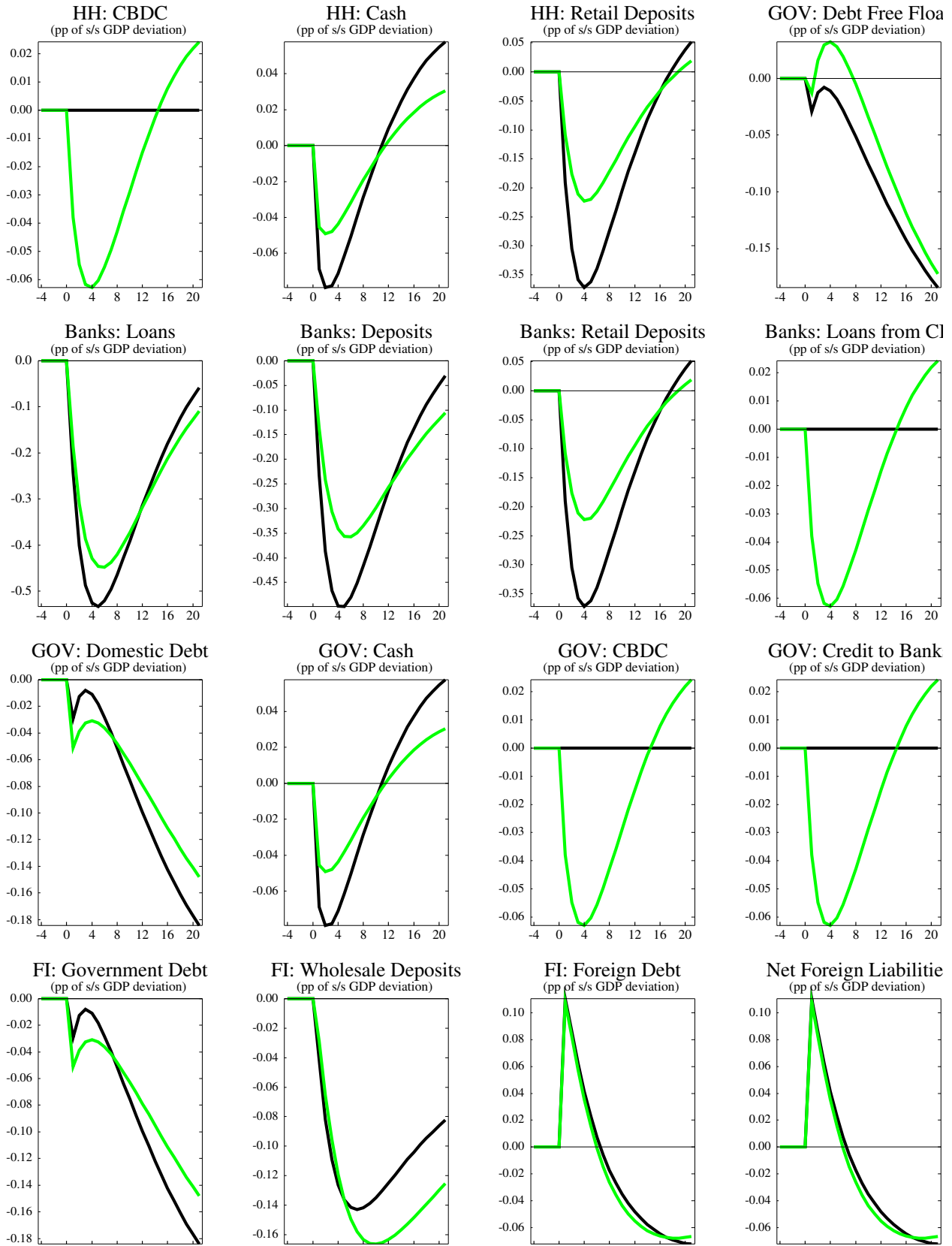


Figure 15: Saving Shock: Balance Sheets

— Without CBDC — With CBDC

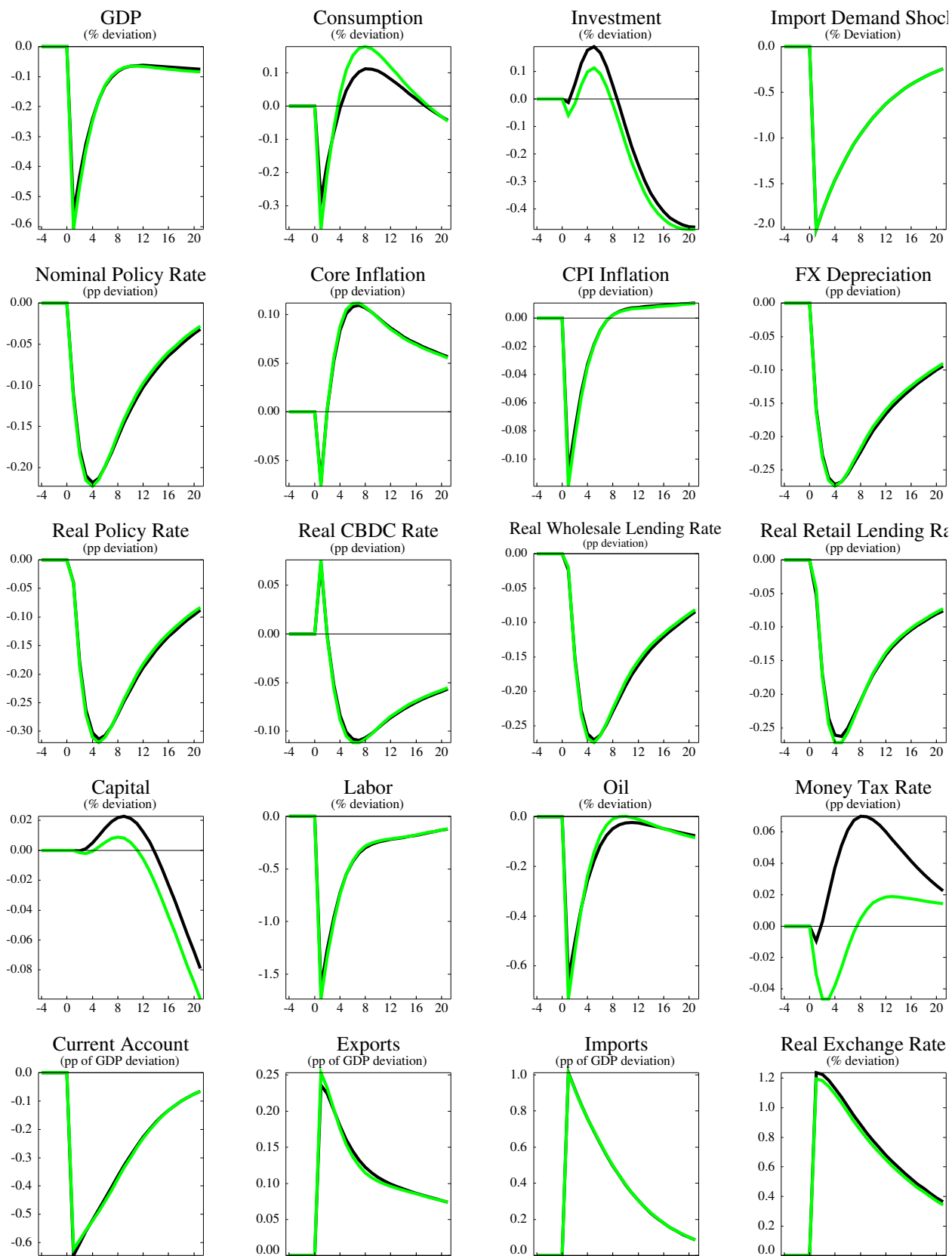


Figure 16: Import Demand Shock: Macroeconomic Implications

— Without CBDC — With CBDC

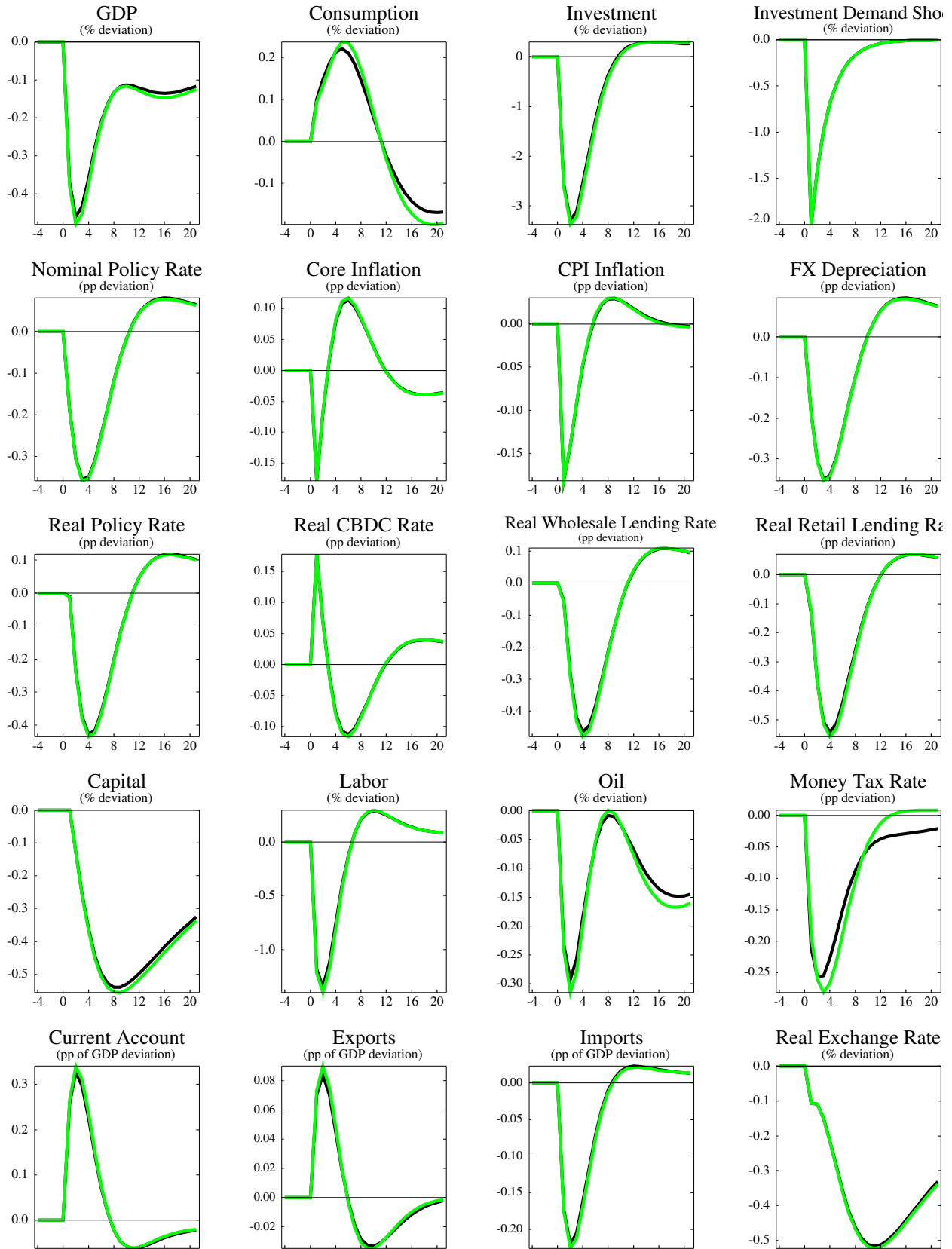


Figure 17: Investment Demand Shock: Macroeconomic Implications

