Conducting Unconventional Monetary Policy with Foreign Exchange Reserves*

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Abstract

This paper studies sterilized asset purchase programs in emerging markets and developing economies. Sterilized asset purchase is an unconventional monetary policy implemented for the first time during the recent COVID-19 crisis. The paper provides a theoretical framework to examine the effectiveness and design of this new policy tool. The model economy is vulnerable to sudden stops due to financial market imperfection and liability dollarization. In a sudden stop, the balance sheet effect is triggered, causing large contractions in real economic activities. Instead of constrained domestic banks, the government plays a key role in funding intermediation. Sterilized asset purchase relaxes banks' leverage constraints, breaking down the balance sheet effect. The policy effectively mitigates the impact of sudden stop, improving welfare. The trade-offs are also discussed. Deep contractions in real activities can be avoided with a large-scale asset purchase. It might, however, potentially impede the economy's recovery. In terms of policy design, purchasing corporate bonds sterilized with foreign exchange reserves is most effective compared to other types of sterilized asset purchase.

JEL Classification: E52, E58, F32, F41

Keywords: Sudden Stops, Currency Mismatch, Balance Sheet Effect, Unconventional Monetary Policy, Asset Purchase Program, Sterilization, Foreign Exchange Reserves

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1 Introduction

Emerging market and developing economies (EMDEs) are vulnerable to sharp reversals in capital inflows, known as *sudden stops* (Dornbusch and Werner 1994; Calvo 1998). In a sudden stop, country risk premium rises and local currency devaluates, making it harder for domestic agents to repay foreign currency debt. In many EMDEs, foreign currency debt is mostly unhedged, and more importantly, financial markets are imperfect. In this environment, the impact of sudden stop is amplified through the *balance sheet effect* (Krugman 1999; Aghion, Bacchetta and Banerjee 2004; Céspedes, Chang and Velasco 2004), causing large contractions in real economic activities.[1] What should the policymakers do in a sudden stop? It is a question that goes beyond the traditional Mundell-Fleming framework with frictionless financial markets.[2] One policy prescription would be to raise the interest rates to defend the currency as in the recommendation by the International Monetary Fund (IMF) in the late 1990s.[3] Raising policy rates, however, does not fully resolve the issue. It helps defend the exchange rate, but it also increases the cost of credit for domestic agents, exacerbating financial market disruptions. If not the conventional monetary policy, can unconventional policies cope with sudden stops?

Recognizing the risks of capital flows, EMDEs have adopted unconventional policy measures including capital controls, macroprudential policies, and foreign exchange (FX) interventions.[4] More recently, during the COVID-19 crisis, EMDEs implemented asset purchase programs for the first time. They purchased government bonds, corporate bonds, and commercial papers in order to ease financial market disruptions. The details of asset purchase programs vary across countries. Figure 1 shows that, from March to August in 2020, Philippines purchased government bonds by 5.7 percent of GDP, while Chile purchased private assets by 2.1 percent of GDP. A distinctive feature is that, unlike in advanced economies, asset purchases were mostly sterilized in an effort to avoid inflationary pressures, weak exchange rates, or balance sheet expansions.[5] *Sterilized asset purchase* is newly adopted, and hence, less studied compared to other unconventional measures.[6] Can it be an effective policy response to sudden stops? If so, how to design this new tool, in particular, which asset to purchase and how to sterilize?

This paper develops a theoretical framework to study the effectiveness and design of sterilized asset purchase programs. To the best of my knowledge, this is the first paper studying asset purchase programs

[1] Appendix A describes dynamics around the 1998 sudden stop episode in Korea as an example.

[2] In this standard framework, an exchange rate depreciation is expansionary due to the expenditure-switching effect. The empirical findings, however, find that the balance sheet effect may dominate the expenditure-switching effect, raising a question on the frictionless financial market assumption (See for example Kearns and Patel 2016 and Culiuc 2020).

[3] This policy recommendation is given to the East Asian countries in the sudden stop during the 1998 East Asian crisis. The goal of this policy was "to make it more attractive to hold domestic currency, which, in turn, requires increasing interest rates temporarily, even if higher interest costs complicate the situation of weak banks and corporations." (Fischer 1998).

[4] See for example Chang (2008) and Céspedes, Chang and Velasco (2014) for the use of unconventional monetary policies in Latin American economies. After the Global Financial Crisis, the IMF provided a guidance for these tools to be used in a way that complements the conventional interest rate policy (International Monetary Fund 2012, 2022).

[5] The sterilization was done by various means: sale of foreign assets (Croatia), security issuance (Poland), or deposit facility. For more details see International Monetary Fund (2020), Adrian et al. (2021), and Arena et al. (2021). See also Reis (2016) that discusses about the funding side of quantitative easing and its implications for inflation.

[6] Note that the idea of sterilizing asset purchases is not new. The Federal Reserve conducted the Maturity Extension Program (Operation Twist) in 1961, and more recently, in 2011 in the aftermath of the Great Recession. See for details Swanson (2011) and Kuttner (2018).

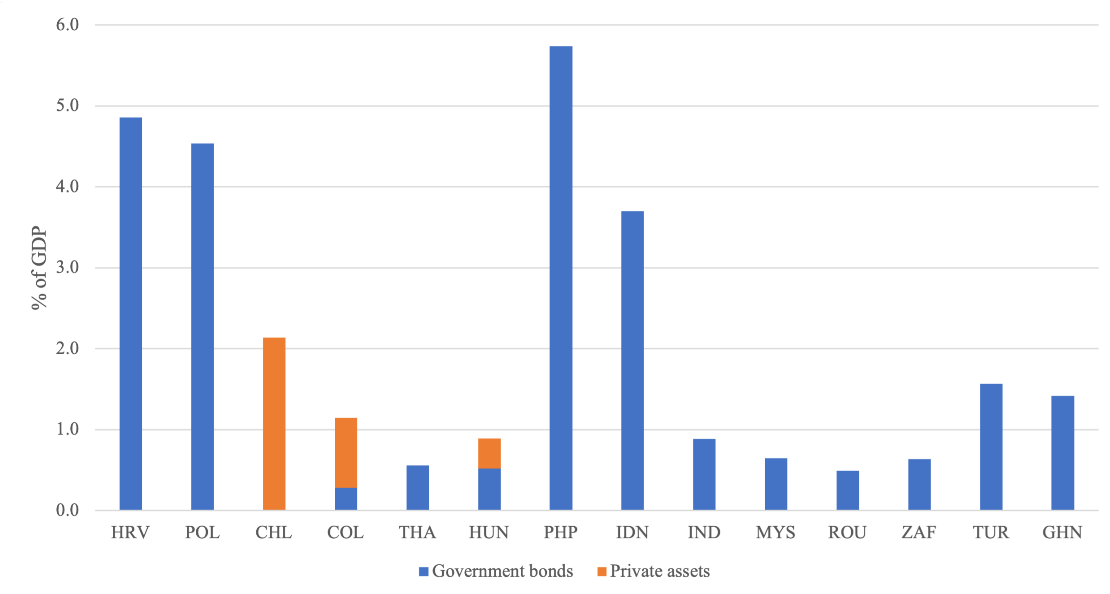


Figure 1: Asset purchases by countries

Note: The vertical axis indicates the asset purchases as a percentage of 2020 GDP conducted from March to August in 2020 by Croatia (HRV), Poland (POL), Chile (CHL), Colombia (COL), Thailand (THA), Hungary (HUN), Philippines (PHP), Indonesia (IDN), Indonesia (IDN), India (IND), Malaysia (MYS), Romania (ROU), South Africa (ZAF), Turkey (TUR), and Ghana (GHN). The blue bar is the government bond purchase in the primary and secondary markets. The orange bar is the purchase of private sector assets including corporate bonds, asset-backed securities, exchange-traded fund, etc. (Source: International Monetary Fund 2020).

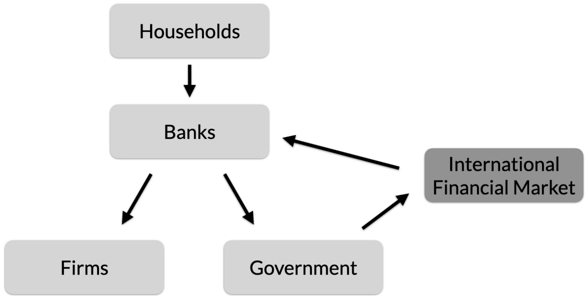
with sterilization in EMDEs.[7] The model is built on the standard small-open economy framework of Gali and Monacelli (2005). It abstracts from nominal rigidities but assumes incomplete financial markets. It incorporates a banking sector à la Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). In the model, a sudden stop is initiated by an adverse shock on the risk premium of country interest rates.

The model has three features that are key for the analysis. First, banks raise funds in foreign currency (i.e., in units of foreign goods) from households and foreign investors. This specification captures the stylized facts about *liability dollarization* in EMDEs: debt dollarization and deposit dollarization.[8] Banks then lend to non-financial firms and the government by purchasing their local currency bonds (i.e., in units of domestic consumption). This funding intermediation activity makes the banks' balance sheet currency-mismatched, and hence, vulnerable to exchange rate depreciations. Second, banks operate under an occasionally-binding constraint imposed on the leverage, called the *leverage constraint*. Combined with liability dollarization, this friction generates the balance sheet effect, amplifying the impact of sudden stops. Third, in response to sudden stop, the government conducts asset purchase programs with sterilization.[9] In the baseline scenario, the government purchases corporate bonds, and at the same time, sells FX reserves. This sterilization operation involves adjusting only the asset composition of the balance sheet, holding

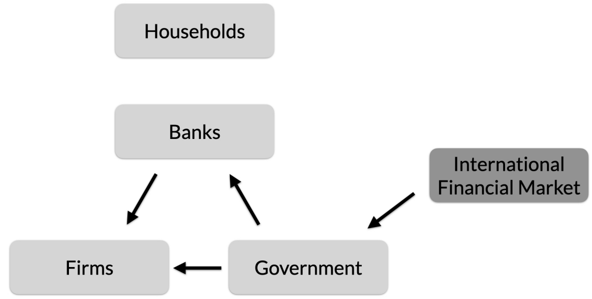
[7] Mimir and Sunel (2021) and Rebucci, Hartley and Jimenez (2022) study asset purchase programs but without sterilization.

[8] See Yeyati (2021) for the recent trends of dollarization especially in Latin American countries. See also the growing literature on deposit dollarization, for example, Dalgic (2018), Christiano et al. (2021), and Ferrante and Gornemann (2022).

[9] In closed economy models, the asset purchases are financed directly with interest-bearing bank reserves or short-term liabilities issued to households under a credible commitment for repayment (Gertler and Kiyotaki 2010, Gertler and Karadi 2011, Gertler and Karadi 2013).



(a) Normal times



(b) Sudden stops

Figure 2: Flow of funds

Note: The figure describes the flow of funds in the economy in normal times (left panel) and in sudden stops (right panel). The arrow indicates the funding flow from the source to the recipient.

the liabilities fixed. In using FX reserves for sterilization, the government faces an occasionally-binding constraint, called the *fear-of-losing-reserves constraint*.[10] When this constraint is binding, the government is balance-sheet constrained, and hence, it can only purchase limited amounts of assets.

Figure 2 describes the flow of funds in the economy. In normal times (left panel), banks are at the center of funding flows, intermediating the supply of funds (from households and foreign investors) and the demand for funds (by non-financial firms and the government). The government in turn accumulates FX reserves from the international financial market. In sudden stops (right panel), however, it is the government that plays a key role in the funding intermediation. The government provides liquidity to domestic agents and resolves financial market disruptions through sterilized asset purchase programs.

The first part of the paper studies the effectiveness of sterilized asset purchases in sudden stops. In a sudden stop, country interest rate rises and exchange rate depreciates, reducing the value of banks' net worth. Being constrained, banks are forced to decrease their asset demand, which causes a sharp fall in asset prices, deteriorating the value of net worth even further. This negative feedback loop is called the balance sheet effect that causes financial market disruptions. Sterilized asset purchase programs effectively break down the balance sheet effect. Specifically, the government asset purchases reduce banks' holdings of corporate bonds. These additional asset demands also prop up asset prices. The sales of FX reserves support exchange rates. Hence, the policy enhances the value of banks' net worth, relaxing the leverage constraint. Consequentially, the economy experiences a milder sudden stop, achieving welfare gains.

The paper highlights policy trade-offs associated with asset purchases: deep recession versus slow recovery. Large-scale asset purchase buffers the economy from getting into a deep recession, however, it then slows down the recovery process of the economy. The paper also emphasizes the role of FX reserves as war chest. Since the policy room for asset purchases is limited by the stock of FX reserves, the government must hoard large enough FX reserves to have viable policy actions in sudden stops.

[10] This specification captures the "fear of losing reserves" in EMDEs. Aizenman and Sun (2012) find that EMDEs depleted the accumulated reserves no more than 1/4 or 1/3 of the pre-crisis stock and rather let the exchange rate depreciate during the Global Financial Crisis.

The second part of the paper studies the design of sterilized asset purchase programs. Two alternative ways of conducting the policy are compared with the benchmark where the government purchases corporate bonds sterilized with FX reserves. One alternative is to purchase government bonds instead of corporate bonds. The other alternative is to issue government bonds, instead of selling FX reserves, to sterilize corporate bond purchases. It is shown that the benchmark policy is more effective in breaking down the balance sheet effect than the two alternatives.

