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ABSTRACT

We study an unconventional policy tool–interest rate uncertainty–that may be used to discourage inefficient capital inflows and to adjust the composition of external accounts between short-term securities and foreign direct investment (FDI). Identified interest rate volatility shocks in several emerging markets cause a decline in GDP growth, increase in inflation, an improvement in the current account, and a depreciation in real exchange rate. Using a calibrated open-economy New Keynesian model, we introduce an interest rate uncertainty policy rule that adjusts the volatility of emerging market economy interest rate shocks in response to drivers of capital flows. The uncertainty policy discourages short-term inflows through portfolio risk and consumption smoothing channels. A markup channel combined with exchange rate depreciation generates FDI inflows. The transmission of uncertainty via markups is influenced by the extent of exchange rate pass-through. The uncertainty policy may be welfare improving if designed against uncertainty shocks that drive capital flows. However, it may be welfare reducing against level shocks that drive capital inflows. We further investigate new channels under different scenarios, including various assumptions about currency of export invoicing, varying degrees of risk aversion, interaction with different types of Taylor rules, and effective-lower-bound in the rest of the world.

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1 Introduction

Starting with the colonial pattern of foreign investment in the 19th century, emerging and developing nations have been subject to the ebbs and flows of international capital.[1] With the general expansion of global finance, recent decades have revealed new patterns and more intense capital flow cycles. Such surges in size and volatility of capital inflows can cause dislocations and pose challenges for economic policy.[2] Central bankers, who are often working under multiple mandates, have been forced to be innovative when facing the challenges posed by large and volatile movements of international capital.

The recent experience of the Central Bank of the Republic of Turkey (CBRT) provides an example of such unconventional policy response to capital flows while also aiming to achieve its mandates of contributing to the country's financial strength and maintaining price stability.[3] The main policy interest rate of the CBRT is the one-week repo rate, which fluctuates within the band (interest rate corridor) between the overnight lending and borrowing rates.[4] A widening of this corridor implies an increase in uncertainty on the future path of the policy rate, because it is possible for the policy rate to move more aggressively in the future. In response to intense capital inflows, the CBRT lowered the floor of its interest rate corridor (widening it from below) in late 2010 to discourage intense short-term flows by increasing uncertainty on its payoff and to channel inflows towards long-term foreign direct investment (FDI); in response to powerful capital outflows less than a year later, the interest rate corridor was narrowed (the floor was raised) by raising overnight borrowing rates with the aim of preventing excessive outflows. Figure 1 illustrates the

[1]See Nurkse (1954) for a comparison of 19th century vs early 20th century capital flows.

[2]See Ahmed and Zlate (2013) and Obstfeld (2015) for examples of studies of capital flows to EMEs and IMF (2013) for a summary of policy responses. Obstfeld (2015) and Rajan (2013) discuss difficulties that these flows create for financial stability and monetary policy. Taylor (2015) and Woodford (2010) question the extent to which financial globalization undermines the ability to pursue monetary policy objectives, but Rey (2013) famously argues that independent monetary policy in EMEs has become impossible without capital controls. Calvo et al. (1996) provide an argument for using multiple instruments to address capital flows.

[3]The Turkish Central Bank Law, which was amended in 2001 by the then Economics Minister Kemal Dervis, provides the Bank with instrument independence to contribute to financial stability in addition to its primary mandate of achieving price stability.

[4]In Federal Reserve System language, the corridor refers to the window between the discount window lending rate and the interest rate on reserves.

implementation of this policy between November 2010 and August 2011.[5,6] Several studies (e.g., Kara, 2016) document an increase in FDI inflows during the application of the interest rate corridor policy.[7] There is no model that studies the unorthodox strategy used by the CBRT to pursue its goals in 2010-11. Emerging markets, in general, are facing similar challenges and the goal of this paper is to fill this void and investigate the lessons that can be learned in a broader context.

We fill the gap in the literature by, first, studying the relevance of interest rate volatility on economic activity in a panel of eleven emerging markets: Brazil, Czechia, Hungary, India, Indonesia, Israel, Korea, Mexico, Poland, South Africa, and Turkey. We use a panel Bayesian Vector Autoregression (BVAR) model and identify volatility shocks in the data as an exogenous increase in the volatility of interest rates. We treat changes in interbank rate volatility as a proxy for the corridor policy. The Turkish experiment shows that the policy rate hardly moved after widening the corridor, whereas interbank rates became substantially more volatile. We use the BVAR to show how higher interest rate volatility affects GDP growth, inflation, current-account-to-GDP, net-FDI-to-GDP, and real exchange rate.

Empirically, a shock to interbank rate volatility causes a decline in output growth, an increase in inflation, an improvement in the current account, an increase in net FDI inflows, and a depreciation in the real exchange rate. We also show that the impact of a shock to interbank rate volatility is robust when we control for the volatility of real GDP growth and the volatility of inflation.

We then provide a laboratory for understanding the transmission channels of interest rate volatility and how they affect the composition of the financial account and navigate the trade-offs between internal objectives and external balance if it is used as a policy tool. For this purpose, we build a New Keynesian model of a two-region world (an EME and the rest of the world, RoW) in which we can decompose the current account into bond and FDI components. The model allows the central bank to manipulate the stochastic volatility of the domestic policy interest rate, which

[5] A widening of the corridor does not necessarily imply an increase in the realized volatility of the policy rate *per se*. However, realized volatility of shorter term rates can get higher within a larger corridor. Figure 1 shows a substantial increase in the volatility of overnight borrowing rates in response to widening of the corridor, whereas the policy rate hardly moved within this episode.

[6] We are particularly interested in this period. The corridor policy against international capital flows was experimental when it was first introduced in Turkey and the policy was communicated with the public through white papers and CBRT policy notes. Among others see Başçı, 2012 and Kucuk et al. , 2014. The former is a note written by the Governor of CBRT during this episode. The movements in the corridor after this period are not related with capital flow management purposes of the central bank.

[7] It is obviously uncertain whether the increase is due to mean reversion of inflows after the Global Financial Crisis or to the success of the policy.

the EME's central bank uses to discourage bond flows and channel inflows toward FDI.