— Without CBDC — With CBDC

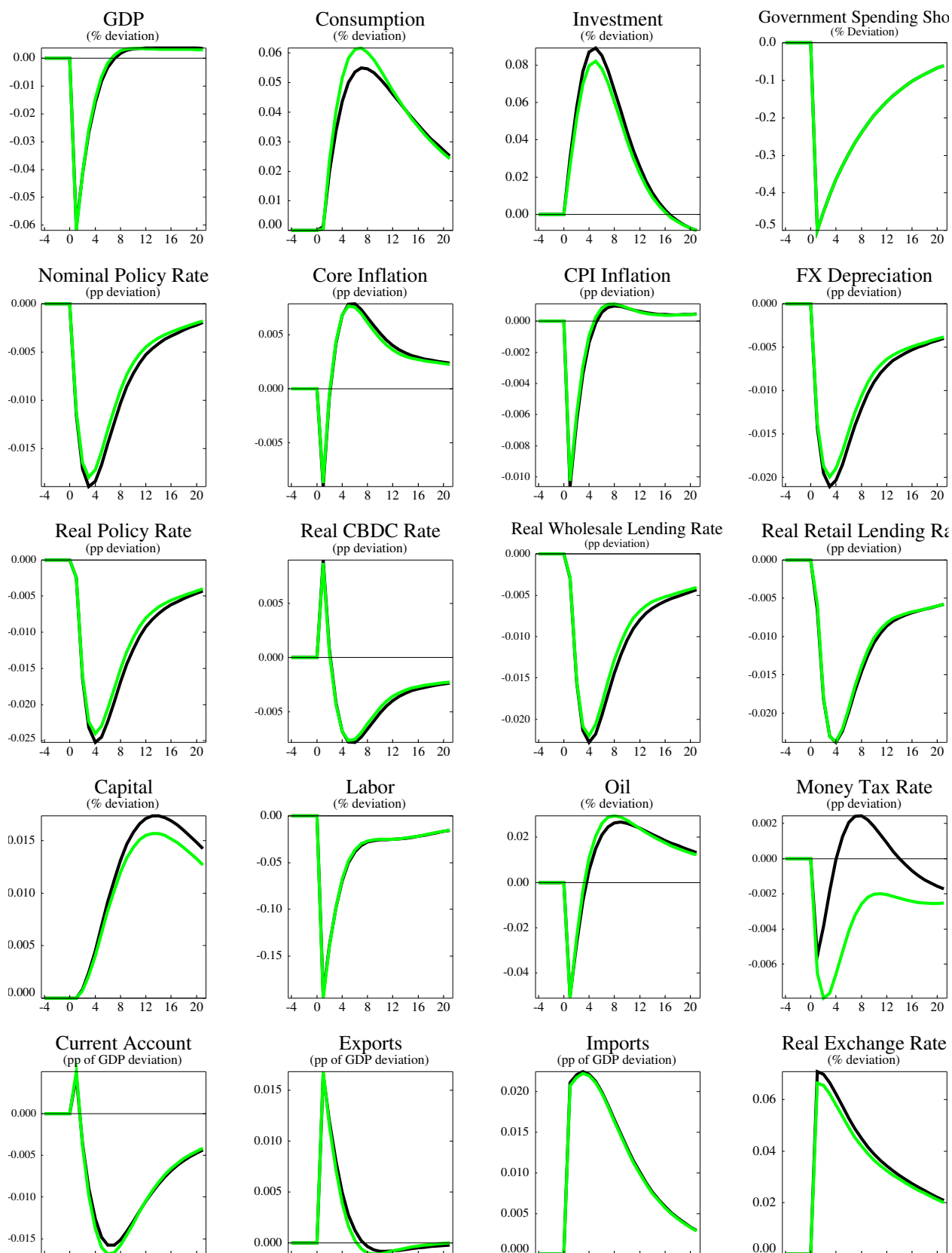


Figure 18: Government Spending Shock: Macroeconomic Implications

— Without CBDC — With CBDC

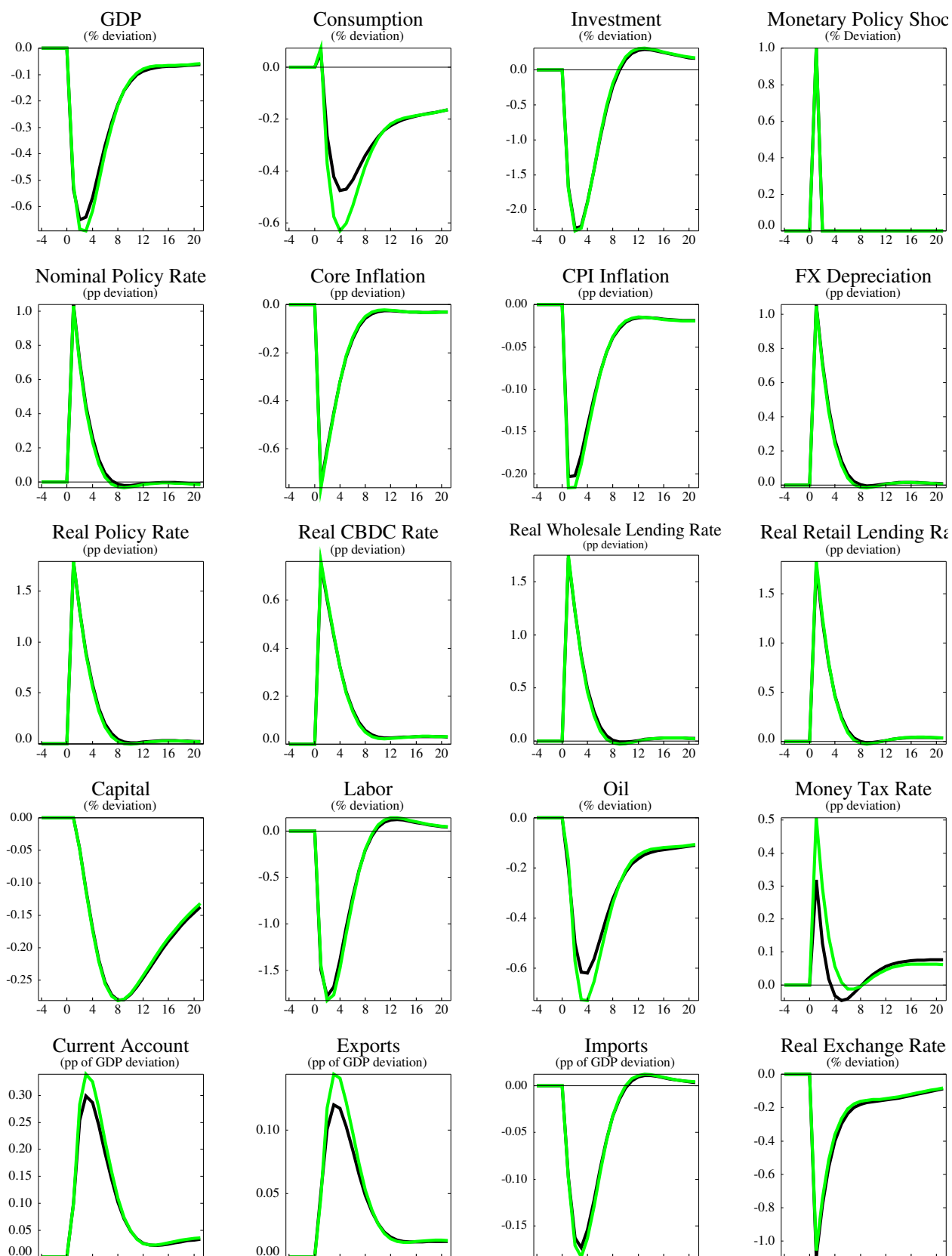


Figure 19: Monetary Policy Shock: Macroeconomic Implications

— Without CBDC — With CBDC

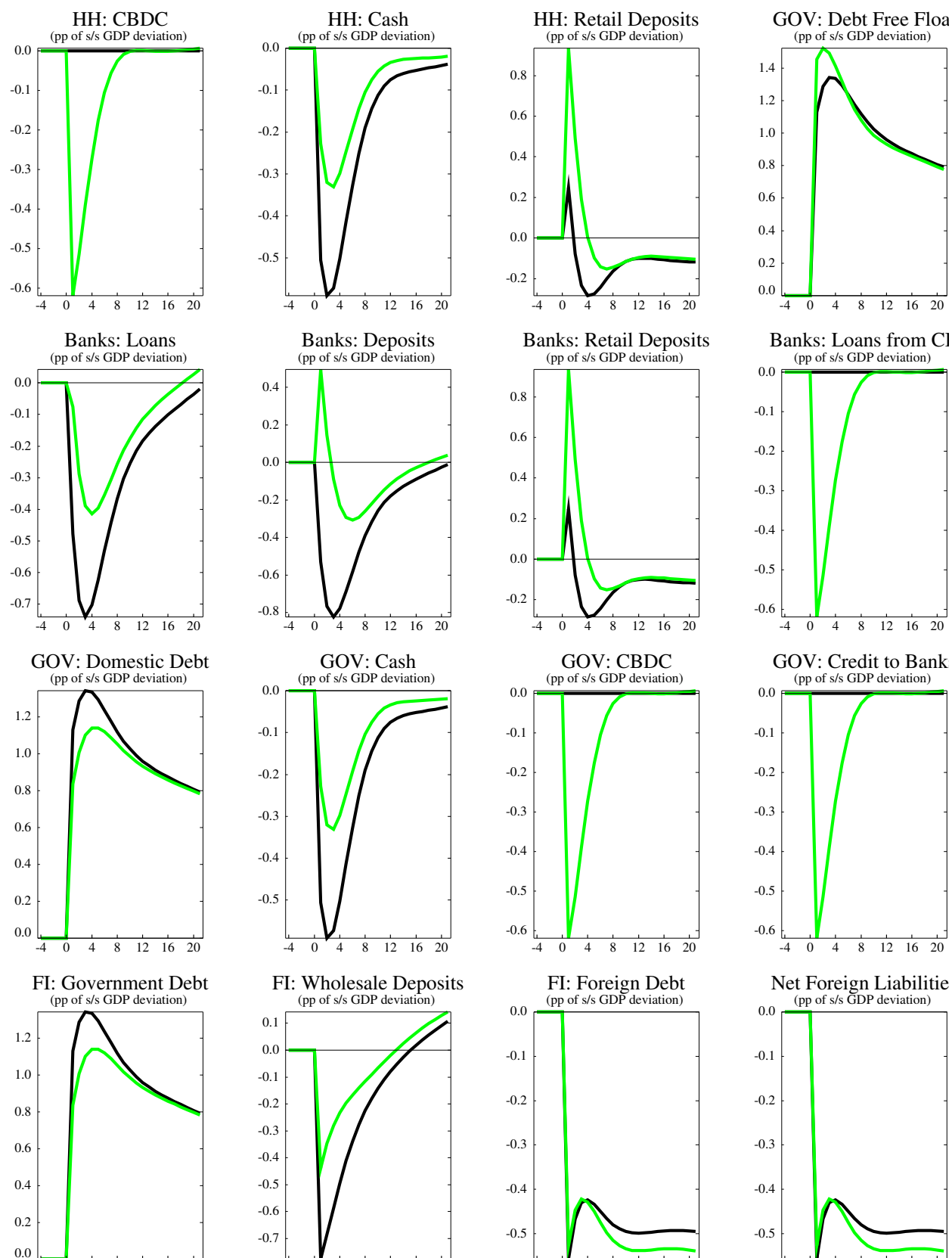