Related literature This paper is related to the literature studying the role of financial frictions in amplifying external shocks. The seminal contributions of Krugman (1999), Aghion, Bacchetta and Banerjee (2004), Céspedes, Chang and Velasco (2004), and Gertler, Gilchrist and Natalucci (2007) show that financial market imperfection is the key to understand financial crises and the associated policies. Céspedes, Chang and Velasco (2004) show that currency mismatch gives rise to an amplification mechanism generating the balance sheet effect. Gertler, Gilchrist and Natalucci (2007) show that the financial accelerator mechanism can account for large contractions in financial crises like the 1997 Asian Financial Crisis. The present paper incorporates financial frictions in the domestic banks' balance sheet in an otherwise standard small-open economy framework. Due to the frictions, banks operate under the leverage constraint with dollarized liabilities. A similar modeling approach is taken by the recent studies including Aoki, Benigno and Kiyotaki (2016), Kitano and Takaku (2020), and Akinci and Queralto (2022). Importantly, the present paper allows the banks' leverage constraint to bind only occasionally, in particular, in a sudden stop.[11] This specification of nonlinearity is suitable to study sterilized asset purchase programs designed to target the financial friction when it matters.

This paper relates to the literature on unconventional monetary policies in open economies. Jeanne and Korinek (2010), Bianchi (2011), and Bianchi and Mendoza (2018) propose the use of capital controls to correct the pecuniary externalities that induce inefficient private borrowings.[12] Céspedes, Chang and Velasco (2017) and Chang and Velasco (2017) analyze three unconventional measures: direct lending, liquidity facilities, and equity injections. They show that relaxing the financial constraint imposed on domestic banks is the key for the policies to be effective. Chang (2018) further extends the analysis by examining FX interventions.[13] More recently, Adrian et al. (2020) and Basu et al. (2020) develop frameworks to guide the use of these unconventional tools to complement the conventional interest rate policy. The present paper is closest to Mimir and Sunel (2021) that studies asset purchase programs in a small-open New Keynesian model. While both papers study the same unconventional tool, the present paper focuses on the policy implementation with sterilization. In contrast to Mimir and Sunel (2021), this paper finds that asset purchases are effective in sudden stops driven by risk premium shocks. It further highlights policy trade-offs and the role of FX reserves involved in asset purchase programs.

Lastly, this paper relates to the literature on the motives for hoarding FX reserves. In Jeanne and Ranciere (2011), FX reserve is an insurance that reduces the probability of sudden stop occurrence. In

[11] Bocola (2016), Karadi and Nakov (2021), and Akinci and Queralto (2022) also consider banks' occasionally-binding constraint but study different policies.

[12] See Bianchi and Mendoza (2020) and Erten, Korinek and Ocampo (2021) for a survey of the literature.

[13] See also the recent work on FX interventions along this line including Carrasco and Hoyle (2020) and Hofmann, Patel and Wu (2021).

Céspedes, Chang and Velasco (2017), Gopinath and Stein (2018), Bocola and Lorenzoni (2020), and Céspedes and Chang (2020), FX reserve is a war chest for the lender of last resort policy.[14] The present paper emphasizes the war chest role of FX reserves. In particular, it shows that FX reserves can be used as a sterilization tool for asset purchase programs. By imposing an occasionally-binding constraint on the use of FX reserves, this paper highlights the importance of reserve accumulation in normal times before a sudden stop hits the economy.[15]

Outline The paper is organized as follows. Section 2 describes the model. Section 3 presents numerical results from the model simulations. Finally, Section 4 concludes.

2 Model

Consider a small-open economy with two tradable goods: domestically produced goods (home goods) and imported goods from the rest of the world (foreign goods). The domestic consumer price index (CPI) is defined as

$$P_t \equiv \left[(1-\gamma)P_{Ht}^{1-\eta} + \gamma P_{Ft}^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

where P_{Ht} and P_{Ft} are the prices for home and foreign goods, γ is the trade openness, and η is the trade elasticity. Assume that the law of one price holds and that the weight of home goods in the consumption basket for the rest of the world is infinitely small. Under this assumption, the real exchange rate is expressed as

$$e_t = \frac{P_{Ft}}{P_t}$$

An increase in e_t indicates a real depreciation. The terms of trade is defined as

$$tot_t \equiv \frac{P_{Ft}}{P_{Ht}}$$

Let $p_{Ht} \equiv P_{Ht}/P_t$ be the relative price of home goods in terms of domestic CPI.[16]

The economy is inhabited by households, banks, non-financial firms, and the consolidated government.

[14] See also Das, Gopinath, Kim and Stein (2022).

[15] Basu, Ghosh, Ostry and Winant (2018) study FX interventions in a stylized model with a similar constraint on the use of FX reserves.

[16] The real exchange rate can be expressed as a function of the terms of trade

$$e_t = [(1-\gamma)tot_t^{\eta-1} + \gamma]^{\frac{1}{\eta-1}}$$

which is increasing in tot_t, in particular, given the model parameterization.

2.1 Households

There is a unit measure of households. Each household is composed of workers (fraction $1-\zeta$) and bankers (fraction ζ). In each period, a banker can operate the business with probability χ. Hence, $(1-\chi)\zeta$ of bankers terminates the business and becomes workers, in which case they give retained earnings as payouts to the households. To replace these exiting bankers, the same number of workers becomes new bankers, holding the relative proportion of workers and banks fixed. The new bankers start the business with the net worth given as transfers by households. Finally, to maintain representative agent framework, assume that (i) workers put deposits in the banks owned by other households, and that (ii) within household, there is perfect consumption insurance.

A representative household has the GHH preference (Greenwood, Hercowitz and Huffman 1988)

$$U(c_t, h_t) = \frac{\left(c_t - \frac{\kappa_h}{1+\varphi} h_t^{1+\varphi}\right)^{1-\sigma} - 1}{1-\sigma}$$

where c_t is a constant elasticity of substitution (CES) composite of consumption on home and foreign goods,

$$c_t = \left[(1-\gamma)^{\frac{1}{\eta}} c_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} c_{Ft}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

h_t is labor hour, β is the discount factor, σ and φ are the inverse of the intertemporal elasticity of substitution and the Frish elasticity, and κ_h is the weight on labor disutility.[17]

The budget constraint expressed in real term is

$$c_t + e_t d_{Ht} = w_t h_t + e_t R_t d_{Ht-1} + \Pi_t - T_t \tag{1}$$

where d_{Ht} is a one-period riskless bank deposit in foreign currency (i.e., in units of foreign goods), R_t is a return on deposits, w_t is wage, Π_t is profits from banks and non-financial firms, and T_t is a lump-sum tax.

The household's problem is to maximize the expected life-time utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(c_t, h_t)$$

subject to (1). The first-order conditions from the problem are

$$1 = \mathbb{E}_t \left(\Lambda_{t,t+1} R_{t+1} \frac{e_{t+1}}{e_t}\right)$$

$$\kappa_h h_t^{\varphi} = w_t$$

[17]The GHH preference is commonly used in the small-open economy literature (Neumeyer and Perri 2005; Uribe and Yue 2006; Mendoza 2010). It eliminates wealth effects on labor supply, preventing an artificial boom following a negative shock on the country interest rate.

where the stochastic discount factor is

$$\Lambda_{t,t+1} = \beta\mathbb{E}_t\frac{mu_{t+1}}{mu_t}$$

with the marginal utility of consumption $mu_t = \left(c_t - \kappa_h\frac{h_t^{1+\varphi}}{1+\varphi}\right)^{-\sigma}$. The consumption for home and foreign goods are $c_{Ht} = (1-\gamma)(p_{Ht})^{-\eta}c_t$ and $c_{Ft} = \gamma(e_t)^{-\eta}c_t$ from the standard intratemporal problem.[18]

2.2 Banks

Banks raise funds with an one-period debt in foreign currency (i.e., in units of foreign goods). The total debt d_t is composed of households' deposit d_{Ht} and borrowing from foreign investors d_{Ft} (i.e., $d_t \equiv d_{Ht} + d_{Ft}$), both of which are subject to interest rate R_t given as exogenous. Banks lend funds to both non-financial firms and the government by purchasing their bonds. Specifically, banks purchase corporate bonds s_{Bt} and government bonds b_{Bt} denominated in local currency (i.e., in units of domestic consumption). The corporate bond is a state-contingent claim on the future returns from one unit of physical capital of non-financial firms. Let q_{kt} and R_{kt} be the price and the return of a corporate bond. The government bond is a perpetuity that pays a fixed coupon payment each period. Let q_{bt} and R_{bt} be the price and the return of a government bond.

An individual bank $j \in [0, \zeta]$ has a balance sheet

$$q_{kt}s_{Bjt} + q_{bt}b_{Bjt} = n_{jt} + e_t d_{jt} \tag{2}$$

where n_{jt} is the net worth of bank j. Notice the mismatch of currency denomination between the assets and the liabilities on the balance sheet. The budget constraint is

$$e_t R_t d_{jt-1} + q_{kt}s_{Bjt} + q_{bt}b_{Bjt} = e_t d_{jt} + R_{kt}q_{kt-1}s_{Bjt-1} + R_{bt}q_{bt-1}b_{Bjt-1} \tag{3}$$

Combining (2) and (3),

$$n_{jt} = R_{kt}q_{kt-1}s_{Bjt-1} + R_{bt}q_{bt-1}b_{Bjt-1} - e_t R_t d_{jt-1} \tag{4}$$

indicating that the net worth is accumulated through retained earnings.

The bank's objective is to maximize the terminal payouts to the household in the form of net worth. The franchise value of the bank is

$$V_t\left(n_{jt}\right) = \max_{s_{Bjt}, b_{Bjt}, d_{jt}} \mathbb{E}_t\Lambda_{t,t+1}\left[(1-\chi)n_{jt+1} + \chi V_{t+1}\left(n_{jt+1}\right)\right] \tag{5}$$

taking into account the probability of terminating the business. Importantly, the bank is subject to the

[18] The problem for consumption demand on each goods is to maximize $\left[(1-\gamma)^{\frac{1}{\eta}}c_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}}c_{Ft}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$ subject to the given level of expenditure $Z_t = P_{Ht}c_{Ht} + P_{Ft}c_{Ft}$.

occasionally-binding incentive compatibility constraint given as

$$V_t(n_{jt}) \geq \theta(q_{kt}s_{Bjt} + \Delta q_{bt}b_{Bjt}) \tag{6}$$

where $\theta \in (0,1)$ is the absconding rate of assets, and $\Delta \in [0,1)$ denotes the relative absconding rate of the government bond compared to the corporate bond (i.e., the government bond is harder to be diverted).[19] This constraint gives rise to non-linear dynamics depending on whether it is binding or not.

The bank's problem is to maximize (5) subject to (2), (4), and (6).[20] The first-order conditions are

$$\mathbb{E}_t\Lambda_{t,t+1}\Omega_{t+1}\left(R_{kt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) = \theta\lambda_t$$
$$\mathbb{E}_t\Lambda_{t,t+1}\Omega_{t+1}\left(R_{bt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) = \Delta\theta\lambda_t$$

The left-hand sides are the expected excess returns on the corporate and the government bonds evaluated with the bank's stochastic discount factor $\Lambda_{t,t+1}\Omega_{t+1}$, while λ_t on the right-hand sides measures the tightness of constraint (6).[21]

When constraint (6) is not binding (i.e., $\lambda_t = 0$), the bank's stochastic discount factor is the same as the households' (i.e., $\Omega_{t+1} = 1$). Hence, the first-order conditions become

$$\mathbb{E}_t\Lambda_{t,t+1}R_{kt+1} = \mathbb{E}_t\Lambda_{t,t+1}R_{bt+1} = \mathbb{E}_t\Lambda_{t,t+1}R_{t+1}\frac{e_{t+1}}{e_t}$$

which implies the standard no-arbitrage condition in a frictionless financial market. In this case, the bank would purchase both of the assets and absorb excess returns. In particular, the asset demand does not depend on bank's net worth.

When constraint (6) is binding (i.e., $\lambda_t > 0$), however, the bank is not able to purchase assets to absorb all the excess returns. Rearranging the first-order conditions,

$$\Delta\mathbb{E}_t\Lambda_{t,t+1}\Omega_{t+1}\left(R_{kt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) = \mathbb{E}_t\Lambda_{t,t+1}\Omega_{t+1}\left(R_{bt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right)$$

indicating the no-arbitrage condition between the two assets. Furthermore, in this case, the bank's asset demand fluctuates with the value of net worth. To see this, define the leverage ratio as

$$l_{jt} \equiv \frac{q_{kt}s_{Bjt} + \Delta q_{bt}b_{Bjt}}{n_{jt}} \tag{7}$$

which measures the riskiness of bank's portfolio. The leverage ratio is a risk-adjusted asset-capital ratio

[19] As standard in the literature, the underlying assumption for this financial friction is that bankers can abscond with $\theta(q_{kt}s_{Bjt} + \Delta q_{bt}b_{Bjt})$ of assets. In such case, the banker exits the industry and the lenders (i.e., households and foreign investors) reclaim the rest of the assets. The given constraint restricts this possibility so that the bankers have no incentives to run away with the assets, and hence, the lenders are willing to lend for the bankers to operate in equilibrium.

[20] The details of bank's problem are given in Appendix B.

[21] As shown in Appendix B, $\Omega_t \equiv (1-\chi) + \chi(\partial V_t(n_{jt})/\partial n_{jt})$ and λ_t is an increasing function of the Lagrange multiplier for constraint (6).

where only Δ fraction of government bonds is taken into account. This reflects the fact that the government bond is safer than the corporate bond exactly by the relative absconding rate Δ. When constraint (6) is binding, the leverage ratio attains its maximum value

$$\bar{l}_t \equiv \frac{\mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} R_{t+1} e_{t+1}/e_t}{\theta - \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} (R_{kt+1} - R_{t+1} e_{t+1}/e_t)}$$

which does not depend on individual specific variables. Constraint (6) is referred to as the leverage constraint, since it can be rewritten in terms of the leverage ratio as

$$l_{jt} \leq \bar{l}_t \tag{8}$$

When it is binding,

$$q_{kt} s_{Bjt} + \Delta q_{bt} b_{Bjt} = \bar{l}_t n_{jt}$$

where the bank's asset demand on the left-hand side becomes dependent on the value of net worth on the right-hand side.