We differ from the standard New Keynesian open-economy literature in two main aspects. First, we explicitly model FDI versus bond flows.[8] Second, we solve the model nonlinearly and trace transmission and propagation of stochastic volatility.[9] Under incomplete international financial markets, there is a time-varying wedge between the ratio of the marginal utilities of consumption in EME and RoW and the real exchange rate, which implies a deviation from perfect risk sharing. Movements in this risk-sharing wedge cause real exchange misalignment and distort incentives to borrow and lend internationally (as explained, for instance, by Corsetti et al. (2018)). The joint analysis of movements in interest rate stochastic volatility and bond-vs-FDI flows in the presence of financial market distortions yields insights on the transmission and propagation of uncertainty both within and across borders.

Simulations indicate that an increase in EME interest rate stochastic volatility shock (henceforth, SV shock) can generate similar dynamics with the VAR evidence. Then, we introduce a policy rule (henceforth, IRUPT (Interest Rate Uncertainty as a Policy Tool)) that adjusts the volatility of EME interest rate shocks in response to drivers of capital flows. We employ a preference SV shock in RoW to trigger the situation to which the EME's central bank responds with its unorthodox tool. Deviations from uncovered interest rate parity (UIP) generate inflows into the EME (consistent with di Giovanni et al. (2017)). Responding to this shock with an increase in the EME's policy interest rate volatility discourages these capital inflows, shifting their composition towards FDI, and it induces a counteracting effect on the risk-sharing wedge across the border.

Three key channels of uncertainty transmission affect external accounts in our model. First, a *consumption smoothing channel*: EME households smooth consumption in response to rising interest rate uncertainty by increasing their savings. This is accomplished by using RoW bonds when EME interest rate volatility rises. Savings also fund increased investment in domestic capital,

[8]We define FDI as overseas investment in physical capital, in line with the definition of FDI capturing both capital-accumulation and capital-gain transactions between countries. The IMF's definition is as follows: "The term describes a category of international investment made by a resident entity in one economy (direct investor) with the objective of establishing a lasting interest in an enterprise resident in an economy other than that of the investor (direct investment enterprise). ... Direct investment involves both the initial transaction between the two entities and all subsequent capital transactions between them and among affiliated enterprises, both incorporated and unincorporated." Link: https://www.imf.org/external/np/sta/di/glossary.pdf

[9]More precisely, we employ third-order perturbation techniques. The standard curse of dimensionality prevents us from employing global methods. We highlight in the main text that some of the model outcome under local and global methods might differ if unconventional calibration is used.

because movements in the real exchange rate make domestic capital more attractive than investment in RoW capital. Second, an international investor's *portfolio risk channel*: In response to increased risk in the EME, RoW investors seek higher returns from the EME bonds, but relative returns on EME bonds do not increase enough to make them a good hedge for RoW investors. Therefore, RoW investors adjust their portfolios away from EME debt. Third, when prices are sticky, a *markup channel* operates: With nominal rigidities in place, firms cannot adjust prices to changes in demand efficiently, and this causes markups to move. In our benchmark scenario, EME firms engage in local currency pricing, while RoW firms operate under producer currency pricing.[10] In this scenario, depreciation of the real exchange rate (from the perspective of the EME) does not affect the prices of EME exports, and this makes them relatively expensive for RoW agents. EME exporters lower markups. Finally, EME firms respond to rising volatility by raising their domestic market prices, which generates inflation in the EME. We show that this precautionary pricing behavior depends heavily on the level of exchange rate pass-through. With imperfect pass-through, precautionary pricing implies that exporters respond to uncertainty by lowering their prices and by increasing their demand for inward FDI to expand production.[11]

We also provide an evaluation of the welfare consequences of the interest rate uncertainty policy. We calculate welfare as the expected present discounted value of utility. To facilitate interpretation of results, we calculate a consumption compensation metric relative to a absence of interest rate uncertainty policy benchmark. We show that, albeit small, IRUPT is welfare-improving against the demand-type SV shocks that we consider. Specifically, under this scenario, IRUPT is successful in closing the wedges associated with imperfect international risk-sharing. However, IRUPT can diminish welfare if capital inflows are driven by types of shocks that would move the wedges in different directions, *e.g.*, level shocks. Since fluctuations in the current account are driven by both level and SV shocks, it is difficult to design IRUPT against macro variables.

We contribute to the literature that studies the relationship between the global financial cycle and monetary policy in EMEs.[12] We differ from this literature mainly by studying an innovative

[10] This is consistent with treating the RoW currency as the dominant currency in international trade transactions. See Goldberg and Tille (2008), Gopinath (2016) and Gopinath et al. (2020).

[11] The precautionary pricing motive in the presence of uncertainty is well known in the closed-economy literature on stochastic volatility shocks. One of our contributions is, in open economies, the impact on export-price setting depends on exchange rate pass-through.

[12] In addition to the references in footnote 2, see also Aoki et al. (2015), Banerjee et al. (2015), Cavallino and Sandri (2019), and Gourinchas et al. (2016).

policy tool that was deployed as defense against the impact of the global financial cycle.

We also contribute to the literature that studies macroprudential policies in response to inefficient capital flows.[13] Instead of considering the consequences of exogenous borrowing constraints, we focus on the propagation of stochastic volatility of policy rates in the workhorse New Keynesian open-economy framework, augmented only by differentiating FDI versus bond trading. A distinct feature of our analysis is that introducing a policy interest rate volatility rule can improve risk sharing by narrowing the wedge in the risk-sharing condition under incomplete markets.

Moreover, we contribute to the literature that studies the effects of stochastic volatility shocks on economic activity.[14] We differ from this literature by studying the implications of using uncertainty as a policy tool and by focusing on an open-economy environment.[15] Our paper is the first to study the effects of uncertainty on different types of capital flows. We do so in an environment of incomplete international financial markets, deviations from purchasing power parity (PPP), price rigidities, and dynamics of different types of investment.

Finally, the focus on interest rate bands in our motivation connects this paper to the literature on exchange rate target zones.[16] Svensson (1991) argues that narrowing exchange rate bands reduces exchange rate volatility, but the variability goes into interest rate variability. Our results indicate that a similar argument emerges in our model from the other direction: an increase in interest rate volatility reduces exchange rate volatility under flexible exchange rates.