Figure 20: Monetary Policy Shock: Balance Sheets

— Without CBDC — With CBDC

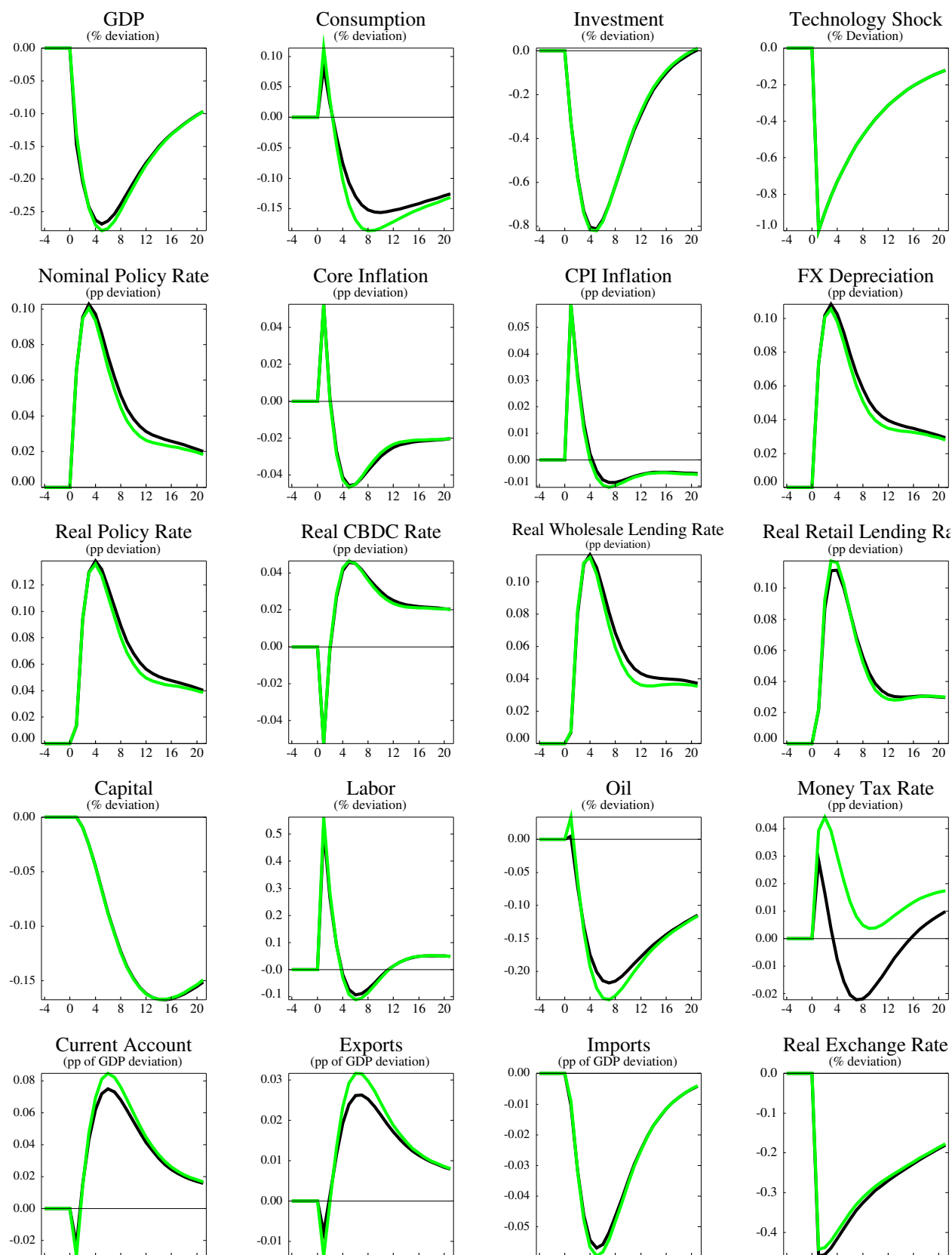


Figure 21: Industrial Goods Supply Shock: Macroeconomic Implications

— Without CBDC — With CBDC

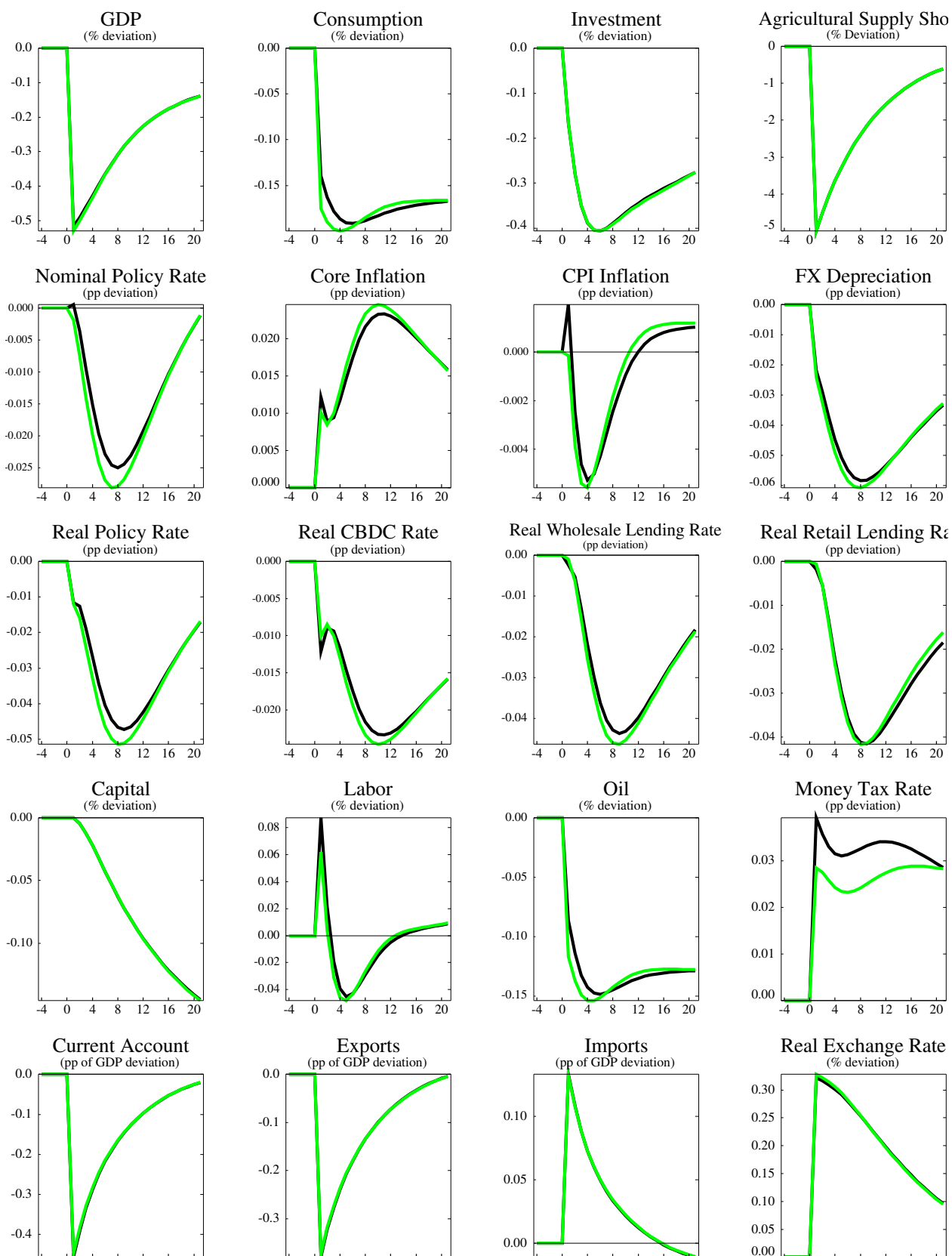


Figure 22: Agricultural Goods Supply Shock: Macroeconomic Implications