Aggregation The aggregate net worth is the sum of the existing banks' net worth (fraction χ) and the new banks' net worth (fraction $1 - \chi$)

$$n_t = \chi \left[\left(R_{kt} - R_t \frac{e_t}{e_{t-1}} \right) q_{kt-1} s_{Bt-1} + \left(R_{bt} - R_t \frac{e_t}{e_{t-1}} \right) q_{bt-1} b_{Bt-1} + R_t \frac{e_t}{e_{t-1}} n_{t-1} \right] + (1 - \chi) n_{yt} \tag{9}$$

where n_{yt} is the net worth for new banks transferred from households

$$n_{yt} = \frac{\iota}{1 - \chi} (q_{kt-1} s_{Bt-1} + \Delta q_{bt-1} b_{Bt-1})$$

which is $\frac{\iota}{1-\chi}$ of the exiting banks' assets $q_{kt-1} s_{Bt-1} + \Delta q_{bt-1} b_{Bt-1}$.

Assuming symmetric leverage ratios across the banks in equilibrium (i.e., $l_{jt} = l_t$ for all j), the aggregate counterpart of the leverage constraint (8) is

$$l_t = \frac{q_{kt} s_{Bt} + \Delta q_{bt} b_{Bt}}{n_t} \leq \bar{l}_t \tag{10}$$

When it is binding,

$$q_{kt} s_{Bt} + \Delta q_{bt} b_{Bt} = \bar{l}_t n_t$$

showing that a fall in the value of aggregate net worth causes a decline in the aggregate asset demand.

Let μ_t denote the spread on the corporate bond

$$\mu_t \equiv \mathbb{E}_t (R_{kt+1} - R_{t+1} e_{t+1}/e_t)$$

Since it becomes positive when banks are constrained, μ_t serves as an indicator of financial market disruptions.

2.3 Non-financial firms

The non-financial firms are owned by households, operating in a perfectly competitive manner. The firms are composed of home goods producers, capital storage firms, and capital producers.

Home goods producers The home goods producers own Cobb-Douglas production technology

$$y_{Ht} = a_t k_{t-1}^{\alpha} h_t^{1-\alpha}$$

where α is the capital income share and a_t is the total factor productivity. To produce goods in period t, the home goods producers rent capital k_{t-1} from the capital storage firms at rate z_t and hire labor h_t at wage w_t. The first-order conditions from the profit-maximization problem are

$$z_t = \alpha p_{Ht} \frac{y_{Ht}}{k_{t-1}}$$
$$w_t = (1-\alpha) p_{Ht} \frac{y_{Ht}}{h_t}$$

Capital storage firms The capital storage firms purchase capital k_{t-1} from the capital producers at price q_{kt-1} in period $t-1$. In period t, the capital storage firms rent the capital out at rate z_t to home goods producers within the period and sell the undepreciated $1-\delta$ fraction of capital at price q_{kt}. Hence, the profit per unit of capital is $z_t + (1-\delta)q_{kt}$.

To finance capital purchase in period $t-1$, the capital storage firms issue a corporate bond s_{t-1} to the banks per unit of capital (i.e., $s_{t-1} = k_{t-1}$) that pays return of

$$R_{kt} = \frac{z_t + (1-\delta) q_{kt}}{q_{kt-1}}$$

in period t.[22]

Capital producers The capital producers make new capital using investment as an input subject to adjustment costs. The investment i_t is a CES composition of investment in home and foreign goods

$$i_t = \left[(1-\gamma)^{\frac{1}{\eta}} i_{Ht}^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} i_{Ft}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

[22] There is no financial frictions in obtaining funds from the banks. Banks can perfectly monitor the capital storage firms and enforce the financial contract with them. Furthermore, due to perfect competition, the price of capital is equal to the price of corporate bond. As a result, banks take all state-contingent returns $z_t + (1-\delta)q_{kt}$ generated from the contract, letting the capital storage firms make zero profits.

The capital producers sell capital k_t to the capital storage firms and purchase back the undepreciated capital $(1-\delta)k_{t-1}$ at price q_{kt}. The problem for the capital producers is

$$\max_{\{k_t, i_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left[q_{kt}(k_t - (1-\delta)k_{t-1}) - i_t \right]$$

subject to

$$k_t = (1-\delta)k_{t-1} + i_t \left[1 - \frac{\kappa_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right]$$

where κ_i is a parameter for adjustment costs. The first-order condition is

$$1 = q_{kt} \left[1 - \frac{\kappa_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 - \kappa_i \left(\frac{i_t}{i_{t-1}} - 1 \right) \left(\frac{i_t}{i_{t-1}} \right) \right] + \kappa_i \mathbb{E}_t \Lambda_{t,t+1} q_{kt+1} \left(\frac{i_{t+1}}{i_t} - 1 \right) \left(\frac{i_{t+1}}{i_t} \right)^2$$

The investment for home and foreign goods are $i_{Ht} = (1-\gamma)(p_{Ht})^{-\eta} i_t$ and $i_{Ft} = \gamma(e_t)^{-\eta} i_t$ from the standard intratemporal problem similar to the one for consumption.

2.4 Government

The consolidated government makes a fixed public spending $g_t = g$ of home goods. It hoards FX reserves f_t purchased from the international financial market. FX reserve is a one-period asset in foreign currency (i.e., in units of foreign goods) that pays return of R_t^*. The government also issues a long-term bond b_t at price q_{bt}, which is a perpetuity with geometrically decaying coupon payments. The return from holding the government bond from period $t-1$ to t is

$$R_{bt} = \frac{\Xi + \varrho q_{bt}}{q_{bt-1}} \tag{11}$$

where Ξ is the fixed coupon payment and ϱ is the decaying rate of the bond.

The balance sheet is

$$q_{kt} s_{Gt} + e_t f_t = q_{bt} b_t \tag{12}$$

The left-hand side is the value of total assets composed of corporate bonds s_{Gt} and FX reserves f_t, while the right-hand side is the value of net liabilities b_t.[23] The budget constraint is

$$p_{Ht} g_t + R_{bt} q_{bt-1} b_{t-1} + q_{kt} s_{Gt} + e_t f_t = q_{bt} b_t + R_{kt} q_{kt-1} s_{Gt-1} + e_t R_t^* f_{t-1} + T_t \tag{13}$$

Sterilized asset purchase Consider that the government conducts sterilized asset purchases. In particular, the government purchases corporate bonds and sterilizes with FX reserves. In the balance sheet, this

[23] Assume that the net worth of the government is constant and normalized to be zero, abstracting from the issues related to the evoluation and management of government net worth.

operation involves adjustments in the asset composition

$$q_{kt} \underbrace{s_{Gt}}_{\uparrow} + e_t \underbrace{f_t}_{\downarrow} = q_{bt} \underbrace{b_t}_{\text{constant}}$$

holding the supply of government bond fixed $b_t = b$.[24] Assume that the government follows a policy rule to sell fraction Γ_t of FX reserves for sterilization. Hence, the remaining stock of FX reserves is

$$f_t = (1 - \Gamma_t) f$$

where f is the steady-state FX reserve holdings. Define the fraction Γ_t as

$$\Gamma_t \equiv \phi_\mu(\mu_t - \mu)$$

where $\mu_t - \mu$ is the difference between the spread on the corporate bond and its steady-state value and $\phi_\mu > 0$ is the degree of intervention. The higher ϕ_μ is, the more aggressive the government intervention is in response to the financial market disruptions measured by $\mu_t - \mu$.

Assume further a limit on the use of FX reserves

$$\Gamma_t \leq \bar{\Gamma}$$

where $\bar{\Gamma} \in (0, 1]$. Notice that this constraint, called fear-of-losing-reserves constraint, is occasionally-binding depending on the size of Γ_t. When it is binding, the government would not be able to purchase assets as much as it would without the constraint.

2.5 Rest of the model

The country interest rate is debt-elastic as in Schmitt-Grohé and Uribe (2003). It depends on the difference between the net foreign debt to GDP ratio from its steady-state value

$$R_t = R_t^* + \psi \left[\exp\left(\frac{e_t(d_{Ft} - f_t)}{y_t} - \frac{e(d_F - f)}{y} \right) - 1 \right] + \xi_t$$

where R_t^* is the foreign interest rate, $\psi > 0$ measures the responsiveness to net foreign debt to GDP ratio, $y_t \equiv p_{Ht} y_{Ht}$ is the GDP, and ξ_t is a risk premium shock following an AR(1) process $\xi_t = \rho_\xi \xi_{t-1} + \varepsilon_{\xi t}$ that initiates a sudden stop.

The market clearing condition for home goods requires

$$y_{Ht} = c_{Ht} + i_{Ht} + g_t + x_t \tag{14}$$

[24] Section 3.4 discusses other ways of conducting sterilized asset purchases. For example, the government could retire the government bonds b_t instead of purchasing corporate bonds s_{Gt}. Also, the government could issue additional bonds b_t to sterilize asset purchases.

where the export x_t is defined as

$$x_t \equiv \gamma^* tot_t^{\eta} y_t^*$$

with foreign trade openness parameter γ^* and foreign output y_t^*.[25] The trade balance is defined as the difference between exports and imports,

$$tb_t \equiv p_{Ht} x_t - e_t m_t \tag{15}$$

where $m_t = c_{Ft} + i_{Ft}$ is the import of foreign goods. The balance of payments is

$$tb_t = -e_t(d_{Ft} - f_t) + e_t(R_t d_{Ft-1} - R_t^* f_{t-1})$$

describing the law of motion for the country's net foreign debt.[26] The current account is the sum of the trade balance and the net interests on the net foreign asset

$$ca_t \equiv tb_t - e_t[(R_t - 1)d_{Ft-1} - (R_t^* - 1)f_{t-1}]$$

which can be reduced to

$$ca_t = -e_t[(d_{Ft} - d_{Ft-1}) - (f_t - f_{t-1})]$$

the change in country's net foreign asset position. Finally, market clearing conditions for the financial markets are

$$s_t = s_{Bt} + s_{Gt}$$
$$b_t = b_{Bt}$$

where the left-hand (right-hand) sides indicate the supply of (the demand for) the corporate and the government bonds.

Equilibrium A competitive equilibrium is a set of processes $\{c_t, c_{Ht}, c_{Ft}, h_t, d_{Ht}, \Lambda_{t,t+1}, d_t, d_{Ft}, s_{Bt}, b_{Bt}, n_t, l_t, \lambda_t, \Omega_t, y_t, y_{Ht}, k_{t-1}, i_t, i_{Ht}, i_{Ft} b_t, s_{Gt}, f_t, g_t, T_t, \mu_t, \Gamma_t, x_t, m_t, tb_t, ca_t, p_{Ht}, e_t, tot_t, w_t, z_t, R_t, R_{kt}, R_{bt}, q_{kt}, q_{bt}\}$ such that (i) households, banks, and non-financial firms optimize under the constraints, and (ii) goods and financial markets clear, given the exogenous processes $\{a_t, y_t^*, R_t^*, \xi_t\}$. The complete equilibrium conditions are given in Appendix D.

[25] I assume a symmetric CES composite for foreign consumption c_t^* and investment i_t^* with trade openness γ^* and trade elasticity η. The foreign demand for home goods is $x_t = \gamma^* \left(\frac{p_{Ht}}{e_t}\right)^{-\eta} y_t^*$ where $y_t^* = c_t^* + i_t^*$.

[26] See Appendix C for the derivation.

Parameter	Value	Description	Source/Target
β	0.99	Discount factor	Standard
σ	2	Inverse of intertemporal elasticity of substitution	Standard
α	0.33	Income share for capital	Standard
δ	0.025	Depreciation rate	Standard
κ_i	1	Adjustment cost in capital production	Standard
κ_h	2.2434	Utility weight on labor	Labor hours
φ	1/3	Inverse of Frisch elasticity	Gertler and Kiyotaki (2010)
η	1.5	Trade elasticity	Kitano and Takaku (2020)
γ	0.29	Trade openness	Export-GDP ratio
Δ	0.37	Relative divertible fraction of gov. bond	Spread on gov. bond
χ	0.92	Banks' surviving probability	Mimir and Sunel (2021)
ι	{0.0112,0.0019}	Transfer rate for new banks	Small positive number
θ	{0.1587,0.6116}	Divertible fraction of total assets	Leverage ratio and spreads
Ξ	0.0275	Coupon payment for gov. bond	Spread on gov. bond
ϱ	0.9848	Decaying rate for gov bond	10 years duration
g	0.13	Government public spending	Gov. expenditure to GDP ratio
f	0.64	FX reserves	Reserve to GDP ratio (annual)
ϕ_μ	{250,1000,2500}	Responsiveness to spreads in policy rule	
$\bar{\Gamma}$	{1,0.3}	Limit on the use of FX reserves	
ρ_ξ	0.91	Persistence in risk premium	AR(1) estimation
ψ	0.001	Elasticity of debt in interest rate	Small positive number
R^*	1.0101	Foreign interest rate	Implied from model
y^*	1	Foreign output	Normalization
γ^*	0.344	Foreign trade openness	Implied from model

Table 1: Parameter values

Note: The table summarizes the parameter values used in the simulations. There are two sets of values for θ and ι. For the analysis in Sections 3.2 and 3.3, θ and ι are set to 0.0112 and 0.1587. In Section 3.4, θ and ι are set to 0.0019 and 0.6116. For the parameters related to the policy rule, I consider three values of ϕ_μ and two values of $\bar{\Gamma}$ as shown in the table.