The rest of the paper is organized as follows. Section 2 provides empirical evidence, Section 3 presents the model. Section 4 discusses calibration, solution method, and results. Section 5 compares the welfare implications of IRUPT. Section 6 summarizes the results of model extensions.

[13] Recent contributions include Acharya and Bengui (2018), Benigno et al. (2016), Bianchi and Mendoza (2018), Dávila and Korinek (2018), Farhi and Werning (2016), Reyes-Heroles and Tenorio (2020) and Schmitt-Grohé and Uribe (2016). In a relevant work, Reyes-Heroles and Tenorio (2020) studies macroprudential policies against an increase in world interest rate risk. They employ a small open economy model with flexible prices and collateral constraints. See Erten et al. (forthcoming) and Rebucci and Ma (2019) for surveys of this extensive literature.

[14] Significant contributions include Bloom (2009), Justiniano and Primiceri (2008) and Basu and Bundick (2017), Fernández-Villaverde et al. (2015), and Leduc and Liu (2016). See Fernández-Villaverde and Guerron-Quintana (2020) for a survey.

[15] Related to the broadly-defined idea of uncertainty as a policy tool, Nosal and Ordoñez (2016) show that uncertainty about providing bank bailouts can act as a self-disciplining mechanism for banks by limiting the riskiness of their portfolios. Akkaya (2014) interpreted stochastic volatility shocks to the interest rate as forward guidance shocks. Fernández-Villaverde et al. (2011) introduce stochastic volatility shocks in Mendoza (1991)'s small open economy model of real business cycles. Benigno et al. (2012) use second-order approximations to study a two-country endowment model under internationally complete markets with recursive preferences that cause departures from perfect risk sharing. Kollmann (2016) uses third-order approximations to study the effects of output volatility in a setting similar to Benigno et al. (2012).

[16] Among others, see Flood and Garber (1989), Svensson (1991), and Krugman (1991).

Section 7 concludes. An appendix contains additional details and results.

2 Empirical Evidence

In this section, we examine the effects of interbank rate volatility shocks in the data. We estimate a panel Bayesian Vector Autoregressive (BVAR) model for eleven emerging market economies to capture the effects of volatility shocks in the data on real GDP growth, inflation, current account-to-GDP, net FDI-to-GDP, and real exchange rate. We also conduct a robustness analysis with controlling for output growth volatility and inflation volatility. We calculate 12-month rolling standard deviations of interbank interest rates and convert them into quarterly data. Our sample is composed of data from Brazil, Czech Republic, Hungary, India, Indonesia, Israel, South Korea, Mexico, Poland, South Africa, and Turkey. We also conduct country-by-country analysis for several advanced economies in the appendices for comparison purposes.

Our research question is motivated by the widening of the policy interest rate corridor, which implies higher realized volatility in shorter term rates than the policy rate. Indeed, during the Turkish experiment, the policy rate hardly moved whereas fluctuations in overnight interbank rate substantially increased. Therefore, as a first-order approximation to capture the change in implied volatility of the policy rate, we focus on realized overnight interbank rate volatility.[17,18] In appendices, we provide further explanations on data construction and also conduct additional exercises to present a broader analysis.

2.1 VAR Evidence

Our baseline BVAR model includes six time-series variables. Interbank rate volatility (as described above), real GDP growth measured as quarterly changes in real GDP, inflation rate measured as year-over-year changes in consumer price index in quarterly frequency, current-account-to-GDP ratio, net-FDI-to-GDP ratio, and real effective exchange rate. Net-FDI-to-GDP is defined

[17] As noted by a referee, a widening in the interest rate corridor by the U.S. Federal Reserve would imply higher volatility in the effective federal funds rate rather than an increase in the volatility of the target federal funds rate.

[18] It is informative to point to the reader that the movements in interbank rate volatility does not necessarily imply a small realized policy rate volatility. A more ideal measure of implied volatility could be calculated by using interest rate options; however, to the best of our knowledge, no such data is available for emerging market economies. Our goal in this paper is to study an experimental policy introduced only by Turkey for a period about 12 months. Therefore, we treat the VAR analysis only suggestive for the implications of the corridor policy.

as liabilities subtracted from assets, so a negative movement in this variable indicates inflows. Real exchange rate is also defined in emerging market consumption units, so a decrease in this variable indicates depreciation.[19] The sample covers from 2002:QII to 2022:QII.

We identify a volatility shock by using a Cholesky decomposition with the interbank interest rate volatility ordered first. Ordering interest rate volatility first implies that volatility shocks can have an instant impact; however, non-volatility shocks do not affect the overnight interbank rate volatility instantaneously. In the subsequent periods, interbank interest rate volatility responds to other shocks due to lags in the BVAR. Our methodology follows the literature on identification of uncertainty shocks, such as in Basu and Bundick (2017) and Leduc and Liu (2016).

Figure 2 shows estimated impulse responses to an identified interbank rate volatility shock and the 68% confidence intervals. The solid purple lines indicate estimates of the impulse responses and the dashed black lines indicate the confidence bands. We translate the interbank rate volatility shock to percent deviation from its average. One standard deviation shock translates into a 55% deviation from its average. The movements in real GDP growth, inflation, current-account-to-GDP, net-FDI-to-GDP, and real exchange rate are in percentage points.

An unexpected interbank rate volatility shock generates a fall in output growth for two quarters. Furthermore, interbank rate volatility generates an increase in inflation, a decrease in the current account deficit, and a real exchange rate depreciation. The impact on the current account remains significant for 5 quarters, whereas the effect on inflation and real exchange rate is only significant on impact. The volatility shock also generates net-FDI-inflows between second and fifth quarters. Due to long term nature of FDI, it is possible that the response is generated with some delay. However, the response of FDI is insignificant. It does not come as surprise due to big variations in FDI across countries. The cross-country variation in the size of FDI can yield to insignificant responses although the sign of the variable across countries is the same. The correction in the current account and inflows of FDI imply that short-term financement of the current account is being reversed in response to an unexpected increase in interbank rate volatility.

[19] Due to the original structure of the data, we keep this definition of exchange rate in the empirical analysis. As we highlight below, in the description of our model, real exchange rate is defined in RoW consumption units.