— Without CBDC — With CBDC

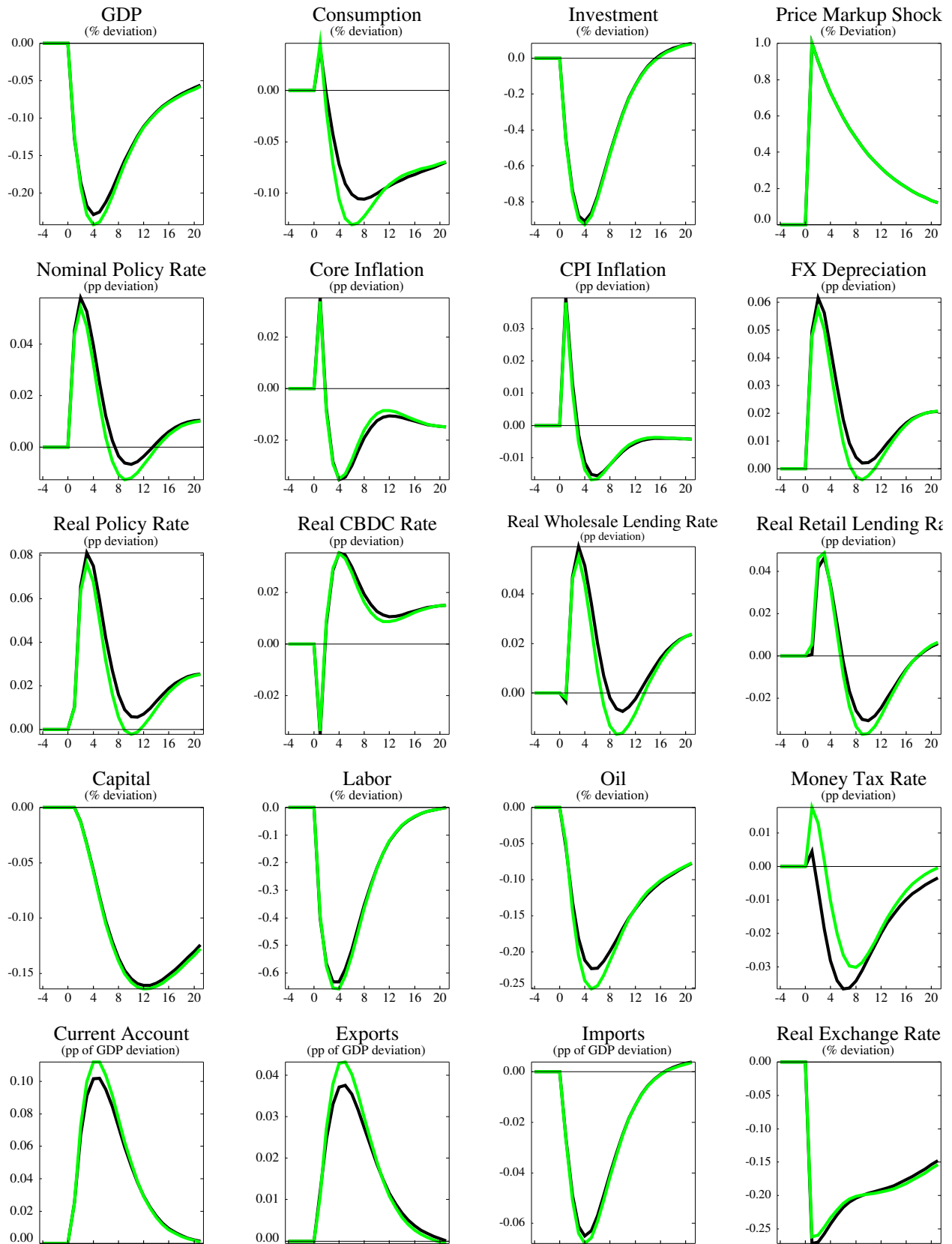


Figure 23: Price Markup Shock: Macroeconomic Implications

— Without CBDC — With CBDC

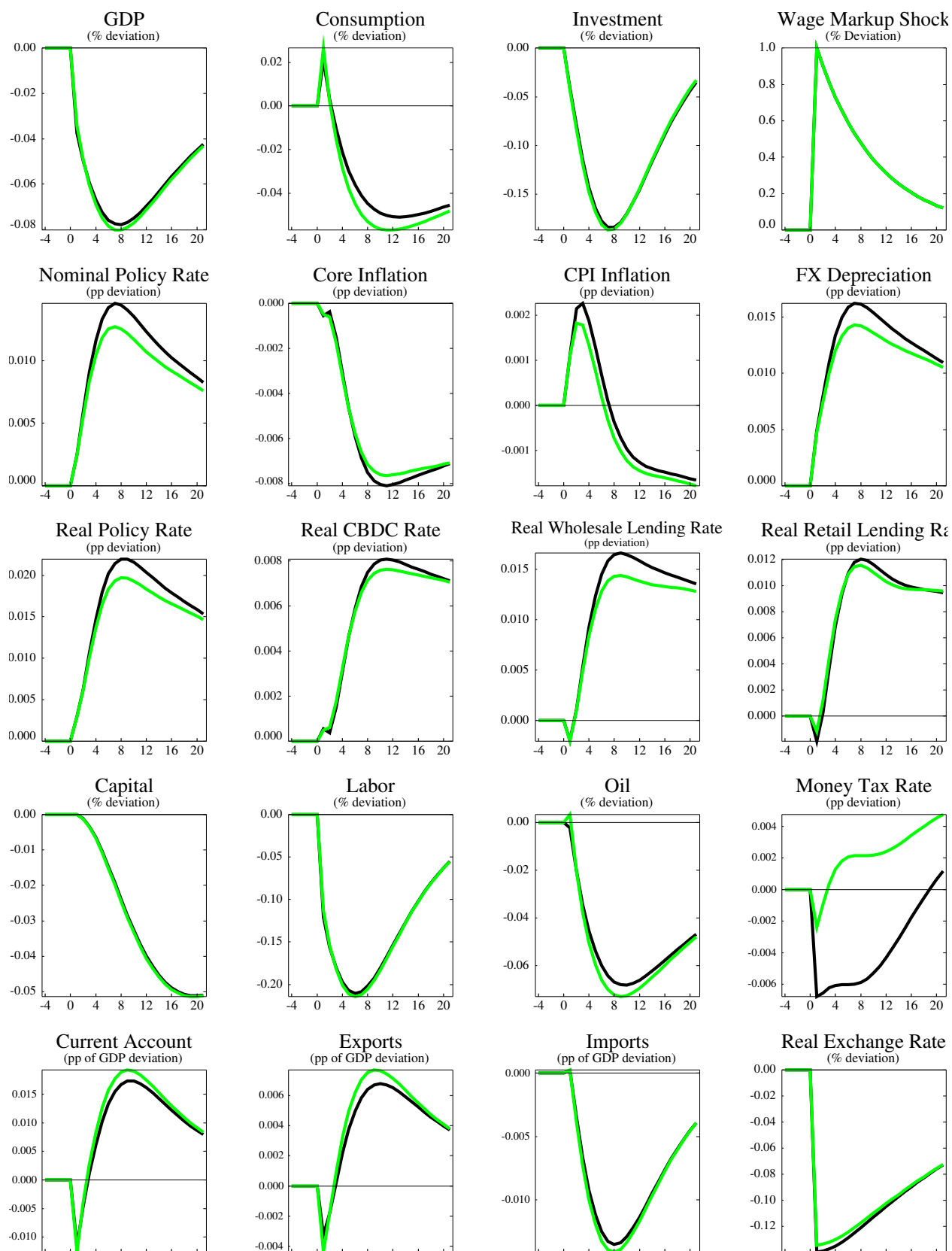


Figure 24: Wage Markup Shock: Macroeconomic Implications

— Without CBDC — With CBDC

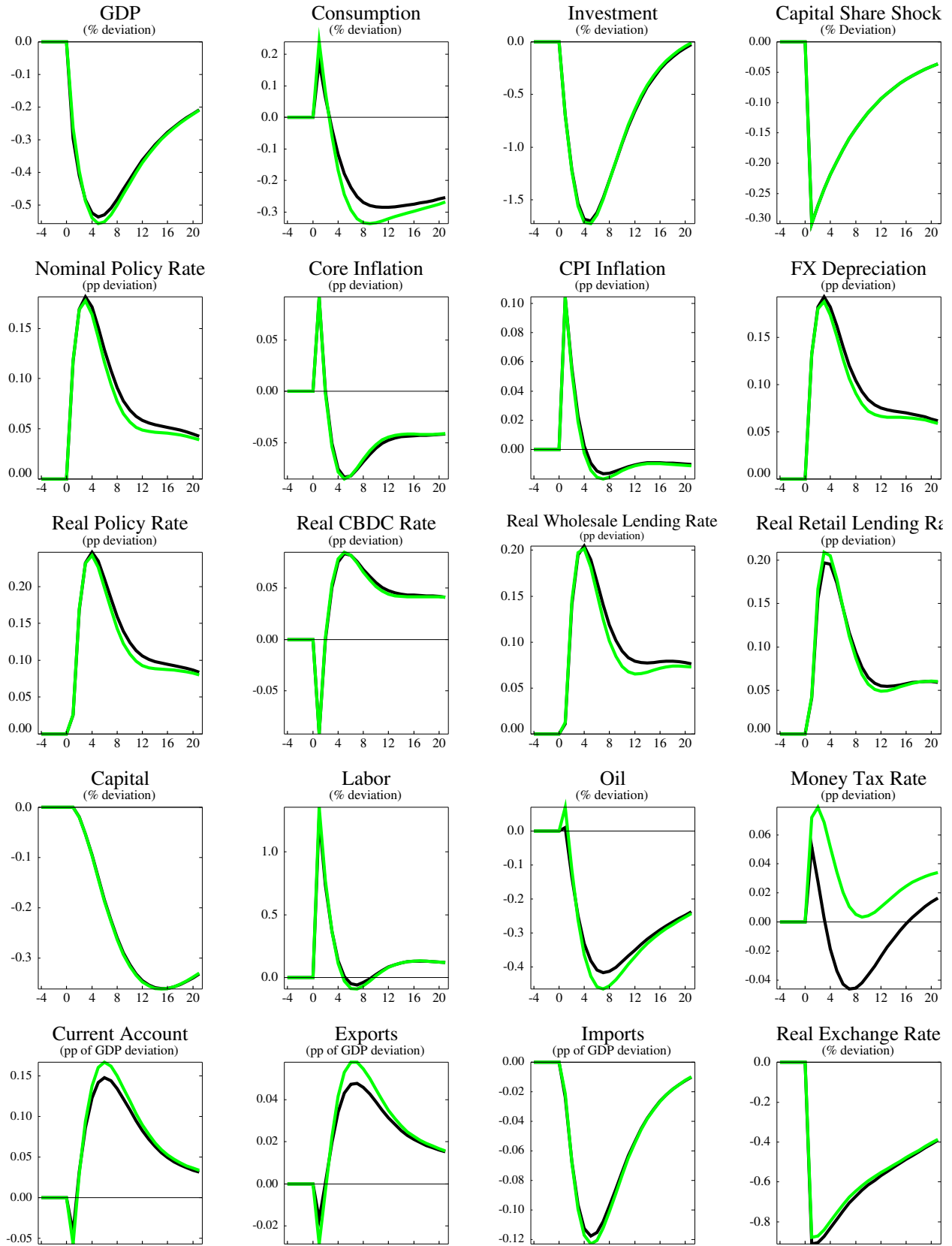