3 Results

This section provides numerical results from the model simulation. The parameterization and the solution method are described in Section 3.1. Section 3.2 illustrates the impact of a sudden stop with and without sterilized asset purchase programs. Section 3.3 further examines the role of FX reserves in sterilized asset purchase programs. Section 3.4 presents the results related to the design of sterilized asset purchase programs.

3.1 Parameterization and solution method

Table 1 summarizes the parameter values used in model simulation. Among others, $\{\beta, \sigma, \alpha, \delta, \eta_i\}$ is the set of parameters pinned down by the standard values in the literature. I set the inverse of Frisch elasticity to 1/3.[27] The trade elasticity is set to 1.5 as in Kitano and Takaku (2020).[28]

For calibration, I use yearly data from 2000 to 2020 for five countries: Chile, Colombia, Korea, Philippines, Turkey.[29] From the data, I compute the average values for government expenditure to GDP ratio (0.13), export to GDP ratio (0.26), external debt to GDP ratio (0.38), and FX reserve to GDP ratio (0.16). To compute the spread on the corporate and the government bonds in the steady state, I use lending rates, deposit rates, and 10-year government bond yields. The difference between lending rates and deposit rates (410 basis points per annum) captures the corporate bond spread in the model. The spread on government bond in the model is captured by the difference between 10-year government bond yields and deposit rates (150 basis points per annum).[30] The leverage ratio is calculated as banks' asset to capital ratio. As in Akinci and Queralto (2022), I define banks' capital as the sum of total capital and other liabilities. The average leverage ratio is 6.3 for the five countries.[31]

The calibrated parameters are as follows. The utility weight on labor is set for the steady-state labor hours to be 1/3. The trade openness is 0.29 to target the export to GDP ratio. The surviving probability for banks is set to 0.92, as in Mimir and Sunel (2021), targeting the 3-year average life of banks. The parameters for the government bond $\{\Xi, \varrho\}$ are set to target the spread and 10-year duration of the government bond. The parameter set $\{\theta, \iota, \Delta\}$ targets the corporate and the government bond spreads, and the leverage ratio just equal to its maximum value. For the analysis in Sections 3.2 and 3.3, I set θ and ι to 0.0112 and 0.1587 for zero spreads on the bonds (i.e., $\mu = 0$) so that banks are not constrained in the steady state. In Section 3.4, θ and ι are set to 0.0019 and 0.6116 to analyze the equilibrium around the steady state where banks are constrained (i.e., $\mu > 0$). Finally, for the parameters related to the policy rule, I consider three values of ϕ_μ and two values of $\bar{\Gamma}$ as shown in the table.

Turning to the parameters for the country interest rate and the foreign variables, the persistence parameter for risk premium is set to 0.91, which is the average of estimates from fitting an AR(1) process on J.P. Morgan Emerging Markets Bond Spread (EMBI+) series in quarterly frequency.[32] Following Schmitt-Grohé and Uribe (2003), I set the debt elasticity parameter in the interest rate to a small positive number so that it has little impact on the results but help make the model stationary. Lastly, the steady-state foreign output is normalized to 1, the steady-state foreign interest rate and foreign trade openness are implied from the equilibrium conditions in the steady state.

[27] The conventional range for the Frisch elasticity is between 1 and 3 in the literature. As in Gertler and Kiyotaki (2010), I set the Frisch elasticity to a relatively high value to reflect other frictions absent in the model (e.g. nominal rigidities).

[28] This value can also be found in the early international real business cycle literature (e.g., see Backus, Kehoe and Kydland 1994).

[29] See Appendix E for the data sources.

[30] The lending rate is the interest rate charged by banks for the short-term and medium-term financing needs of the private sector. The deposit rate is the interest rate offered by banks for demand, time, or savings deposits. See for details the introductory notes for the International Financial Statistics at the IMF.

[31] This value falls into the conventional range in the literature. While it is set to 4 in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), the leverage ratio in open economy models typically has a higher values ranged from 6 to 7 (e.g., see Mimir and Sunel 2021 and Akinci and Queralto 2022).

[32] The quarterly series is constructed by averaging the original monthly series obtained from the Global Economic Monitor at the World Bank.

Moments	Model		Data		
			Average	Minimum	Maximum
$\rho(c, y)$	1.00	0.99	0.71	0.22	0.94
$\rho(i, y)$	0.85	0.79	0.49	0.34	0.75
$\rho(tb, y)$	-0.68	-0.61	-0.46	-0.66	-0.27
$\rho(ca, y)$	-0.66	-0.55	-0.41	-0.73	-0.22
$\rho(e, y)$	-0.3	-0.15	-0.15	-0.48	0.51
$\rho(l, y)$	-0.47	-0.53	-0.06	-0.17	0.11
$\rho(\mu, y)$	-0.51	-0.61	-0.16	-0.7	0.36
$\sigma(c)/\sigma(y)$	0.87	0.92	1.04	0.24	1.63
$\sigma(i)/\sigma(y)$	5.41	6.19	4.07	2.28	7.72

Table 2: Untargeted moments

Note: The table describes untargeted moments over business cycles. $\rho(\cdot, y)$ is the correlation with GDP. $\sigma(\cdot)/\sigma(y)$ is the standard deviation relative to GDP. The moments from the model are listed in the first two columns. The corresponding data moments are listed in the rest of the columns in terms of average, maximum and minimum values for the five countries.

Solution method The model features two occasionally-binding constraints: the leverage constraint and the fear-of-losing-reserves constraint. In order to solve the model with these occasionally-binding constraints, I use the Levenberg-Marquardt mixed complementarity problem (LMMCP) solver by Kanzow and Petra (2004) incorporated in the perfect-foresight solver of Dynare package (Adjemian et al. 2022).[33] Using this method, I derive impulse responses of the endogenous variables to an unexpected shock in the initial period starting from the steady state. Besides the shock in the initial period, all future uncertainty is assumed to be anticipated (i.e., certainty equivalence holds). It is also assumed that the model economy moves back to the steady state within a finite horizon. The advantage of this solution method is that the model is solved exactly up to rounding errors fully taking into account model nonlinearities.

Model fit Table 2 examines performance of the model in terms of untargeted moments over business cycles. In particular, the table describes the correlations of consumption, investment, trade balance, current account, real exchange rates, banks' leverage, corporate bond spread with GDP. The table also reports the standard deviations of consumption and investment relative to the GDP. The model moments are computed from the simulation without policy under the risk premium shock. The first (second) column corresponds to the simulation starting from the steady state where banks' leverage constraint is not binding (binding). The data moments are from quarterly data for the five countries from 2000Q1 to 2020Q4.[34] Despite incorporating only one shock, the model correctly captures the dynamics of business cycles for the five countries. Although the magnitude is greater, the model delivers the correct cyclicality. It reports strong procyclicality of consumption and investment. It also displays countercyclical trade balance, current account, and real exchange rates. The banks' leverage and the spread on corporate bond are countercyclical.

[33]The LMMCP uses the Newton method with a generalized Jacobian to solve simultaneously the equilibrium conditions stacked over the simulation periods. Karadi and Nakov (2021) also use this method to solve the model with occasionally-binding constraints. See Swarbrick (2021) for a review of solution methods dealing with occasionally-binding constraints.

[34]The variables y, c, and i are HP-filtered in logs. The variable ca is HP-filtered in levels. The trade balance is the difference between exports and imports HP-filtered in logs. See Appendix E for the data sources.

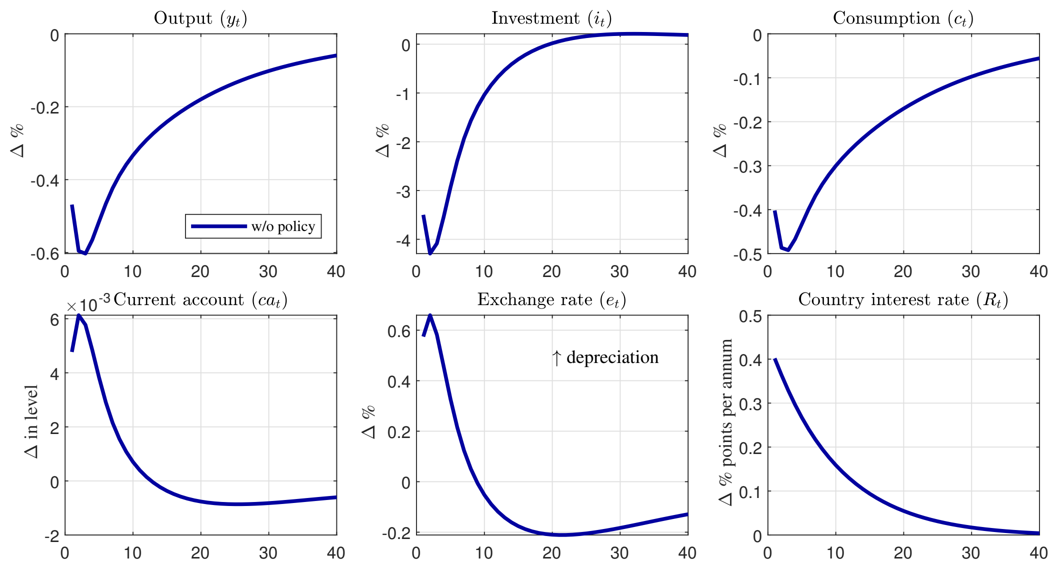


Figure 3: Impulse responses in a sudden stop without policy

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The horizontal axis indicates time periods in quarters.

The model delivers relative volatilities of consumption and investment reasonably close to the ones from data.

3.2 Sudden stop episode

Consider the steady state in which banks are not constrained (i.e., $\mu = 0$). Suppose there is an unanticipated rise in risk premium by 0.1 percentage point, initiating a sudden stop. This section analyzes the impact of sudden stop on the economy with and without sterilized asset purchase programs.

Sudden stop without policy Consider first the case where the government does not conduct sterilized asset purchase programs. Figures 3 and 4 describe the responses of the key variables to the given risk premium shock. Figure 3 shows that, as the shock hits, the country interest rate rises (bottom-right panel). The economy experiences abrupt capital outflows (bottom-left panel) and the exchange rate depreciations (bottom-middle panel). In terms of real activities (top panels), the sudden stop induces sharp hump-shaped contractions in output, investment, and consumption. The economy moves back to the steady state as the country interest rate goes down. What is the channel through which the sudden stop negatively affects the economy? How is the financial shock of risk premium transmitted to the real economy?

Figure 4 illustrates the responses of the variables related to financial markets. It shows that banks get constrained (bottom-left panel) in the first nine periods, which is mirrored by the positive spread on the corporate bond (top-right panel). The figure also shows that the banks' net worth falls sharply (top-left

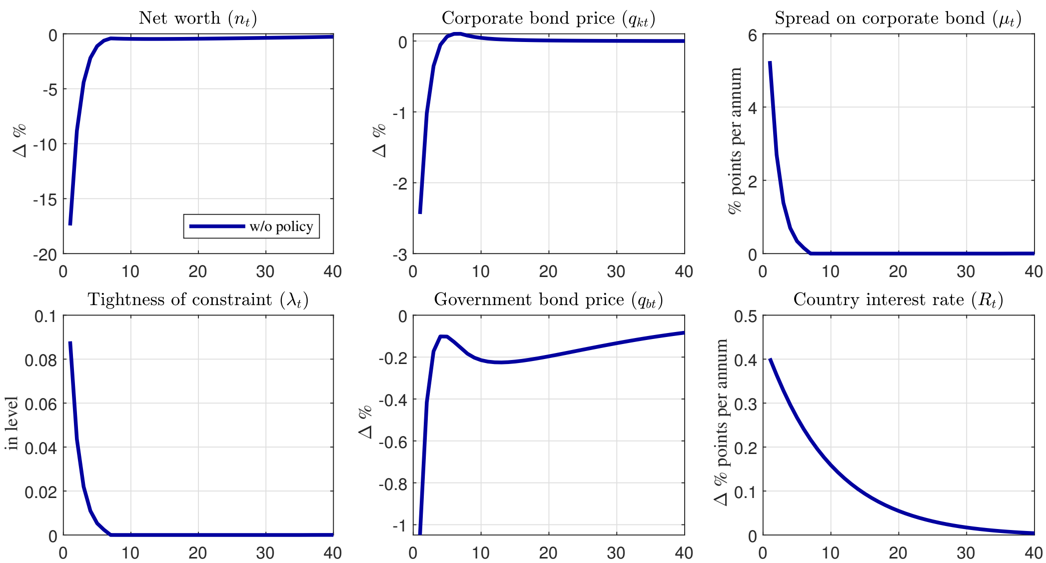


Figure 4: Impulse responses in a sudden stop without policy

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The horizontal axis indicates time periods in quarters.

panel). To examine the mechanism in more detail, recall that banks' net worth is the retained earnings

$$\underbrace{n_t}_{\downarrow} = R_{kt}q_{kt-1}s_{Bt-1} + R_{bt}q_{bt-1}b_{Bt-1} - \underbrace{e_t R_t d_{t-1}}_{\uparrow}$$

As the country interest rate and the exchange rate rise, the banks' net worth falls due to an increase in the value of liabilities. As the net worth falls, the constrained banks decrease their asset demand, reducing asset prices for the corporate and the government bonds (top- and bottom-middle panels). The reduction in asset prices brings down the value of net worth even further, creating a negative feedback loop. To see this, rewrite the net worth in terms of the current asset prices

$$\underbrace{n_t}_{\downarrow\downarrow} = \underbrace{(z_t + (1-\delta)q_{kt})s_{Bt-1}}_{\downarrow} + \underbrace{(\Xi + \varrho q_{bt})b_{Bt-1}}_{\downarrow} - \underbrace{e_t R_t d_{t-1}}_{\uparrow}$$

by replacing R_{kt} and R_{bt}. As the asset prices fall, the value of banks' asset holdings decreases, deteriorating the net worth. Consequentially, banks lose more than 15 percent of the net worth on the onset of the sudden stop. Through this negative feedback loop, called the balance sheet effect, the sudden stop brings a severe disruption in the financial markets.