2.2 Robustness of VAR Evidence

The impact of an unexpected increase in interbank rate volatility on the variables that are discussed above is robust when we control for the volatility of real GDP growth and inflation. Figure 4 shows estimated impulse responses to an identified interbank rate volatility shock and the 68% confidence intervals. When we include these two variables in our panel BVAR, we don't observe any significant changes in the responses of other variables. One variable that is worth to point out is the response of net-FDI-to-GDP. We observe that our extended panel BVAR suggests net-FDI inflows, also on impact.

3 The Model

We examine the transmission channels of changes in interest rate stochastic volatility in an open economy New Keynesian model. We show that movements in the interest rate stochastic volatility has impact on the composition of capital inflows.

The world is composed of two regions, EME and RoW.[20] The total measure of the world economy is normalized to unity, with EME and RoW having measures n and $1 - n$, respectively. International financial markets are incomplete as only non-contingent bonds are internationally traded. In addition to engaging in international trade of short-term bonds, RoW (EME) agents can invest in productive capital that will be used as an input in EME's (RoW's) production activity. RoW variables are denoted with an asterisk.

Households consume a basket of final goods, which is an Armington aggregator of EME and RoW goods. Domestic intermediate goods are produced by monopolistically competitive firms, which combine labor with real capital from domestic and foreign agents.

Goldberg and Tille (2008), Gopinath (2016), and Gopinath et al. (2020) document that the most trade is invoiced in U.S. dollars, indicating its role as the worldwide dominant currency. Following their evidence, our baseline model setup assumes that EME exporters set prices for the RoW market in RoW currency, while RoW exporters set prices of both domestic and foreign sales in their own currency. Combined with price stickiness, the departure from a world in which both

[20] RoW can be thought of as the aggregate of countries that engage in international transactions with EME. Alternatively, it can be thought as the main trading partner and the origin of most FDI received by EME after adjusting for the respective country sizes.

EME and RoW exporters engage in PCP is a source of deviations from purchasing power parity (PPP). In addition, we assume home bias in the composition of final output, which ensures that PPP does not hold also when all firms engage in PCP. Figure 5 shows the model architecture.

Our baseline model considers preference shocks in RoW and monetary policy shocks in EME. Both of the shocks have time-varying second moments. We call the second-moment shock to the preference as the RoW preference stochastic volatility shock and the second-moment shock to the monetary policy as the policy rate stochastic volatility shock.

3.1 Households

The economy is populated by atomistic households. Each household is a monopolistic supplier of a specific labor input. The representative household, indexed by h, maximizes the expected inter-temporal utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t(h), L_t(h)), \tag{1}$$

where $U(C_t(h), L_t(h)) = e^{\vartheta_t} \frac{\left(C_t(h) - \chi \frac{L_t(h)}{1+\varphi}^{1+\varphi}\right)^{1-\gamma} - 1}{1-\gamma}$, $\gamma, \chi, \varphi \geq 0$, $\beta \in (0,1)$ is the discount factor. The preference structure follows Greenwood, Hercowitz, and Huffman (1988) and abstracts from wealth effects on labor supply. e^{ϑ_t} is an exogenous preference shock which follows an $AR(1)$ process with stochastic volatility:

$$\vartheta_t = \rho^{\vartheta} \vartheta_{t-1} + e^{\sigma^{\vartheta}_{t-1}} \varepsilon^{\vartheta}_t$$

where the log of the standard deviation of the preference shock, σ^{ϑ}_t, follows an $AR(1)$ process:

$$\sigma^{\vartheta}_t = (1 - \rho^{\sigma^{\vartheta}})\sigma^{\vartheta} + \rho^{\sigma^{\vartheta}} \sigma^{\vartheta}_{t-1} + \eta_{\sigma^{\vartheta}} \varepsilon^{\sigma^{\vartheta}}_t.$$

where $\varepsilon^{\sigma^{\vartheta}}_t$ is a normally distributed shock with zero mean and unit variance. We call this shock as preference stochastic volatility (SV) shock. The parameter σ^{ϑ} controls the mean volatility of the preference level shock. The preference shock structure follows Basu and Bundick (2017). In our simulations, we assume that only RoW is subject to preference shocks.

Households accumulate physical capital in EME and RoW consumption units, K and K_*, which is used in the respective region's production of intermediate goods.[21] Households rent these two types of capital to intermediate EME and RoW firms. The rental rates they receive from EME and RoW producers are also in EME and RoW consumption units, respectively. Investments in the respective physical capital stock, I and I_*, require use of the same composite of goods as in the final consumption bundles. The laws of motion for both types of capital are standard:

$$K_{t+1}(h) = (1-\delta)K_t(h) + I_t(h), \tag{2}$$

$$K_{*,t+1}(h) = (1-\delta)K_{*,t}(h) + I_{*,t}(h), \tag{3}$$

where $\delta \in (0,1)$ denotes the rate of depreciation.

Households supply differentiated labor inputs, which gives them wage setting power. Intermediate good producers employ a Dixit-Stiglitz composite of labor inputs: $L_t \equiv \left[\int_0^1 L_t(h)^{\frac{\epsilon_W - 1}{\epsilon_W}} dh\right]^{\frac{\epsilon_W}{\epsilon_W - 1}}$ where $\epsilon_W > 1$ is the elasticity of substitution between the differentiated labor inputs. The aggregate nominal wage index is $W_t \equiv \left[\int_0^1 W_t(h)^{1-\epsilon_W} dh\right]^{\frac{1}{1-\epsilon_W}}$, where $W_t(h)$ is the nominal wage set by household h. Optimal demand of labor input h is determined by:

$$L_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\epsilon_W} L_t. \tag{4}$$

Household h sets the nominal wage $W_t(h)$ subject to (4) when maximizing utility. Wage setting is subject to a quadratic cost of adjusting the nominal wage rate between period $t-1$ and t as in Rotemberg (1982):

$$\frac{\kappa^W}{2}\left(\frac{W_t(h)}{W_{t-1}(h)} - 1\right)^2 W_t(h)L_t(h),$$

where $\kappa^W \geq 0$ determines the size of the adjustment cost (if $\kappa^W = 0$, then wages are flexible). The size of this cost is proportional to labor income.