Figure 25: Capital Share Shock: Macroeconomic Implications

— Without CBDC — With CBDC

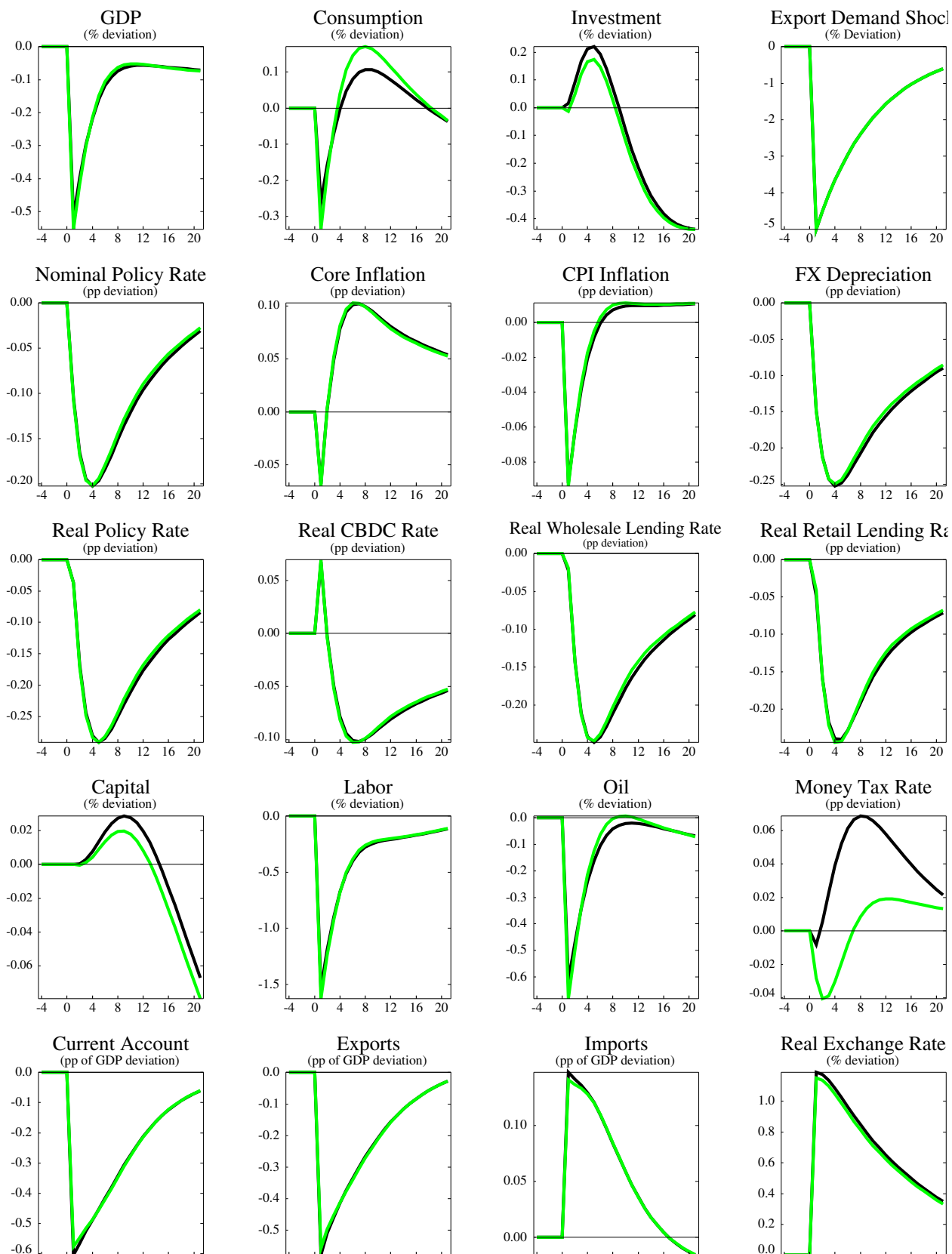


Figure 26: Industrial Goods Export Demand Shock: Macroeconomic Implications

— Without CBDC — With CBDC

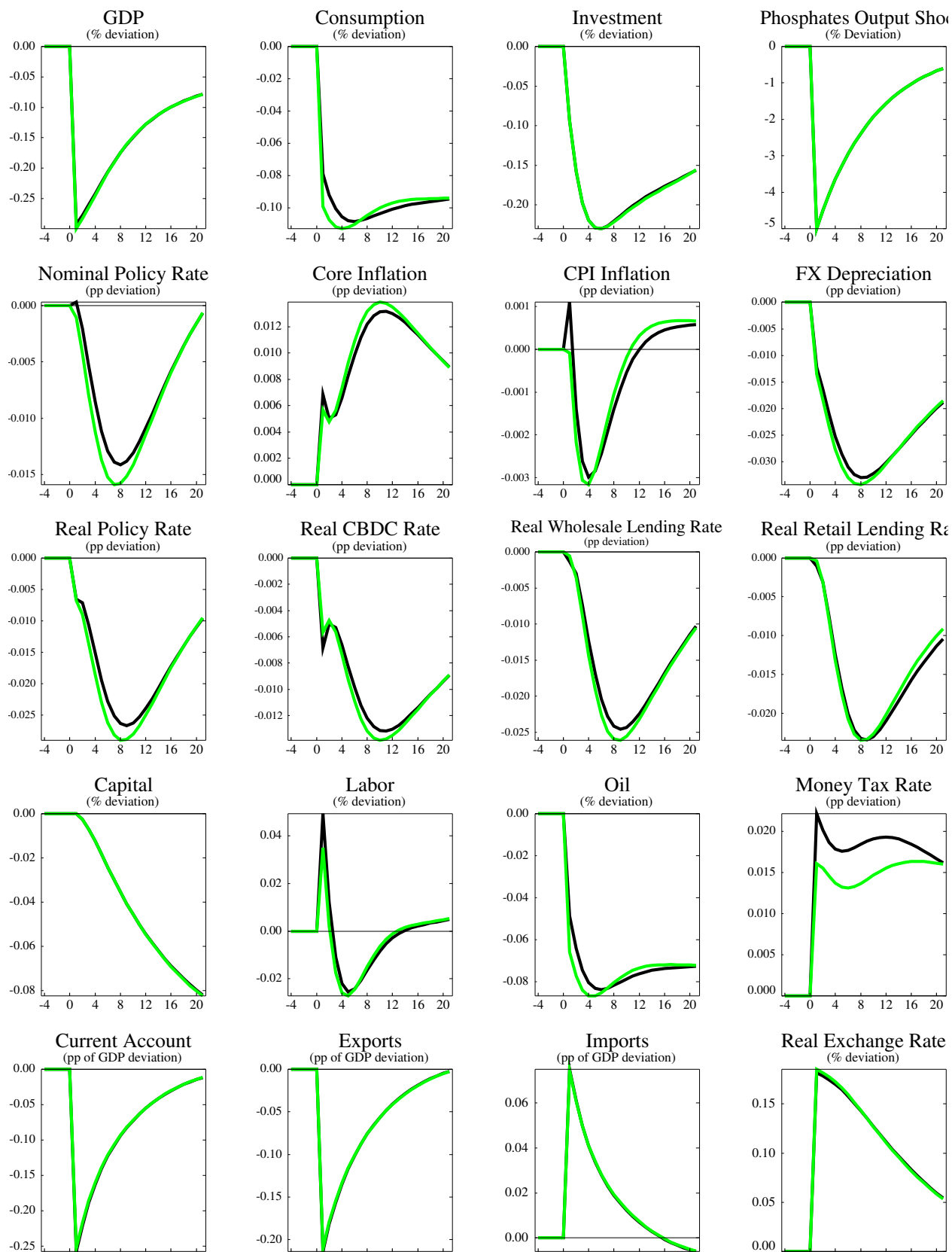


Figure 27: Phosphates Output Shock: Macroeconomic Implications