The financial market disruptions, in turn, spill over to the real economy. Specifically, as banks are constrained, the spread on corporate bonds rises, implying that non-financial firms face a high cost of credit. Since the firms are not able to borrow from the banks, their investment declines significantly, and thus, the economy suffers large contractions in real activities. The fall in aggregate demand for home goods causes the exchange rate to depreciate.

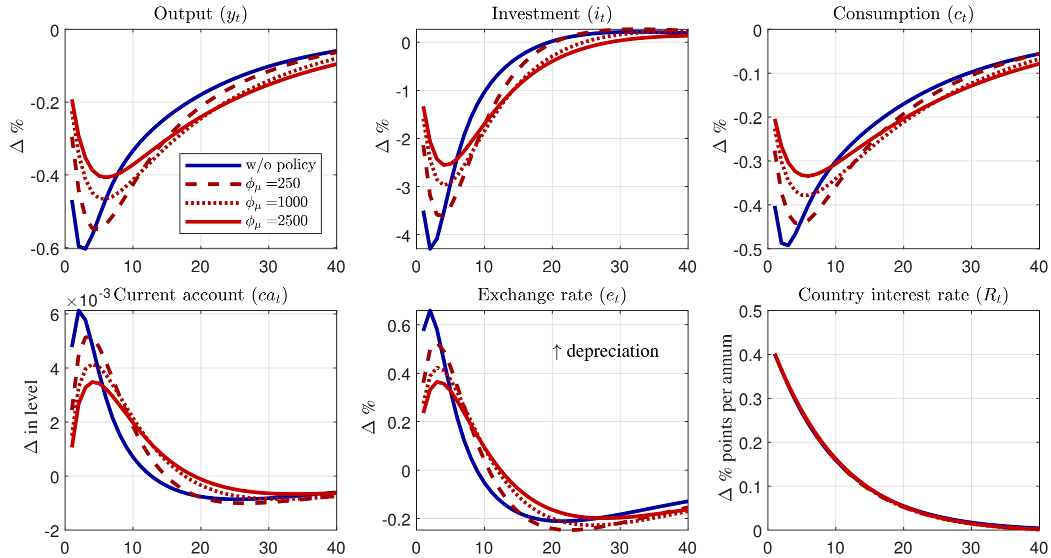


Figure 5: Impulse responses in a sudden stop with policy

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The blue solid lines are the reponses without policy. The red lines are the reponses under policy with ϕ_μ = 250, 1000, 2500. The horizontal axis indicates time periods in quarters.

To sum up, the sudden stop brings a severe recession to the economy. The key amplification mechanism is the balance sheet effect that disrupts banks' funding intermediation activities.[35] Thus, it is crucial for the government to break down the balance sheet effect in order to buffer the economy against the sudden stop.

Sudden stop with sterilized asset purchases Suppose now that the government conducts sterilized asset purchase programs. Consider the same magnitude of risk premium shock that hits the economy in the same steady state. Figures 5, 6, and 7 describe impulse responses in the sudden stop episode. The blue solid lines are the responses without the policy as in the previous analysis. The red lines are the responses under sterilized asset purchase programs with three different degrees of government intervention ϕ_μ = 250, 1000, 2500.

Figure 5 shows that, under sterilized asset purchase programs, the impact of sudden stop is significantly reduced. The economy experiences less capital outflows (bottom-left panel) and mild exchange rate depreciations (bottom-middle panel). Compared to the case without the policy, the real activities suffer far less of a contraction (top panels).

Figure 6 describes how the policy eases financial market disruptions caused by the sudden stop. By purchasing corporate bonds, the government provides liquidity directly to non-financial firms. The government asset purchases also help banks relax the leverage constraint. Holding the supply fixed, it props up asset prices (top- and bottom-middle panels) and reduces banks' holdings of corporate bonds. Since the government sells FX reserves for sterilization, it supports exchange rates. Thus, the policy strengthens

[35]In the absence of the balance sheet effect, the impact of sudden stop would be much milder. See Appendix F for a counterfactual analysis where the leverage constraint is not imposed.

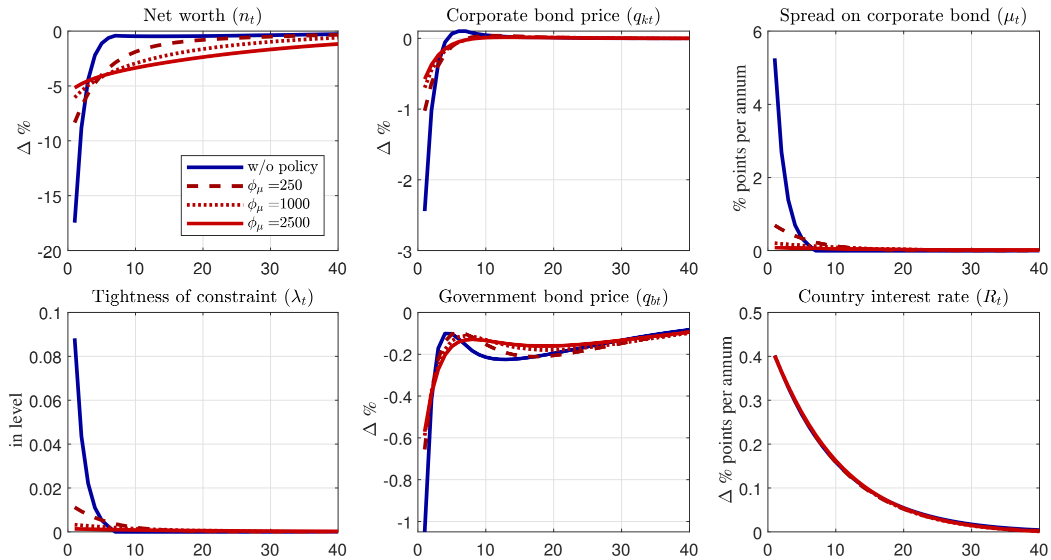


Figure 6: Impulse responses in a sudden stop with policy

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The blue solid lines are the reponses without policy. The red lines are the reponses under policy with ϕ_μ = 250, 1000, 2500. The horizontal axis indicates time periods in quarters.

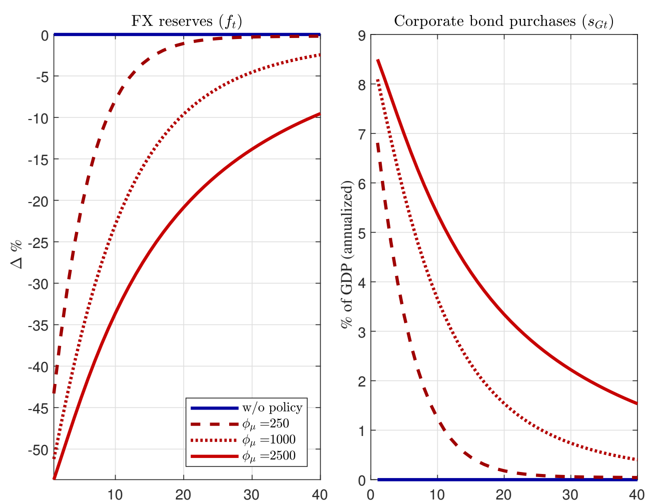


Figure 7: Impulse responses in a sudden stop with policy

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The blue solid lines are the reponses without policy. The red lines are the reponses under policy with ϕ_μ = 250, 1000, 2500. The horizontal axis indicates time periods in quarters.

the value of banks' net worth (top-left panel). Consequentially, the government breaks down the balance sheet effect, mitigating the impact of sudden stop. Under the policy, banks are not as constrained as in the case without the policy (bottom-left panel). The lower spreads on the corporate bond (top-right panel) imply that non-financial firms are facing a relatively lower cost of credit.

Policy trade-offs Figure 7 shows that, when the government intervenes aggressively, the economy gets into a less severe recession. When it intervenes with a high ϕ_μ, the government purchases a large amount of corporate bonds (right panel). To sterilize these asset purchases, the government sells a large amount of FX reserves (left panel). For instance, under the most aggressive policy with $\phi_\mu = 2500$, the government sells more than 50 percent of FX reserve holdings and purchases corporate bonds more than 8 percent of GDP.

The benefit of large-scale asset purchase programs comes with a cost of slow recovery. The top-left panel of Figure 5 displays policy trade-offs in terms of output. The most aggressive policy with $\phi_\mu = 2500$ significantly dampens the impact of sudden stop. The decline in output on impact is less than half of the one without the policy. Within the first 15 quarters, the contraction is much smaller compared to the ones under other less aggressive polices with $\phi_\mu = 250, 1000$. However, under this most aggressive policy, the output goes back to the steady state level more slowly in the phase of recovery. The similar patterns can be observed in the responses of investment and consumption. The slow recovery of the economy is caused by slow recapitalization of banks. To see this, the growth of banks' net worth is

$$\underbrace{\frac{n_t}{n_{t-1}}}_{\downarrow} = \underbrace{\left(R_{kt} - R_t \frac{e_t}{e_{t-1}}\right)}_{\downarrow} \frac{q_{kt-1} s_{Bt-1}}{n_{t-1}} + \underbrace{\left(R_{bt} - R_t \frac{e_t}{e_{t-1}}\right)}_{\downarrow} \frac{q_{bt-1} b_{Bt-1}}{n_{t-1}} + R_t \frac{e_t}{e_{t-1}}$$

Note that the net worth growth depends on the size of excess returns on the corporate and the government bonds: $R_{kt} - R_t \frac{e_t}{e_{t-1}}$ and $R_{bt} - R_t \frac{e_t}{e_{t-1}}$. The excess returns increase profits, contributing to fast recapitalization of banks. By eliminating the spreads on the corporate and the government bonds, the policy reduces profitability of banks and slows down the growth of net worth. This observation is confirmed by the top-left panel of Figure 6. The initial impact of sudden stop on net worth is relatively small under the most aggressive policy. In the recovery phase, however, the net worth goes back to the steady-state level not as quickly as the ones under the less aggressive policies.

Welfare analysis Does the sterilized asset purchase program bring welfare gains? In particular, considering the policy trade-offs, what is the degree of intervention that brings the largest welfare gains? To answer these questions, I examine the consumption-equivalent welfare measure. This welfare measure is defined as the fraction of consumption that households would give up so that they feel indifferent to live without the policy. The welfare measure ω is defined implicitly as

$$\sum_{t=0}^{\infty} \beta^t U(c_t^n, h_t^n) = \sum_{t=0}^{\infty} \beta^t U((1-\omega)c_t^p, h_t^p)$$

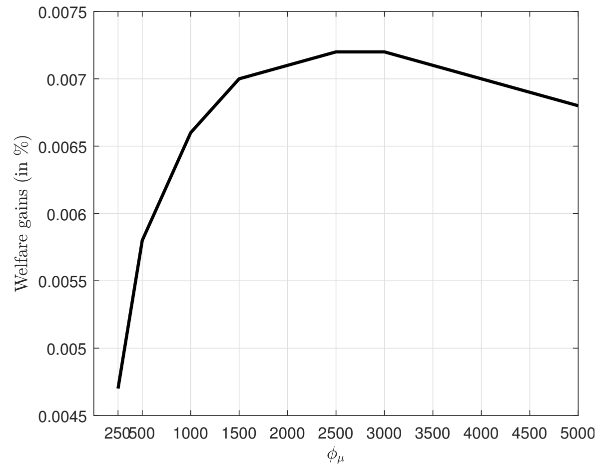


Figure 8: Welfare gains from asset purchase program

Note: The figure describes consumption-equivalent welfare gains as a function of the policy responsiveness parameter ϕ_μ.

where c_t^n and h_t^n (c_t^p and h_t^p) are consumption and labor hours in equilibrium without (with) the policy.

Figure 8 plots the welfare gains as a function of the degree of intervention. The figure shows that the sterilized asset purchase program improves welfare. Compared to the economy without the policy, households enjoy nontrivial positive welfare gains. The welfare gain is the highest (0.0072%) at ϕ_μ = 2500. This means that households would be willing to permanently sacrifice 0.0072% of their equilibrium consumption to live in the economy where the government conducts sterilized asset purchases with ϕ_μ = 2500. The concave shape of welfare gains demonstrates the policy trade-offs. As the government intervenes more aggressively, welfare gain goes up until $\phi_\mu = 2500$. After this point, welfare gain diminishes as the degree of intervention increases. This means that, after the peak at $\phi_\mu = 2500$, the marginal cost of slow recovery is larger than the marginal benefit of buffering against the initial impact of sudden stop.

3.3 The role of FX reserves in sterilized asset purchase program

To examine the role of FX reserves in more detail, suppose that the government conducts sterilized asset purchase programs under a more stringent constraint.