Each household can hold one-period non-contingent nominal bonds issued by other domestic and RoW households, B and B_*. The nominal exchange rate is denoted by S. International asset markets are incomplete, as only bonds and physical capital are traded across countries. EME (RoW)

[21] Similarly, RoW households invest in physical capital that will be used in RoW, K_*^*, and in physical capital that will be rented to EME firms, K^*. As discussed in more detail below, we interpret the transactions related to the latter as the FDI that is flowing into EME.

bonds are issued by EME (RoW) households and denominated in EME (RoW) currency. Quadratic costs of adjusting bond holdings ensure that there is a unique steady state, characterized by zero international bond holdings; hence, the economy goes back to its initial position after temporary shocks.[22] In equilibrium, these costs are rebated back to households in lump-sum fashion.

The period budget constraint of the household can be written as:

$$\begin{aligned} P_tC_t(h) + \tfrac{B_{t+1}(h)}{R_t} + \tfrac{S_tB_{*,t+1}(h)}{R_t^*} + \tfrac{\eta}{2}P_t(\tfrac{B_{t+1}(h)}{P_t})^2 + \tfrac{\eta}{2}S_tP_t^*(\tfrac{B_{*,t+1}(h)}{P_t^*})^2 + P_tI_t(h) + S_tP_t^*I_{*,t}(h) \\ = B_t(h) + S_tB_{*,t}(h) + P_tr_{K,t}K_t(h) + S_tP_t^*r_{K_*,t}K_{*,t}(h) + W_t(h)L_t(h) \\ -\tfrac{\kappa^W}{2}\left(\tfrac{W_t(h)}{W_{t-1}(h)} - 1\right)^2 W_t(h)L_t(h) + d_t(h) + T_t(h), \end{aligned} \tag{5}$$

where $\frac{\eta}{2}\left(P_t(\frac{B_{t+1}(h)}{P_t})^2 + S_tP_t^*(\frac{B_{*,t+1}(h)}{P_t^*})^2\right)$ is the quadratic bond adjustment costs (with $\eta > 0$), and $T_t(h)$ is its rebate, taken as given by the household. R_t and R_t^* are the gross nominal interest rates on EME and RoW bond holdings between t and $t+1$. Finally, $d_t(h)$ denotes profits from producers, and $r_{K,t}$ and $r_{K_*,t}$ are the real rental rates for the capital accumulated by EME households and used in EME and RoW intermediate good production.

The household maximizes (1) subject to (2), (3), (4), and (5). The Euler equations for bond holdings are as follows:

$$\frac{1}{R_t} = \mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\right] - \eta b_{t+1}, \tag{6}$$

$$\frac{1}{R_t^*} = \mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}^*}\frac{rer_{t+1}}{rer_t}\right] - \eta b_{*t+1}, \tag{7}$$

where $\beta_{t,t+s} \equiv \frac{\beta U_{C,t+s}}{U_{C,t}}$ is the stochastic discount factor and $U_{C,t}$ denotes the marginal utility from consumption in period t. Π_t and Π_t^* denote gross inflation between $t-1$ and t in EME and RoW. $b_{t+1} \equiv \frac{B_{t+1}(h)}{P_t}$ and $b_{*t+1} \equiv \frac{B_{*,t+1}(h)}{P_t^*}$ are the real holdings of EME and RoW bonds, and $rer_t \equiv \frac{S_tP_t^*}{P_t}$ is the consumption-based real exchange rate (units of EME consumption per unit of RoW). We omit the transversality conditions for bond holdings.

[22] As discussed in model solution, we solve the model using higher-order approximation methods and these rely on taking approximations around a deterministic steady state. In the absence of adjustment costs, this would imply indeterminacy of the steady-state net foreign assets and nonstationarity. $\eta > 0$ is sufficient to uniquely pin down the steady state. We acknowledge that local solutions around this arbitrary steady state do not perform well at capturing precautionary savings relative to global methods, as shown by de Groot et al. (2019). The standard curse of dimensionality prevents us from employing global methods for our model's solution.

The Euler equations above imply the no-arbitrage condition:

$$\frac{R_t}{R_t^*} = \frac{\mathbb{E}_t[\frac{\beta_{t,t+1}}{\Pi_{t+1}^*}\frac{rer_{t+1}}{rer_t}] - \eta b_{*,t+1}}{\mathbb{E}_t[\frac{\beta_{t,t+1}}{\Pi_{t+1}}] - \eta b_{t+1}}.$$

If it were $\eta = 0$ and if we log-linearized the model around a conveniently chosen steady state with zero foreign bond holdings, this equation would reduce to the standard UIP condition. As discussed earlier, the role of η will be to ensure that zero international bond holding is the unique non-stochastic steady state of the model. In Section 5, we show that calibration of η does not affect the qualitative features of our results but there are quantitative implications. Irrespective of the choice of η , our experiments with volatility shocks and the solution method of the model will imply that there will be deviations from UIP due to a time-varying risk component.

The Euler equations for accumulation of capital used in EME and RoW production of intermediate goods are:

$$1 = \mathbb{E}_t\left[\beta_{t,t+1}\left(r_{K,t+1} + 1 - \delta\right)\right], \tag{8}$$

$$1 = \mathbb{E}_t\left[\beta_{t,t+1}\frac{rer_{t+1}}{rer_t}\left(r_{K_*,t+1} + 1 - \delta\right)\right], \tag{9}$$

with the real prices of each type of capital being:

$$q_t = 1, \tag{10}$$

$$q_{*t} = rer_t. \tag{11}$$

Equations (9) and (11) imply that the EME households' investment in capital that will go into RoW production is not only dependent on the rental rate but also on the fluctuations of the real exchange rate. The benefit of an additional unit of new capital that will be used in foreign production is the present discounted stream of the extra profits earned (marginal products). Equation (11) says that the price of capital that is installed abroad is equal to the real exchange rate.[23]

The first-order-condition with respect to $W_t(h)$ implies that the real wage, $w_t \equiv \frac{W_t}{P_t}$, is a time-

[23] Analogously, the price of physical capital rented to EME firms by RoW agents is $q_t^* = \frac{1}{rer_t}$.

varying markup over the first-order-condition of disutility from labor:

$$w_t = \mu_t^W \left(\chi L_t^{\varphi}\right), \tag{12}$$

where we used the fact that $W_t(h) = W_t$ in the symmetric equilibrium, and μ_t^W is defined by:

$$\mu_t^W \equiv \frac{\epsilon_W}{(\epsilon_W - 1)\left(1 - \frac{\kappa^W}{2}(\Pi_t^W - 1)^2\right) + \kappa^W\left(\Pi_t^W(\Pi_t^W - 1) - \mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}(\Pi_{t+1}^W - 1)(\Pi_{t+1}^W)^2\frac{L_{t+1}}{L_t}\right]\right)},$$

with $\Pi_t^W \equiv \frac{w_t}{w_{t-1}}\Pi_t$ being the gross nominal wage inflation. Markup movements in response to shocks are a familiar source of inefficient output fluctuations in New Keynesian models.