— Without CBDC — With CBDC

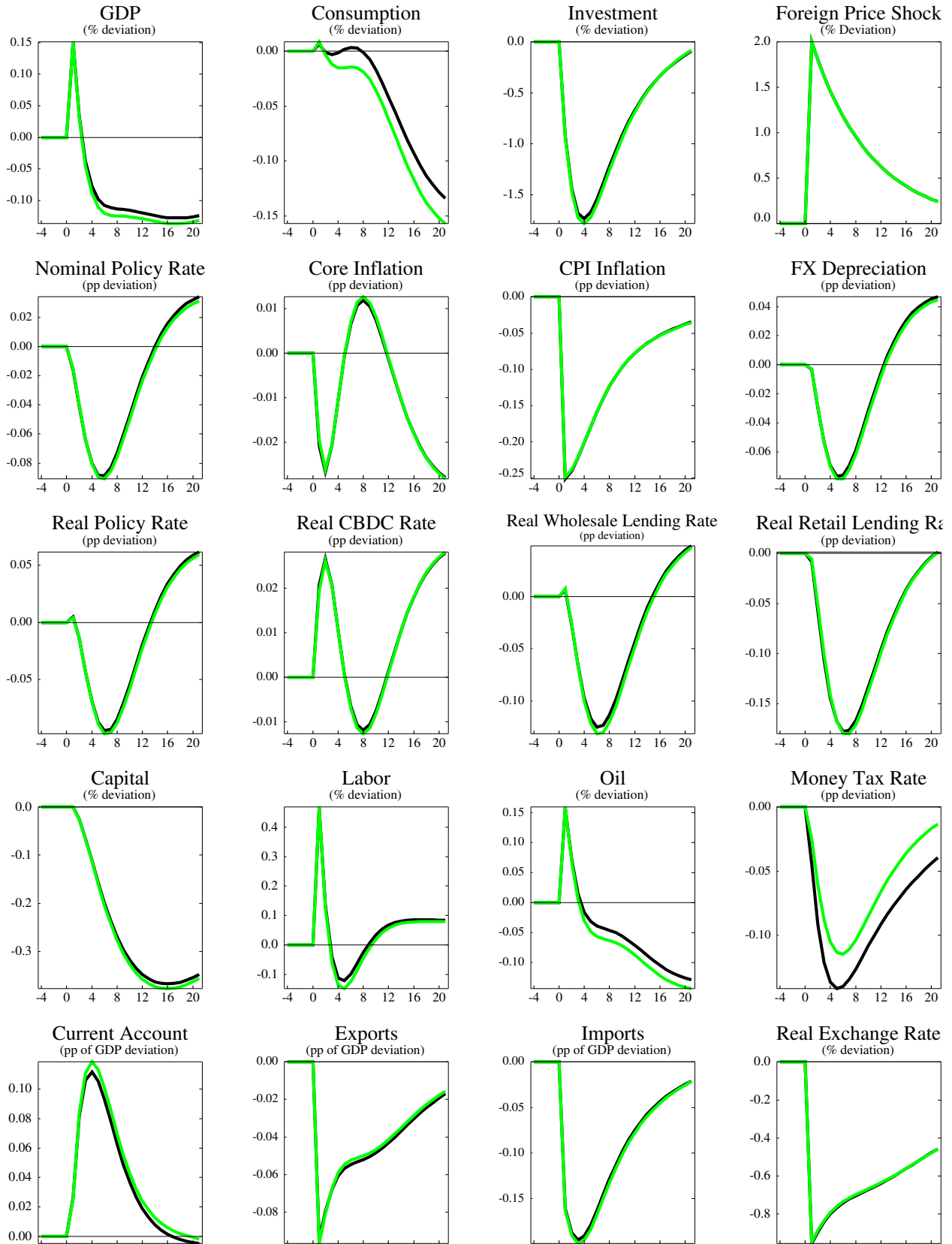


Figure 28: Industrial Goods Import Price Shock: Macroeconomic Implications

— Without CBDC — With CBDC

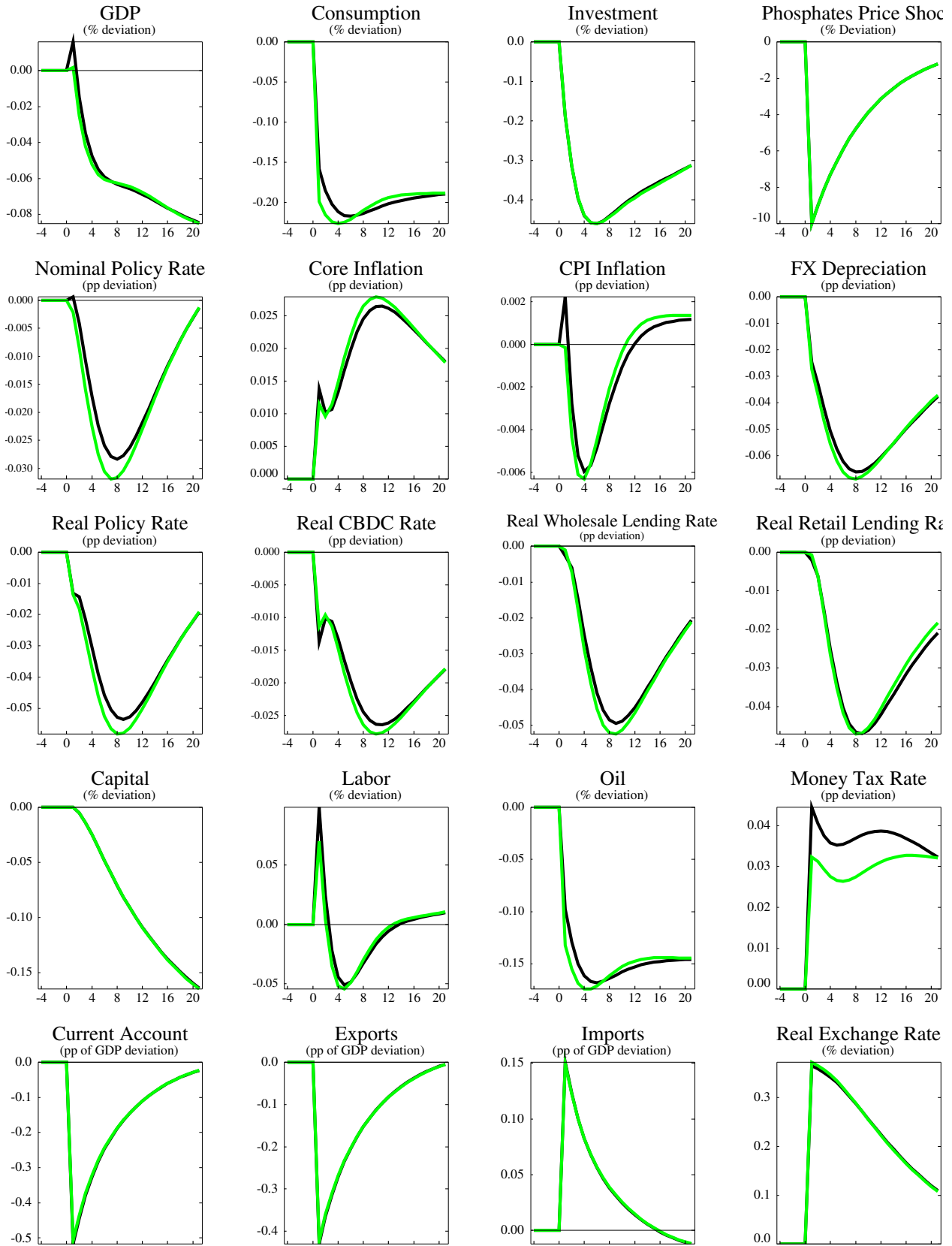


Figure 29: Phosphates Price Shock: Macroeconomic Implications

— Without CBDC — With CBDC