Specifically, assume that the government can only use up to 30 percent of FX reserves (i.e., $\bar{\Gamma} = 0.3$).[36] Figure 9 describes the impulse responses in the same sudden stop episode. Again, the blue solid lines are the responses without the policy. The red dotted lines are the responses under the policy with $\phi_\mu = 2500$ as in the previous section. The red solid lines are the responses under the policy with the same degree of intervention but with the stringent constraint on FX reserves. As the figure shows, on the onset of sudden stop, the government uses FX reserves up to the limit (bottom-middle panel) to sterilize corporate bond purchases. Due to the more stringent constraint, asset purchases are limited up to about 5 percent of GDP (bottom-right panel). This is about a half of purchases that the government would make in the baseline analysis. Hence, the government cannot fully ease financial market disruptions as in the baseline. The fall

[36]This assumption is based on the empirical evidence in Aizenman and Sun (2012).

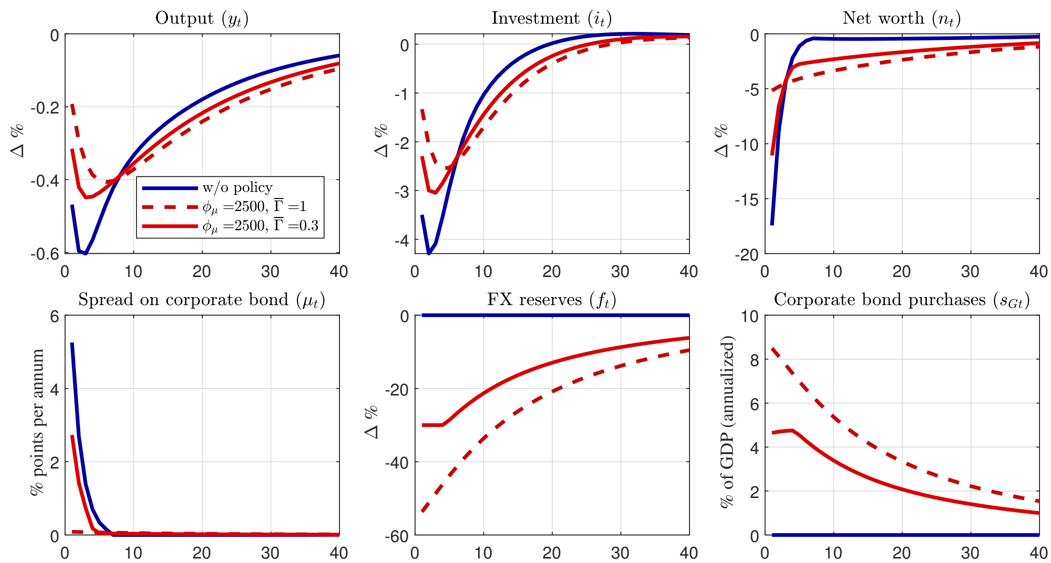


Figure 9: Impulse responses in a sudden stop with policy under constraint

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The blue solid lines are the reponses without policy. The red lines are the reponses under policy with $\phi_\mu = 2500$ and $\bar{\Gamma} = 1, 0.3$. The horizontal axis indicates time periods in quarters.

in banks' net worth is about 10 percent (top-right panel) and the spread on the corporate bond rises to 3 percentage points (bottom-left panel). As a result, output and investment decrease more.

Suppose further that the government hoards small amounts of FX reserves. In particular, the government is facing the same constraint but only with a half of the baseline FX reserves. Figure 10 plots the impulse responses under this additional specification in the same sudden stop episode. The blue solid lines are the responses without the policy as before. The red solid lines are the responses with the policy under the constraint on FX reserves from Figure 9. The gray dotted lines are the responses with the policy under the same constraint but only with a half of FX reserves. As before, the use of FX reserves in asset purchases is limited up to 30 percent (bottom-middle panel). With only a half of FX reserves, the government can purchase corporate bonds about 2 percent of GDP (bottom-right panel). Banks lose the value of net worth by about 15 percent and the spread on the corporate bond rises to 4 percent. In terms of real activities, output and investment contract even more.

The analysis given in this section highlights the role of FX reserves in conducting sterilized asset purchases. When the government is constrained in using FX reserves, the policy space for asset purchases is limited. This implies that it is important to hoard enough ready-to-use FX reserves as a war chest to deal with sudden stops effectively.

3.4 Design of sterilized asset purchase programs

The analysis given in the previous sections focuses on a particular type of sterilized asset purchase programs: corporate bond purchases sterilized with FX reserves. Considering this type as the benchmark, this section provides two alternative policy designs. These alternatives deviate from the benchmark along two

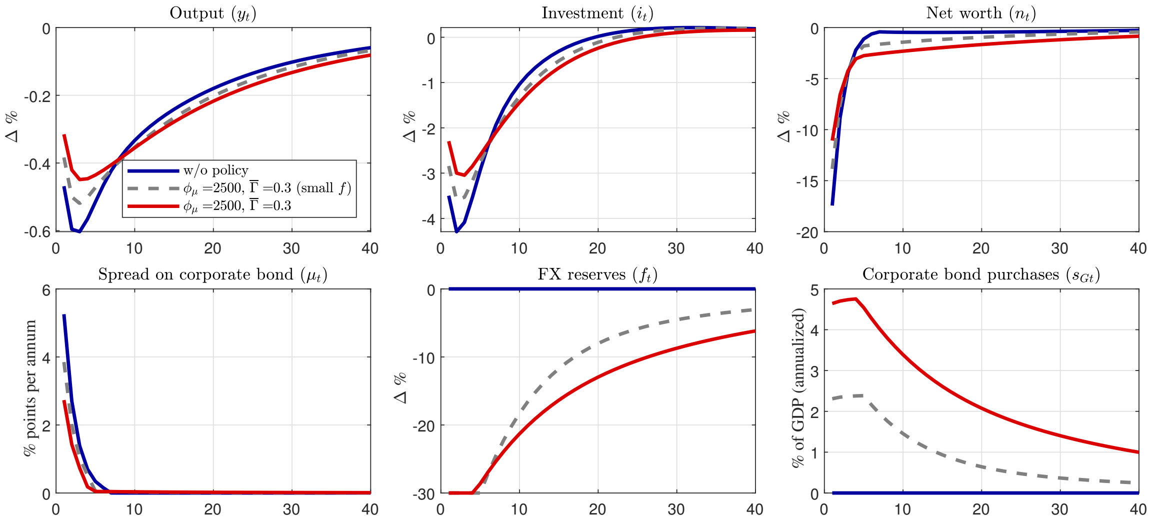


Figure 10: Impulse responses in a sudden stop with policy under constraint

Note: The figure describes the impulse responses to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. The blue solid lines are the reponses without policy. The red solid and gray dotted lines are the reponses under policy with $\phi_\mu = 2500$ and $\bar{\Gamma} = 0.3$. In the gray dotted responses, the amount of FX reserves is a only half of the amount in the red solid responses. The horizontal axis indicates time periods in quarters.

dimensions: asset purchase and sterilization. Suppose that the economy is in the steady state where banks are constrained (i.e., $\mu > 0$). Among the three different policy designs, which one is the most effective in breaking down the balance sheet effect by relaxing banks' constraints?

Asset purchase: Corporate vs. Government bond Suppose that the government sells FX reserves following an AR(1) process

$$\frac{f_t}{f} = (1 - \rho_f) + \rho_f \frac{f_{t-1}}{f} - \varepsilon_{ft}$$

where $\rho_f = 0.96$ and the size of ε_{ft} is 0.01 (i.e., 1 percent of FX reserves sale). Using the FX reserves sold, the government can either purchase corporate bonds as in the benchmark

$$q_{kt} \underbrace{s_{Gt}}_{\uparrow} + e_t \underbrace{f_t}_{\downarrow} = q_{bt} \underbrace{b_t}_{\text{constant}}$$

or purchase government bonds (i.e., bond retirement)

$$q_{kt} \underbrace{s_{Gt}}_{\text{constant}} + e_t \underbrace{f_t}_{\downarrow} = q_{bt} \underbrace{b_t}_{\downarrow}$$

Figure 11 compares the effects of corporate bond purchases (black solid lines) and government bond purchases (yellow dotted lines). The government sells 1 percent of FX reserves (fourth panel) for the purchases of both bonds by 0.16 percent of GDP (second and third panels). Notice that when it purchases corporate

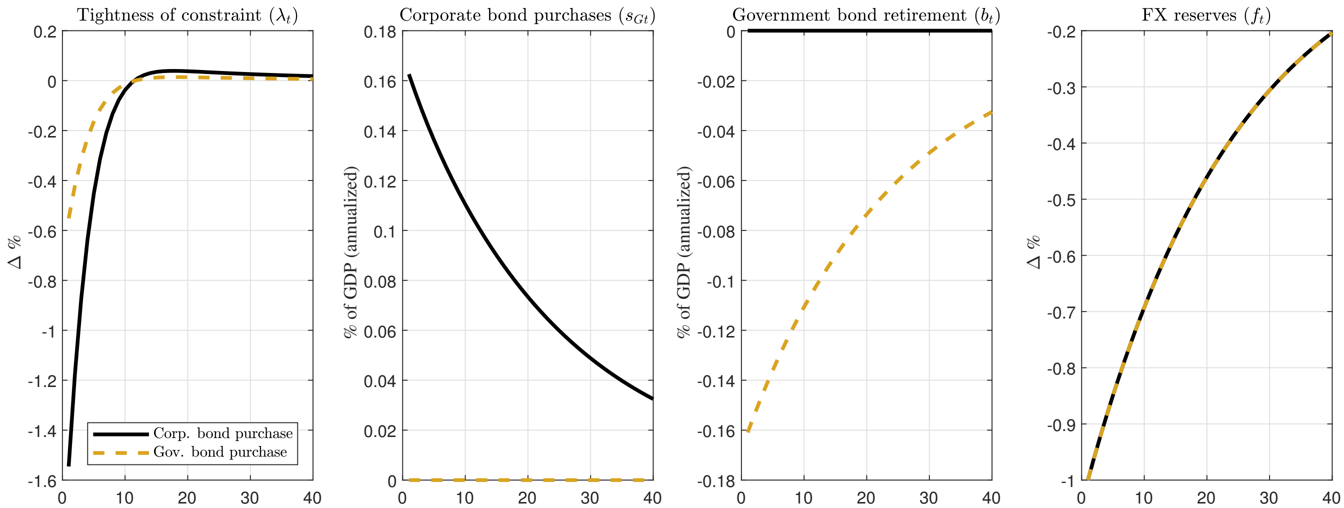


Figure 11: Asset purchase of corporate bond vs. government bond

Note: The figure describes the impulse responses to the discretionary asset purchase by selling 1% of FX reserves from the steady state where banks are constrained. The black solid lines are the reponses under corporate bond purchase. The yellow dotted lines are the reponses under government bond purchase. The horizontal axis indicates time periods in quarters.

bonds, the government relaxes banks' leverage constraint 3 times more than it does with government bond purchases (first panel). To see why, recall that when the leverage constraint is binding, it can be written as

$$\underbrace{q_{kt}(s_t - s_{Gt}) + \Delta q_{bt} b_t}_{\downarrow} = \bar{l}_t n_t$$

after imposing market clearing conditions for the financial markets. The government asset purchases decrease the left-hand side, relaxing the constraint. Notice that the marginal impact of government bond purchases is only Δ of the marginal impact of corporate bond purchases. Since the corporate bond is considered riskier, a reduction of corporate bond holdings in banks' balance sheet has a greater effect in relaxing the constraint.

Sterilization: Selling FX reserves vs. Issuing government bonds Consider an alternative way of sterilizing asset purchases. Instead of adjusting the asset side of balance sheet by selling FX reserves, the government can adjust the liability side for sterilization. In particular, suppose that the government issues bonds to sterilize corporate bond purchases. This operation increases both assets and liabilities, expanding the size of government balance sheet

$$q_{kt} \underbrace{s_{Gt}}_{\uparrow} + e_t \underbrace{f_t}_{\text{constant}} = q_{bt} \underbrace{b_t}_{\uparrow}$$

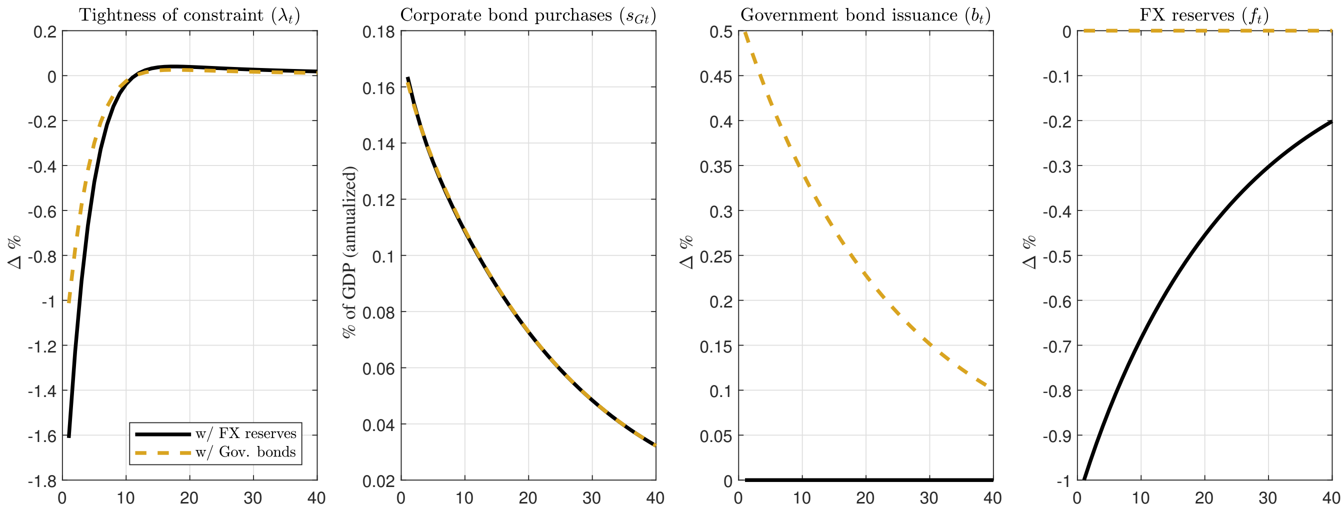


Figure 12: FX reserves vs. other sterilization tools

Note: The figure describes the impulse responses to a discretionary corporate bond purchase from the steady state where banks are constrained. The size of the shock is 0.01. The black solid lines are the reponses under sterilization with FX reserves. The yellow dotted lines are the reponses under sterilization with other securities. The horizontal axis indicates time periods in quarters.