3.2 Firms

Output of final goods in the economy, Y_t, is produced by aggregating a bundle of differentiated intermediate EME goods, indexed by $i \in [0,1]$, along with a bundle of differentiated intermediate RoW goods, indexed by $j \in [0,1]$. The aggregation technology is:

$$Y_t = \left(a^{\frac{1}{\omega}} Y_{E,t}^{\frac{\omega-1}{\omega}} + (1-a)^{\frac{1}{\omega}} Y_{R,t}^{\frac{\omega-1}{\omega}}\right)^{\frac{\omega}{\omega-1}},$$

where $Y_{E,t} = \left(\int_0^1 Y_{E,t}(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}$ represents an aggregate of the EME intermediate goods sold domestically, $Y_{R,t} = \left(\int_0^1 Y_{R,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}}$ is an aggregate of the imported RoW goods, and $a \in (0,1)$. In the RoW economy, the share parameter a is attached to the aggregate of RoW intermediate goods sold domestically. The assumption $a > \frac{1}{2}$ thus ensures home bias in the composition of final output.

Producers of the final goods are perfectly competitive and demand inputs of the EME and RoW bundles according to:

$$Y_{E,t} = a\left(\frac{P_{E,t}}{P_t}\right)^{-\omega} Y_t, \tag{13}$$

$$Y_{R,t} = (1-a)\left(\frac{P_{R,t}}{P_t}\right)^{-\omega} Y_t, \tag{14}$$

where $P_{E,t}$ and $P_{R,t}$ are nominal prices of the aggregate of EME intermediate goods sold domestically and the aggregate of intermediate goods imported from RoW. The EME aggregate price index, P_t, is therefore determined by:

$$P_t = \left(a P_{E,t}^{1-\omega} + (1-a) P_{R,t}^{1-\omega} \right)^{\frac{1}{1-\omega}}. \tag{15}$$

Each differentiated intermediate EME good $i \in [0,1]$ is produced by using capital rented from EME households, $K_t(i)$, capital rented from RoW households, $K_t^*(i)$, and the bundle of labor inputs supplied by the EME households, $L_t(i)$:

$$Y_{E,t}(i) + \left(\frac{1-n}{n} \right) Y_{E,t}^*(i) = K_t(i)^{\alpha_1} K_t^*(i)^{\alpha_2} L_t(i)^{1-\alpha_1-\alpha_2},$$

where $\frac{1-n}{n} Y_{E,t}^*(i)$ is the amount of EME intermediate good i exported to RoW, and α_1, α_2 and $\alpha_1 + \alpha_2 \in (0,1)$.[24]

The producer of each differentiated intermediate EME good is monopolistically competitive and faces demand curves for its domestically sold product, $Y_{E,t}(i) = \left(\frac{P_{E,t}(i)}{P_{E,t}} \right)^{-\epsilon} Y_{E,t}$, and for its product sold in the RoW, $Y_{E,t}^*(i) = \left(\frac{P_{E,t}^{*e}(i)}{S_t P_{E,t}^*} \right)^{-\epsilon} Y_{E,t}^*$, where $P_{E,t}(i)$ is the nominal price of domestically sold EME good i, and $P_{E,t}^{*e}(i)$ is the domestic currency price of the exported good i, with the price in the foreign market being $P_{E,t}^*(i) = \frac{P_{E,t}^{*e}(i)}{S_t}$. Finally, $P_{E,t} = \left(\int_0^1 P_{E,t}(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}$ is the nominal price of the bundle of domestically sold EME intermediate goods, and $P_{E,t}^* = \left(\int_0^1 P_{E,t}^*(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}$ is the nominal foreign currency price of the exported bundle.

Let $r_{K^*,t}$ be the rental price of the capital rented from RoW households. The real marginal cost of producing the intermediate EME good is:

$$mc_t = \frac{w_t^{1-\alpha_1-\alpha_2} r_{K,t}^{\alpha_1} \left(r_{K^*,t} \right)^{\alpha_2}}{(1-\alpha_1-\alpha_2)^{1-\alpha_1-\alpha_2} \alpha_1^{\alpha_1} \alpha_2^{\alpha_2}}. \tag{16}$$

Firms in both EME and RoW set export prices in RoW currency. The monopolistic EME producer i sets the prices $P_{E,t}(i)$ and $P_{E,t}^*(i)$ and chooses factor demands to maximize expected discounted profits:

[24] A three-input Cobb-Douglas production function implies RoW capital and domestically produced capital are neither substitutes nor complements. Under a general CES function $f(x,y,z) = \left(\alpha_1 x^b + \alpha_2 y^b + (1-\alpha_1-\alpha_2) z^b \right)^{1/b}$, it refers to the case with $b = 0$.

$$\mathbb{E}_t\left[\sum_{s=t}^{\infty}\beta_{t,t+s}\left(\begin{array}{c}\left(1-\frac{\kappa}{2}\left(\frac{P_{E,t+s}(i)}{P_{E,t+s-1}(i)}-1\right)^2\right)\frac{P_{E,t+s}(i)}{P_{t+s}}Y_{E,t+s}(i)\\ +\ \left(\frac{1-n}{n}\right)\left(1-\frac{\kappa^*}{2}\left(\frac{P^*_{E,t+s}(i)}{P^*_{E,t+s-1}(i)}-1\right)^2\right)\frac{S_{t+s}P^*_{E,t+s}(i)}{P_{t+s}}Y^*_{E,t+s}(i)\\ -mc_t\left(Y_{E,t+s}(i)+\left(\frac{1-n}{n}\right)Y^*_{E,t+s}(i)\right)\end{array}\right)\right],$$

where the quadratic terms are costs of price adjustment, subject to the demand equations $Y_{E,t}(i) = \left(\frac{P_{E,t}(i)}{P_{E,t}}\right)^{-\epsilon} Y_{E,t}$ and $Y^*_{E,t}(i) = \left(\frac{P^{*e}_{E,t}(i)}{S_t P^*_{E,t}}\right)^{-\epsilon} Y^*_{E,t}$ in each period.