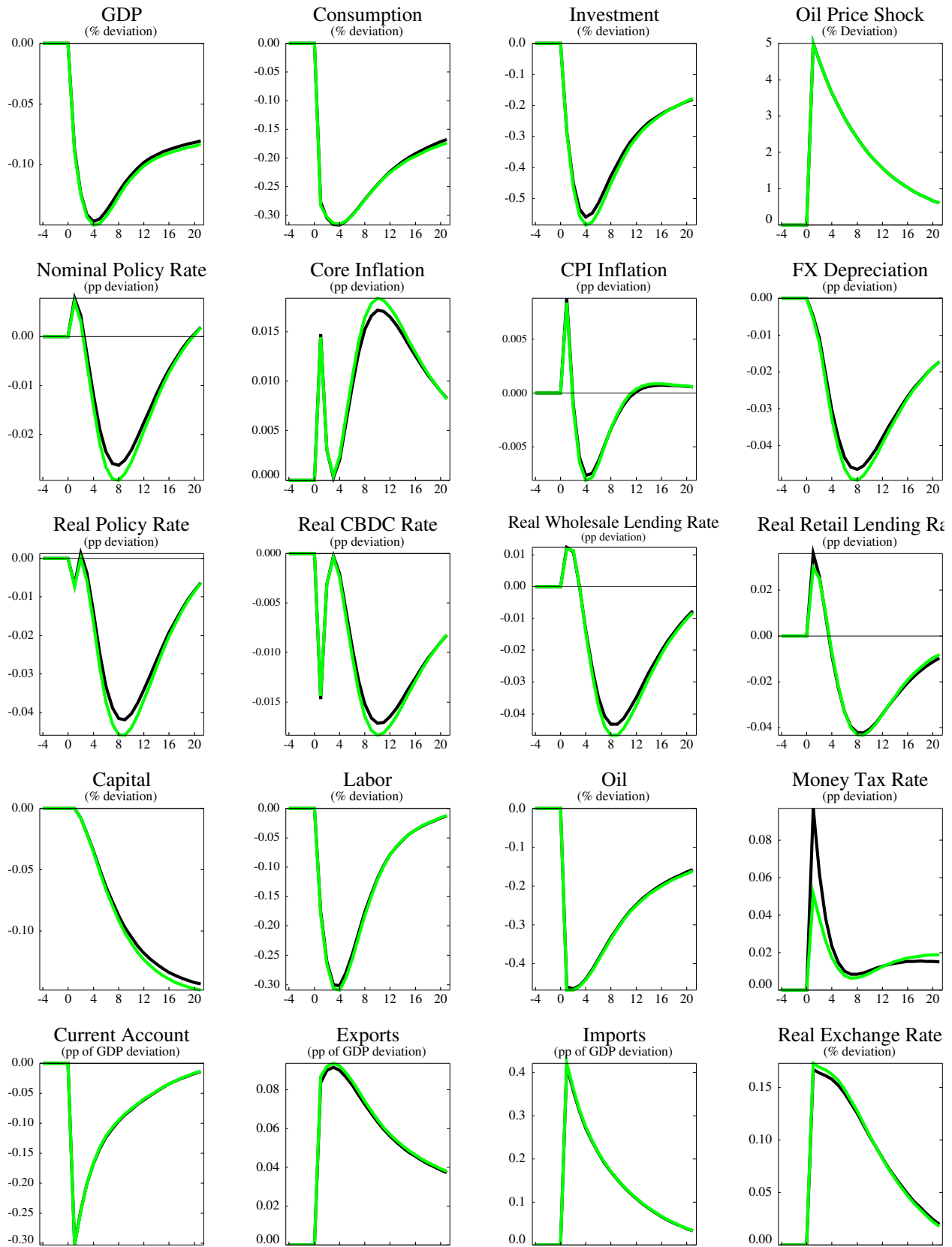


Figure 30: Oil Price Shock: Macroeconomic Implications

— Without CBDC — With CBDC

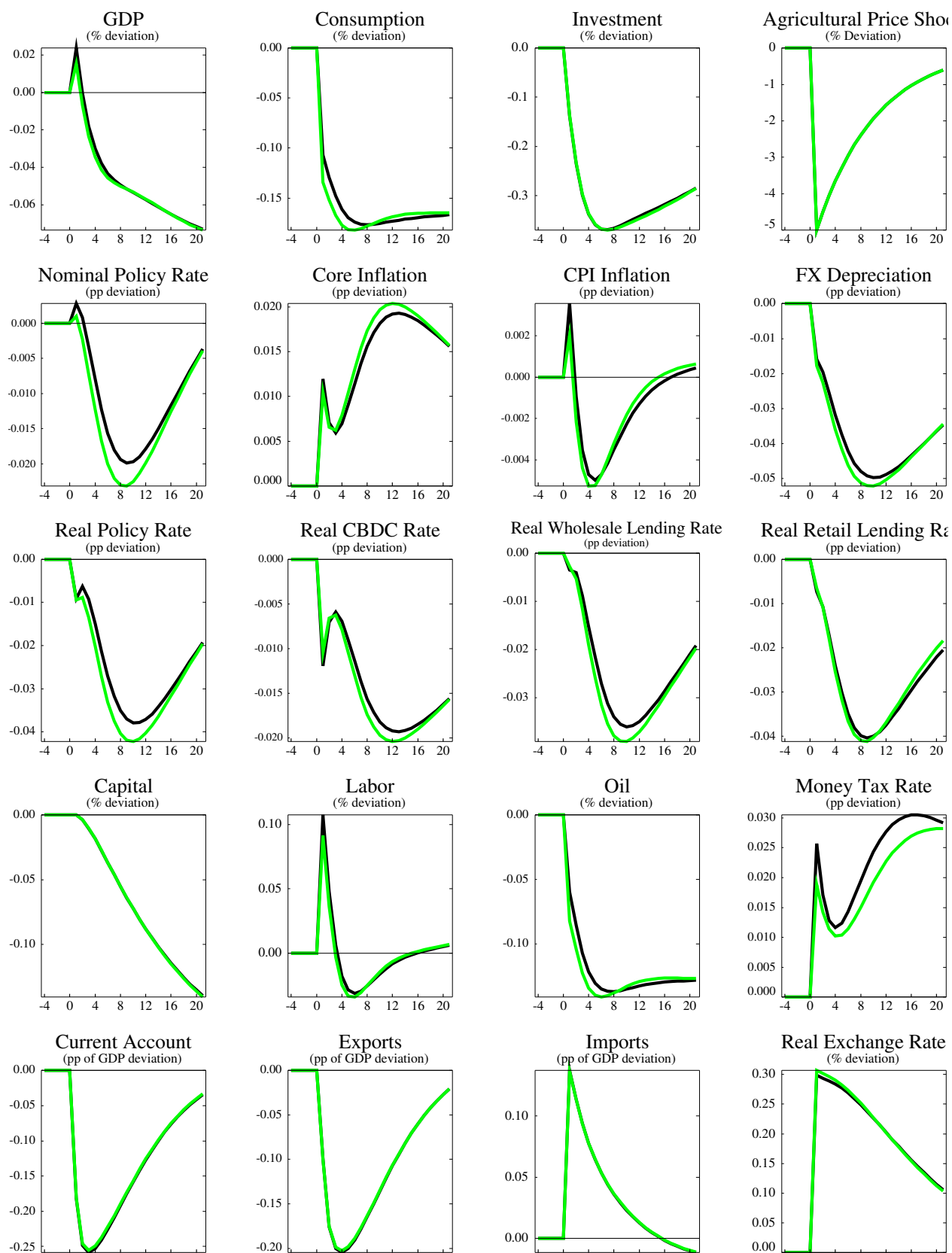


Figure 31: Agricultural Goods Price Shock: Macroeconomic Implications

— Without CBDC — With CBDC

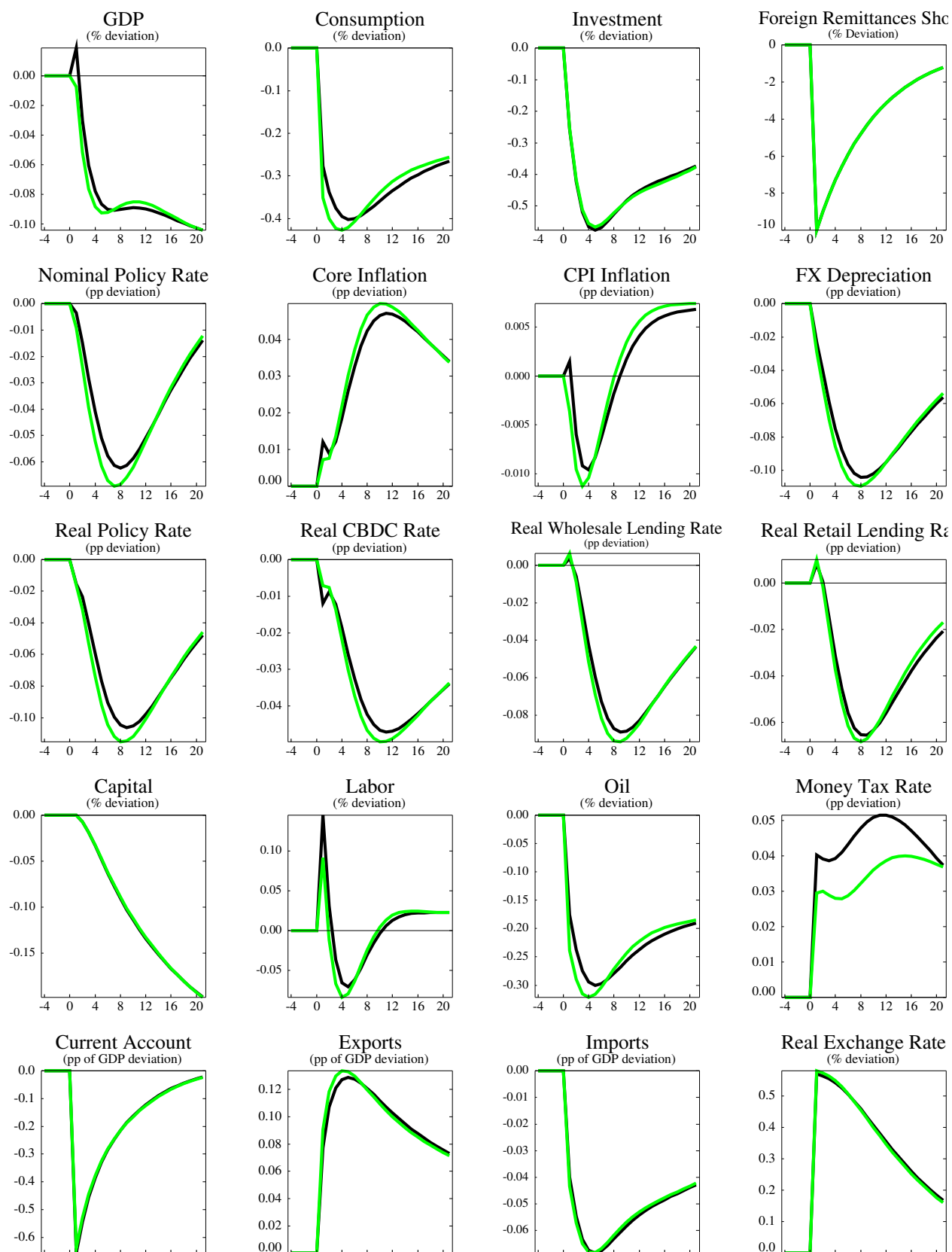