Suppose that the government purchases corporate bonds following an AR(1) process

$$\frac{s_{Gt}}{s_G} = (1 - \rho_G) + \rho_G \frac{s_{Gt-1}}{s_G} + \varepsilon_{Gt}$$

where $\rho_G = 0.96$ and the size of ε_{Gt} is 0.01.

Figure 12 plots the effects of corporate bond purchases sterilized by selling FX reserves (black solid lines) and by issuing government bonds (yellow dotted lines). Although the amount of asset purchases is the same in both cases (second panel), the effect on relaxing banks' leverage constraint is about 1.5 times greater when sterilized with FX reserves (first panel). As discussed, the effectiveness of asset purchases depends on the extent to which the leverage constraint is relaxed. When the government issue bonds for sterilization, it is not able to support exchange rates directly. Furthermore, the effect of constraint relaxation is partially offset due to additional government bond issuance. This is because banks must absorb these bonds on their balance sheets, which makes the leverage constraint even more binding. Therefore, selling FX reserves is a better way of sterilization for asset purchases.

4 Conclusion

Sterilized asset purchase program is an unconventional monetary policy adopted by EMDEs during the recent COVID-19 crisis. The unique feature of this policy tool is sterilization of asset purchases. This paper aims to provide insights about the implementation of this new policy during the sudden stops.

The paper develops a theoretical framework incorporating three key financial frictions in EMDEs: liability dollarization, financial market imperfection, and fear of losing reserves. In this framework, the paper analyzes the effectiveness and design of sterilized asset purchase programs. Sterilized asset purchase mitigates the impact of sudden stops, bringing welfare gains to the economy. In particular, the policy breaks down the balance sheet effect that causes disruptions in domestic banks' funding intermediation.

The main results of this paper provide useful policy guidelines for EMDEs. It is advisable to conduct sterilized asset purchase programs in a sudden stop when domestic banks are constrained. The most effective way of implementing the policy is to purchase corporate bonds and use FX reserves for sterilization. It is important to acknowledge that there are policy trade-offs regarding the degree of intervention. Purchasing assets in a large scale can prevent deep contractions in real activities. However, it may also slow down the recovery process of the economy. Finally, hoarding large enough FX reserves expands the policy room for asset purchase programs during the sudden stops.

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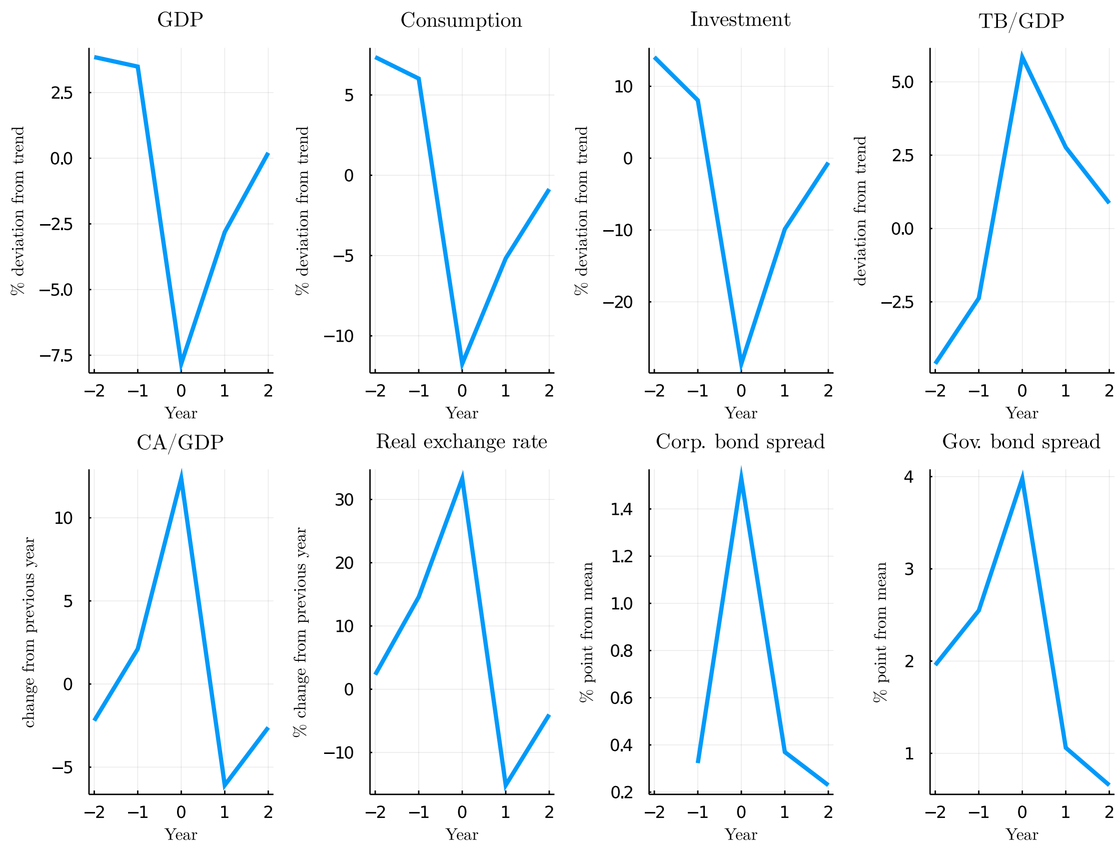

Figure 13: Sudden stop episode

Note: The figure describes the dynamics around the 1998 sudden stop episode in Korea. The horizontal axis indicates the 5-year window around the episode. TB/GDP and CA/GDP are the trade balance and the current account to GDP ratios. Corp. bond spread and Gov. bond spread are the spreads on the corporate and government bonds.

Appendix

A Sudden stop episode

Figure 13 describes the 1998 sudden stop episode in Korea, which is identified using the filter by Calvo, Izquierdo and Loo-Kung (2006).[37] The yearly data is used from the earliest data point for each series to 2020.[38] GDP, consumption, and investment are detrended using the HP-filter in logs. The trade balance to GDP ratio is HP-filtered in levels. The corporate bond spread is defined as the interest rate differentials between the three-year maturity government bond and AA- grade corporate bond with the same maturity. The government bond spread is defined as the interest rate differentials between the US government bond and the Korean government bond.

The figure shows that the current account to GDP ratio displays a sharp jump on the onset of the sudden stop. This means that the economy experiences sudden capital outflows. The trade balance improves and

[37]The filter identifies sudden stop episodes if the current account to GDP ratio increases more than two standard deviation from the mean value. See Korinek et al. (2014) and Bianchi and Mendoza (2020) for the discussions on other filters.

[38]See Appendix E for the data sources.

the real exchange rates depreciate. The real activities in terms of GDP, consumption, and investment contract significantly. Notice also that the sudden stop has persistent effects, and hence, the recovery of real activities is slow. The spreads on the corporate and government bonds rise substantially in the sudden stop.

B Bank's problem

First note that, combining (2) and (4), the law of motion for bank's net worth is

$$n_{jt+1} = \left(R_{kt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) q_{kt} s_{Bjt} + \left(R_{bt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) q_{bt} b_{Bjt} + R_{t+1}\frac{e_{t+1}}{e_t} n_{jt} \tag{16}$$

Since the problem is linear, let $V_t \equiv v_t n_{jt}$, a linear function of n_{jt} with coefficient v_t to be determined. Using (16), the banks' problem can be rewritten as

$$v_t = \max_{s_{Bjt}, b_{Bjt}} \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left[\left(R_{kt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) \frac{q_{kt} s_{Bjt}}{n_{jt}} + \left(R_{bt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) \frac{q_{bt} b_{Bjt}}{n_{jt}} + R_{t+1}\frac{e_{t+1}}{e_t} \right]$$

s.t.

$$v_t \geq \theta \left(\frac{q_{kt} s_{Bjt}}{n_{jt}} + \Delta \frac{q_{bt} b_{Bjt}}{n_{jt}} \right) \tag{17}$$

where $\Omega_{t+1} = (1-\chi) + \chi v_{t+1}$.

Let υ_t denote the Lagrange multiplier attached to (17) and define $\lambda_t \equiv \upsilon_t / (1 + \upsilon_t)$. The first-order conditions are

$$\mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_{kt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) = \theta \lambda_t$$

$$\mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_{bt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) = \Delta \theta \lambda_t$$

and the complementary slackness conditions are $\lambda_t \geq 0$, $v_t \geq \theta l_{jt}$, and

$$\lambda_t \left(v_t - \theta l_{jt}\right) = 0$$

where

$$l_{jt} \equiv \frac{q_{kt} s_{Bjt} + \Delta q_{bt} b_{Bjt}}{n_{jt}}$$

is the leverage ratio. Combining the first-order conditions, one can find the no-arbitrage condition as

$$\Delta \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_{kt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_{bt+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right)$$

By plugging this equation back in the objective function,

$$v_t = v_{kt} l_{jt} + v_{nt}$$

where $v_{kt} = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} (R_{kt+1} - R_{t+1} e_{t+1}/e_t)$ and $v_{nt} = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} R_{t+1} e_{t+1}/e_t$.

Consider the case where (17) is binding. In this case, $\lambda_t > 0$ and

$$\theta l_{jt} = \nu_{kt} l_{jt} + \nu_{nt}$$

Hence, the leverage ratio attains the maximum value

$$\begin{aligned} l_{jt} &= \frac{\nu_{nt}}{\theta - \nu_{kt}} \\ &\equiv \bar{l}_t \end{aligned}$$

the coefficient for the value function becomes

$$\nu_t = \theta l_{jt}$$

and $\lambda_t = \nu_{kt}/\theta$, or

$$\lambda_t = 1 - \frac{\nu_{nt}}{\theta l_{jt}}$$

using the leverage ratio.

Consider now the case where (17) is not binding. In this case, $\lambda_t = 0$ implying that $\nu_{kt} = 0$. Hence, the coefficient for the value function becomes

$$\nu_t = \nu_{nt}$$

Hence, combining the two cases,

$$\nu_t = \frac{\nu_{nt}}{1 - \lambda_t}$$

where

$$\lambda_t = \max\left\{0, 1 - \frac{\nu_{nt}}{\theta l_{jt}}\right\}$$

Assuming symmetric leverage ratios across banks in equilibrium, $l_{jt} = l_t$ for all j, the aggregate leverage ratio is

$$l_t = \frac{q_{kt} s_{Bt} + \Delta q_{bt} b_{Bt}}{n_t}$$

where $n_t \equiv \int_0^{\zeta} n_{jt} dj$, $s_{Bt} \equiv \int_0^{\zeta} s_{Bjt} dj$, $b_{Bt} \equiv \int_0^{\zeta} b_{Bjt} dj$ are the aggregate net worth, corporate bond holdings, and government bond holdings. Notice that when (17) is binding, $l_t = \bar{l}_t$, impliyng that the aggregate demand for assets are tied to the value of net worth,

$$q_{kt} s_{Bt} + \Delta q_{bt} b_{Bt} = n_t \bar{l}_t$$

Aggregating over (16), the aggregate net worth for existing banks in period t is

$$\left(R_{kt} - R_t \frac{e_t}{e_{t-1}}\right) q_{kt-1} s_{Bt-1} + \left(R_{bt} - R_t \frac{e_t}{e_{t-1}}\right) q_{bt-1} b_{Bt-1} + R_t \frac{e_t}{e_{t-1}} n_{t-1}$$

C Appendix: Balance of payments derivation

To derive the balance of payments, first combine the budget constraints for households (1) and the aggregate banks (3). Given the fact that in equilibrium (i) $s_t = k_t$ and $s_{Bt} = k_t - s_{Gt}$; (ii) the profits from home good producers and capital storage firms are zero,

$$\begin{aligned}
&c_t + q_{kt}(k_t - s_{Gt}) + e_t R_t d_{Ft-1} + q_{bt} b_{Bt} \\
&\quad = w_t h_t + R_{kt} q_{kt-1}(k_{t-1} - s_{Gt-1}) + R_{bt} q_{bt-1} b_{Bt-1} + e_t d_{Ft} + \Pi_t^c + T_t
\end{aligned}$$

where Π_t^c is the profits from capital producers. Since $\Pi_t^c = q_{kt}(k_t - (1-\delta)k_{t-1}) - i_t$ and $p_{Ht} y_{Ht} = z_t k_{t-1} + w_t h_t$, the above equation is reduced to

$$c_t + i_t - q_{kt} s_{Gt} + e_t R_t d_{Ft-1} + q_{bt} b_{Bt} = p_{Ht} y_{Ht} - R_{kt} q_{kt-1} s_{Gt-1} + R_{bt} q_{bt-1} b_{Bt-1} + e_t d_{Ft} + T_t$$

Combining it with the government budget constraint (13),

$$p_{Ht} g_t + c_t + i_t + e_t(R_t d_{Ft-1} - R_t^* f_{t-1}) = p_{Ht} y_{Ht} + e_t(d_{Ft} - f_t)$$

Since $c_t = p_{Ht} c_{Ht} + e_t c_{Ft}$ and $i_t = p_{Ht} i_{Ht} + e_t i_{Ft}$, the above equation becomes

$$e_t(R_t d_{Ft-1} - R_t^* f_{t-1}) = p_{Ht} x_t - e_t m_t + e_t(d_{Ft} - f_t)$$

after imposing the market clearing condition for home goods (14).