From the first-order conditions with respect to $P_{E,t+s}(i)$ and $P^*_{E,t+s}(i)$ evaluated at the symmetric equilibrium, we obtain the real price of EME output for domestic sales ($i.e.\ rp_E \equiv \frac{P_E}{P}$) as a time-varying markup, $\mu_{E,t}$ over marginal cost:

$$rp_{E,t} = \mu_{E,t} mc_t, \tag{17}$$

and the real price of EME output for export sales (in units of RoW consumption, $i.e.\ rp^*_E \equiv \frac{P^*_E}{P^*}$) as a time-varying markup, $\mu^*_{E,t}$, over marginal cost:

$$rp^*_{E,t} = \mu^*_{E,t}\frac{mc_t}{rer_t},$$

where

$$\mu_{E,t} \equiv \frac{\epsilon}{(\epsilon-1)\left(1-\frac{\kappa}{2}(\Pi_{E,t}-1)^2\right)+\kappa\left(\Pi_{E,t}(\Pi_{E,t}-1)-\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}(\Pi_{E,t+1}-1)(\Pi_{E,t+1})^2\frac{Y_{E,t+1}}{Y_{E,t}}\right]\right)},$$

$$\mu^*_{E,t} \equiv \frac{\epsilon}{(\epsilon-1)\left(1-\frac{\kappa^*}{2}(\Pi^*_{E,t}-1)^2\right)+\kappa^*\left(\Pi^*_{E,t}(\Pi^*_{E,t}-1)-\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi^*_{t+1}}(\Pi^*_{E,t+1}-1)(\Pi^*_{E,t+1})^2\frac{rer_{t+1}}{rer_t}\frac{Y^*_{E,t+1}}{Y^*_{E,t}}\right]\right)}.$$

with $\Pi_{E,t} \equiv \frac{rp_{E,t}}{rp_{E,t-1}}\Pi_t$ and $\Pi^*_{E,t} \equiv \frac{rp^*_{E,t}}{rp^*_{E,t-1}}\Pi_t$.

Given the cost of adjusting prices in domestic and export markets, firms must move their markups to smooth price changes over time.

3.3 Aggregate Accounting and Net Foreign Assets

Under symmetric equilibrium, we also have:

$$Y_{E,t} + \left(\frac{1-n}{n}\right) Y^*_{E,t} = K_t{}^{\alpha_1} K_t^{*\alpha_2} L_t{}^{1-\alpha_1-\alpha_2}, \tag{18}$$

where $K_t = \int_0^1 K_t(i)di$, $K^*_t = \int_0^1 K^*_t(i)di$, and $L_t = \int_0^1 L_t(i)di$. Cost minimization implies:

$$\alpha_1 w_t L_t = (1-\alpha_1-\alpha_2)\, r_{K,t} K_t, \tag{19}$$

$$\alpha_2 r_{K,t} K_t = \alpha_1 r_{K^*,t} K^*_t. \tag{20}$$

Hence, the trade-off between domestic capital, RoW capital, and labor inputs depends on the relative cost of each.

Market clearing requires that final production net of the costs of adjusting nominal wages and prices equals consumption plus the investment received from EME and RoW agents:

$$Y_t = C_t + I_t + I^*_t + \frac{\kappa^W}{2}\left(\Pi^W_t - 1\right)^2 w_t L_t + \frac{\kappa}{2}\left(\Pi_{E,t} - 1\right)^2 rp_{E,t} Y_{E,t} + \left(\frac{1-n}{n}\right)\frac{\kappa^*}{2}\left(\Pi^*_{E,t} - 1\right)^2 rp^*_{E,t} Y^*_{E,t}. \tag{21}$$

Finally, bonds are in zero net supply, which implies $b_{t+1} + b^*_{t+1} = 0$ and $b^*_{*,t+1} + b_{*,t+1} = 0$ in all periods. The lump sum transfer of bond adjustment costs to the household is $T_t = \frac{\eta}{2}\left[P_t(\frac{B_{t+1}(h)}{P_t})^2 + S_t P^*_t(\frac{B_{*,t+1}(h)}{P^*_t})^2\right]$.

We show in Appendix B that EME net foreign assets are determined by:

$$\begin{aligned} &\tfrac{b_{t+1}}{R_t} + rer_t \tfrac{b_{*,t+1}}{R^*_t} + \left(\tfrac{1-n}{n}\right) rer_t K_{*,t+1} - K^*_{t+1} \\ &= \tfrac{b_t}{\Pi_t} + \tfrac{rer_t b_{*,t}}{\Pi^*_t} + \left(\tfrac{1-n}{n}\right) rer_t \left(r_{K,*,t} + 1 - \delta\right) K_{*,t} - \left(r^*_{K,t} + 1 - \delta\right) K^*_t + TB_t, \end{aligned} \tag{22}$$

where the trade balance is: $TB_t \equiv \left(\frac{1-n}{n}\right) \mu^*_{E,t} mc_t Y^*_{E,t} - rer_t \mu_{R,t} mc^*_t Y_{R,t}$.

The law of motion for net foreign assets above differs from those in standard open-economy models by the terms that indicate the stock of physical capital received from the RoW, net of the physical capital installed into the RoW, and the terms that indicate the respective rental gains from this transaction. The change in net foreign assets between t and $t+1$ is determined by the current account, CA_t:

$$\underbrace{(b_{t+1} - b_t) + rer_t\,(b_{*,t+1} - b_{*,t})}_{\text{Bond component, } CA^{Bond}} + \underbrace{\left(\frac{1-n}{n}\right) rer_t\,(K_{*,t+1} - K_{*,t}) - \left(K^*_{t+1} - K^*_t\right)}_{\text{FDI component, } CA^{FDI}} \equiv CA_t,$$

As indicated under the brackets, the current account is decomposed into a short-term bond flows component and an FDI flows component.