Figure 32: Foreign Remittances Shock: Macroeconomic Implications

— Without CBDC — With CBDC

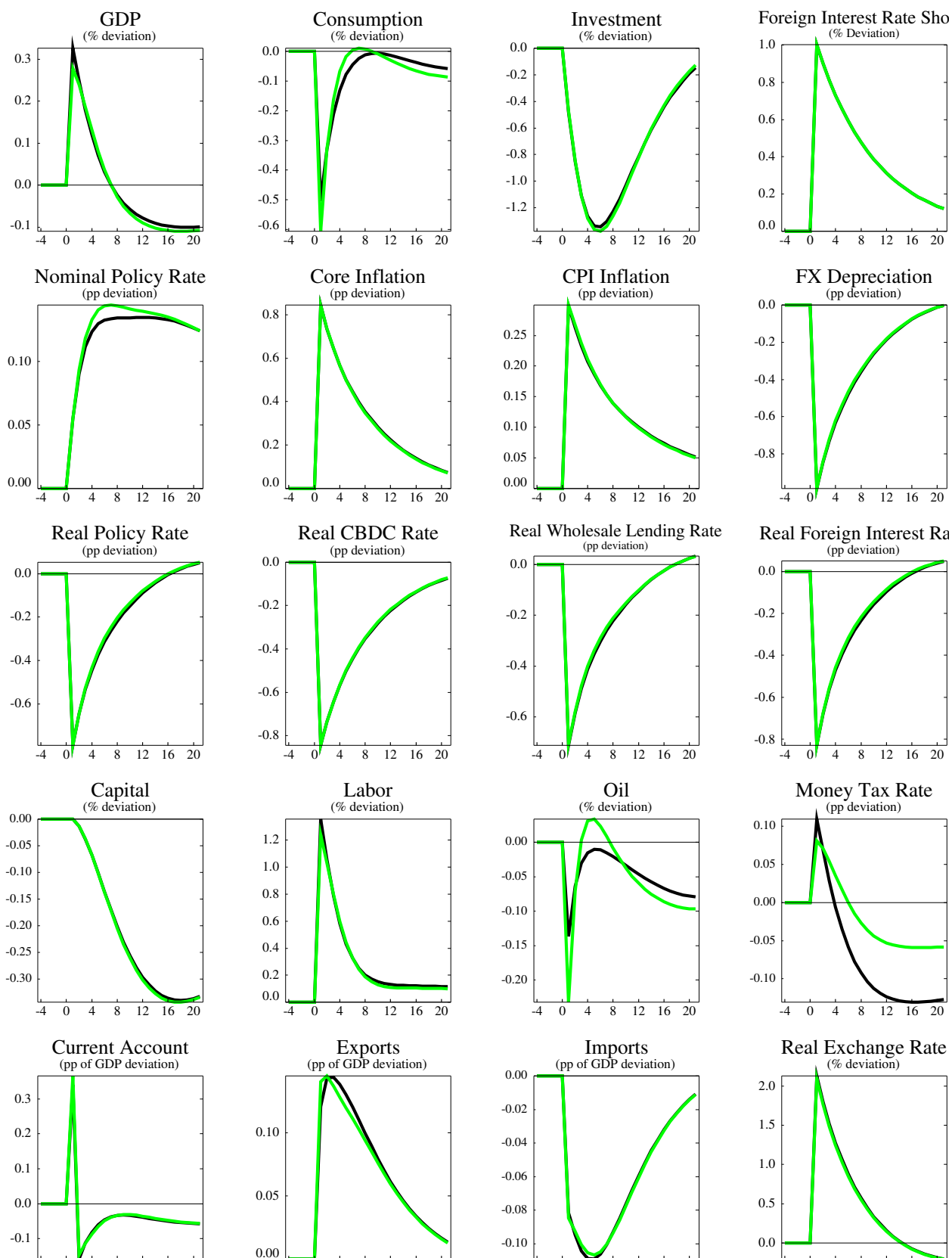


Figure 33: Foreign Interest Rate Shock: Macroeconomic Implications

— Without CBDC — With CBDC

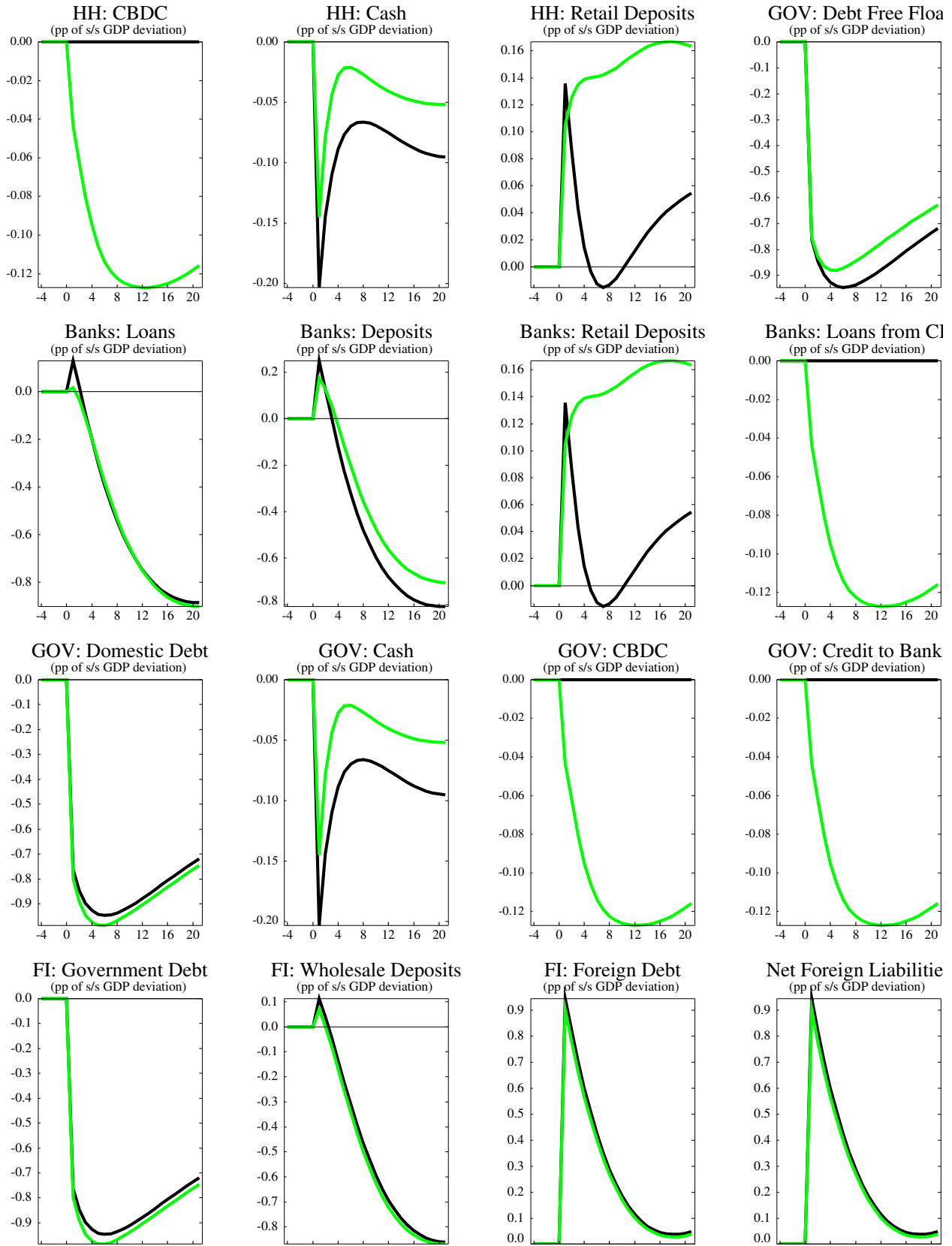


Figure 34: Foreign Interest Rate Shock: Balance Sheets

— Without CBDC — With CBDC