Hence, using the definition of trade balance (15), one can derive the balance of payments

$$tb_t = -e_t(d_{Ft} - f_t) + e_t(R_t d_{Ft-1} - R_t^* f_{t-1})$$

and the national income identity

$$y_t = p_{Ht} g_t + c_t + i_t + tb_t$$

where $y_t \equiv p_{Ht} y_{Ht}$.

D Equilibrium conditions

$$mu_t = \left(c_t - \frac{\kappa_h \, h_t^{1+\varphi}}{1+\varphi} \right)^{(-\sigma)}$$

$$\Lambda_{t,t+1} = \frac{\beta \, mu_{t+1}}{mu_t}$$

$$1 = \mathbb{E}_t \Lambda_{t,t+1} \, R_{t+1} \, \frac{e_{t+1}}{e_t}$$

$$\kappa_h \, h_t^{\varphi} = w_t$$

$$c_{Ht} = (1-\gamma)(p_{Ht})^{-\eta} c_t$$

$$c_{Ft} = \gamma (e_t)^{-\eta} c_t$$

$$y_{Ht} = a_t \, k_{t-1}^{\alpha} \, h_t^{1-\alpha}$$

$$(1-\alpha) \, p_{Ht} y_{Ht} = w_t h_t$$

$$\alpha p_{Ht} y_{Ht} = z_t k_{t-1}$$

$$k_t = (1-\delta) \, k_{t-1} + i_t \left(1 - \frac{\kappa_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right)$$

$$1 = q_{k\,t} \left(1 - \frac{\kappa_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 - \kappa_i \left(\frac{i_t}{i_{t-1}} - 1 \right) \frac{i_t}{i_{t-1}} \right) + \kappa_i \mathbb{E}_t \Lambda_{t,t+1} \, q_{k\,t+1} \left(\frac{i_{t+1}}{i_t} - 1 \right) \left(\frac{i_{t+1}}{i_t} \right)^2$$

$$i_{Ht} = (1-\gamma)(p_{Ht})^{-\eta} i_t$$

$$i_{Ft} = \gamma (e_t)^{-\eta} i_t$$

$$R_{k\,t} = \frac{z_t + (1-\delta) \, q_{k\,t}}{q_{k\,t-1}}$$

$$R_{b\,t} = \frac{\Xi + \varrho \, q_{b\,t}}{q_{b\,t-1}}$$

$$l_t = \frac{q_{k\,t} \, s_{Bt} + \Delta \, q_{b\,t} b_{Bt}}{n_t}$$

$$q_{k\,t}\, s_{B\,t} + q_{b\,t}\, b_{B\,t} = n_t + e_t\, d_t$$

$$n_t = \chi\ \left(\left(R_{k\,t} - R_t \frac{e_t}{e_{t-1}}\right)\ q_{k\,t-1}\, s_{B\,t-1} + \left(R_{b\,t} - R_t \frac{e_t}{e_{t-1}}\right)\ q_{b\,t-1}\, b_{B\,t-1} + R_t \frac{e_t}{e_{t-1}}\ n_{t-1}\right) + \iota\ \left(q_{k\,t-1}\, s_{B\,t-1} + \Delta q_{b\,t-1} b_{B\,t-1}\ \right)$$

$$\Omega_t = 1 - \chi + \chi \nu_t$$

$$\nu_t = \frac{\nu_{nt}}{1 - \lambda_t}$$

$$\lambda_t = \max\left\{0, 1 - \frac{\nu_{nt}}{\theta l_t}\right\}$$

$$\nu_{nt} = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} R_{t+1} e_{t+1}/e_t$$

$$\mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_{kt+1} - R_{t+1} \frac{e_{t+1}}{e_t}\right) = \theta \lambda_t$$

$$\mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \left(R_{bt+1} - R_{t+1} \frac{e_{t+1}}{e_t}\right) = \Delta \theta \lambda_t$$

$$y_{Ht} = g_t + (1 - \gamma)\ p_{Ht}{}^{(-\eta)}\ (c_t + i_t) + \gamma^*\, tot_t^{\eta} y_t^*$$

$$y_t = p_{Ht} y_{Ht}$$

$$y_t = c_t + i_t + p_{Ht} g_t\ - e_t\ (d_{F\,t} - f_t) + e_t\ \left(R_t\, d_{F\,t-1} - R_t^*\, f_{t-1}\right)$$

$$1 = (1 - \gamma)\ p_{Ht}{}^{1-\eta} + \gamma\, e_t^{1-\eta}$$

$$tot_t = \frac{e_t}{p_{Ht}}$$

$$xp_t = p_{Ht}\, \gamma^* tot_t^{\eta}\, y_t^*$$

$$mp_t = \gamma\, e_t^{1-\eta}\, (c_t + i_t)$$

$$tb_t = xp_t - mp_t$$

$$ca_t = tb_t + e_t\ \left(f_{t-1}\ \left(R_t^* - 1\right) - d_{F\,t-1}\ (R_t - 1)\right)$$

$$k_t = s_t$$

$$s_t = s_{Bt} + s_{Gt}$$

$$b_t = b_{Bt}$$

$$d_{Ht} = d_t - d_{Ft}$$

$$q_{kt}\, s_{Gt} + e_t f_t = q_{bt} b_t$$

$$f_t = (1 - \Gamma_t) f$$

$$b_t = b$$

$$g_t = g$$

$$\Gamma_t = \min\left\{\phi_\mu(\mu_t - \mu), \bar{\Gamma}\right\}$$

$$\mu_t = \mathbb{E}_t\left(R_{k\,t+1} - R_{t+1}\frac{e_{t+1}}{e_t}\right)$$

$$a_t = a$$

$$R_t = R_t^* + \psi\left(\exp\left(\frac{e_t\,(d_{Ft} - f_t)}{y_t} - \frac{e(d_F - f)}{y}\right) - 1\right) + \xi_t$$

$$\xi_t = \rho_\xi\, \xi_{t-1} + \varepsilon_{\xi t}$$

$$y_t^* = y^*$$

$$R_t^* = R^*$$

E Data appendix

The data for five countries (Chile, Colombia, Korea, Philippines, Turkey) are from the International Financial Statistics (IFS) and Financial Soundness Indicator (FSI) at the International Monetary Fund, the World Development Index (WDI) and Global Economic Monitor (GEM) at the World Bank, Main Economic Indicators (MEI) at the Organization for Economic Co-operation and Development, and the central banks. The data series from each source are listed below.

- IFS
  - Gross Domestic Product, Real, Seasonally Adjusted, Domestic Currency, Millions (NGDP_R_SA_XDC)
  - Gross Domestic Product, Real, Domestic Currency, Millions (NGDP_R_XDC)
  - Private Sector Final Consumption Expenditure, Real, Seasonally Adjusted, Domestic Currency, Millions (NCP_R_SA_XDC)
  - Private Sector Final Consumption Expenditure, Real, Domestic Currency, Millions (NCP_R_XDC)
  - Gross Capital Formation, Real, Seasonally Adjusted, Domestic Currency, Millions(NI_R_SA_XDC)[39]
  - Gross Capital Formation, Real, Domestic Currency, Millions (NI_R_XDC)
  - Exports of Goods and Services, Real, Seasonally Adjusted, Domestic Currency, Millions (NX_R_SA_XDC)[40]
  - Exports of Goods and Services, Real, Domestic Currency, Millions (NX_R_XDC)
  - Imports of Goods and Services, Real, Seasonally Adjusted, Domestic Currency, Millions (NM_R_SA_XDC)[41]
  - Imports of Goods and Services, Real, Domestic Currency, Millions (NM_R_XDC)
  - Balance of Payments, Supplementary Items, Current Account, Net (excluding exceptional financing), US Dollars, Millions (BCAXF_BP6_USD)
  - Exchange Rates, Real Effective Exchange Rate based on Consumer Price Index, Index (EREER_IX)[42]
  - Exchange Rates, Domestic Currency per U.S. Dollar, Period Average, Rate (ENDA_XDC_USD_RATE)
  - Prices, Consumer Price Index, All items, Index (PCPI_IX)
  - Financial, Interest Rates, Lending Rate, Percent per annum (FILR_PA)[43]
  - Financial, Interest Rates, Deposit, Percent per annum (FIDR_PA)
- FSI
  - Deposit Takers, Earnings and Profitability, Capital (FSDERE_XDC)
  - Deposit Takers, Earnings and Profitability, Total Assets (FSDERA_XDC)

[39]This series is not available for Turkey and Philippines.
[40]This series is not available for Philippines.
[41]This series is not available for Philippines.
[42]This series is not available for Korea and Turkey. For these countries, I construct real exchange rates with nominal exchange rates and the consumer price indices.
[43]This series is not available for Turkey.

- Deposit-takers, Liabilities, Debt, Other liabilities (FS_ODX_LDO_XDC)

- WDI
  - General government final consumption expenditure, % of GDP (NE.CON.GOVT.ZS)
  - Exports of goods and services, % of GDP (NE.EXP.GNFS.ZS)
  - External debt stocks, total, DOD, current US$ (DT.DOD.DECT.CD)[44]
  - Total reserves minus gold, current US$ (FI.RES.XGLD.CD)
  - GDP, current US$ (NY.GDP.MKTP.CD)
  - Balance of Payments, Supplementary Items, Current Account, Net (excluding exceptional financing), US Dollars, Millions (BN.CAB.XOKA.GD.ZS)
- GEM
  - J.P. Morgan Emerging Markets Bond Spread, EMBI+ (EMBIG)
- MEI
  - Long-term government bond yields, 10-year (IRLTLT01)[45]
- Bank of Chile
  - External debt to market value (millions of dollars)
- Bank of Korea
  - 1.3.2.2. Market Interest Rates, Yields of Treasury Bonds(3-year), Percent Per Annum
  - 1.3.2.2. Market Interest Rates, Yields of Corporate Bonds : O.T.C (3-year, AA-), Percent Per Annum
  - 2.6.2.1. External Debt, 1. Short-term, Mil.U$
  - 2.6.2.1. External Debt, 2. Long-term, Mil.U$

[44]Since this series is not available for Chile and Korea, I use data directly from the central banks for the two countries.

[45]The series includes data for Chile, Colombia, and Korea. The data for Turkey is not available. Philippines is not part of OECD.

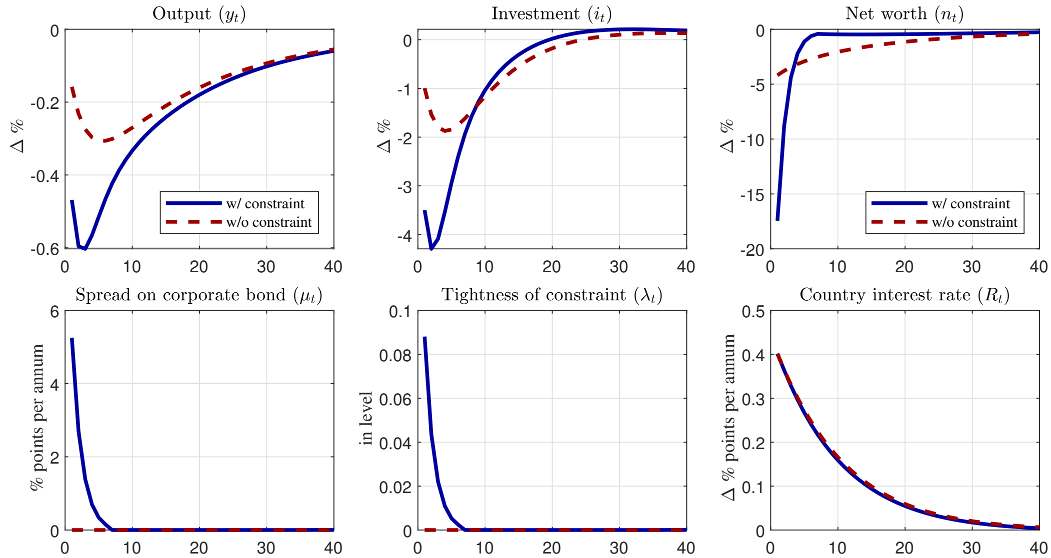

Figure 14: Impulse responses in a sudden stop without policy

Note: The figure describes the impulse responses without policy to 0.1 percentage point of risk premium shock from the steady state where banks are not constrained. Compared to the benchmark responses in blue solid lines, the red solid lines are the reponses where the leverage constraint is not imposed on banks. The horizontal axis indicates time periods in quarters.

F Balance sheet effect

To see in more detail the amplification of the sudden stop through the balance sheet effect, I perform a counterfactual analysis in which banks' leverage constraint is not imposed. Figure 14 describes the impulse responses without policy in a sudden stop. The blue solid lines are the same responses as in Figures 3 and 4 from Section 3.2. In addition to these responses, the figure depicts the responses in red dotted lines without the leverage constraint imposed on the banks. The comparison between the two cases highlights the role of balance sheet effect in a sudden stop.

The figure shows that, for the same size of risk premium shock, the economy experiences much milder impact of the sudden stop, in the absence of balance sheet effect. Without the amplification mechanism, banks lose only about 5 percent of net worth (top-right panel). Since banks are not constrained (bottom-middle panel), they can absorb any excess returns on the corporate bond (bottom-left panel). As a result, the contractions in output and investment are much milder. This counterfactual analysis demonstrates that the balance sheet effect is the key mechanism that amplifies the adverse effect of the sudden stop.