3.4 Monetary Policy

The central bank in EME sets the nominal interest rate according to a Taylor rule that reacts to inflation, output, and fluctuations in nominal exchange rate. The interest rate rule also displays stochastic volatility:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho} \left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho)\rho_\Pi} \left(\frac{Y_t}{Y}\right)^{(1-\rho)\rho_Y} \left(\frac{S_t}{S_{t-1}}\right)^{(1-\rho)\rho_S} e^{u_t}, \tag{23}$$

in which ρ is a smoothing parameter that captures gradual movements in interest rates, and the parameters ρ_Π, ρ_Y, and ρ_S denote the responsiveness of the nominal interest rate to deviations of inflation, output, and change in nominal exchange rate from their steady-state values. This extended Taylor rule is frequently used in the literature that focuses on major emerging markets (Chertman et al. (2020)). We assume that RoW central bank follows a more standard Taylor rule reacting to inflation and output deviations without being augmented by any shocks.[25]

The monetary policy shock, u_t, represents discretionary deviations from the rule-based policy, including the EME central bank's reactions to capital flows. We allow this term to incorporate time-varying volatility in the form of stochastic volatility.[26]

The monetary policy shock, u_t, follows an $AR(1)$ process:

$$u_t = \rho^u u_{t-1} + e^{\sigma_{t-1}} \varepsilon_t, \tag{24}$$

where ε_t is a normally distributed shock with zero mean and unit variance. Moreover, the standard

[25] In Section 6, we provide results with the standard Taylor employed in EME as well.

[26] Introducing stochastic volatility in this fashion can be interpreted as uncertainty about deviations from the rule-based policy.

deviation, σ_t, follows an $AR(1)$ process:

$$\sigma_t = (1-\rho^\sigma)\sigma + \rho^\sigma \sigma_{t-1} + \eta_\sigma \varepsilon_t^\sigma, \tag{25}$$

where ε_t^σ is a normally distributed shock with zero mean and unit variance. We call this shock as interest rate stochastic volatility (SV) shock. The parameter σ controls the mean volatility of the exogenous component in the Taylor rule. A positive shock to the volatility implies that the distribution of disturbances to u_t are flatter and wider.

3.5 Summary

Table 1 summarizes the key equilibrium conditions of the model. Equations ((2), (3), (6), (7), (8), (9), (12), (13), (14), (15), (16), (17), (42), (18), (19), (20), (21), (23)) and their RoW counterparts, together with the net foreign asset condition in equation (22), determine 37 endogenous variables of interest: (Y_t, C_t, I_t, I_{*t}, K_t, $K_{*,t}$, L_t, $Y_{E,t}$, $Y^*_{E.t}$, mc_t, $rp_{E,t}$, $rp^*_{E,t}$, w_t, $r_{K,t}$, $r_{K,*,t}$, b_t, R_t, Π_t) and their foreign counterparts, and rer_t. The auxiliary variables and exogenous processes are described above.

4 Model Calibration and Simulations

In this section, we calibrate our model to examine the effects of changes in emerging market economy policy rate stochastic volatility. We study the impact of policy rate stochastic volatility on the cross-country risk-sharing wedge and its transmission channels in affecting the composition of capital inflows. We also study the implications of introducing movements in policy rate stochastic volatility as a feedback rule.

4.1 Calibration

The model is calibrated using literature on emerging markets and based on our VAR evidence. Table 2 summarizes the calibration.

We set the discount factor, β, to 0.9914, which implies a steady state real interest rate of 3.5% per annum. Magud and Tsounta (2012) provide estimation of the natural rate for several emerging market economies and their values range between 2% and 5%. We use the average of their estimates. Relative risk aversion, γ, is set to 2 and relative weight of labor in the utility function, χ, is set to 1 as in Dvorkin et al. (2020), among others. The inverse of the Frisch elasticity is set to 3.79, which is within the range of the values used in the open economy New Keynesian literature, such as Akinci and Queralto (2020), Arellano et al. (2020), and Galí and Monacelli (2015). We set the scale parameter for the costs of adjusting bond holdings, η, to 0.0025 as in Ghironi and Melitz (2005). A strictly positive value of η pins down the non-stochastic steady state and ensures mean reversion. In Section 6, we also conduct experiments with $\eta = 0.00025$ and show that our results in this section are not affected from this parameterization.[27]

Parameters related with nominal rigidities are also set according to the values used in open economy New Keynesian literature with applications to emerging markets. Rotemberg adjustment parameters for price and wage stickiness are set to the values that would replicate the slopes of the Phillips curves derived using one-year Calvo stickiness in a linearized setup, which is the case in Akinci and Queralto (2020), Arellano et al. (2020), and Galí and Monacelli (2015).[28] This implies $\kappa^W = 2513$ and $\kappa = \kappa^* = 237.48$ when $\epsilon^W = \epsilon = 21$. The latter implies that wage and price markups are equal to 5% when wages or prices are flexible.[29]

For the parameters that are related to producer optimization, we set the home bias in final production to 0.65 which is the average of the values employed in the literature (see Cook (2014), Elekdag and Tchakarov (2007), Gertler et al. (2007), Unsal (2013) among others) The shares of domestic and foreign capital in intermediate goods productions, α_1 and α_2, to 0.30 and 0.15, as in Aoki et al. (2015). The elasticity of substitution between EME and RoW produced traded goods, ω, is set to 1.2 as in Ghironi (2006), among others.[30]

Regarding our choice of parameters in the EME Taylor rule, we set the smoothing coefficient, ρ, the responsiveness to inflation, ρ_Π, the responsiveness to output, ρ_Y, and the responsiveness to nominal exchange rate fluctuations to 0.7, 1.5, 0.5/4, and 0.03 respectively. These values are suggested in Chertman et al. (2020) who also cover EMEs. Similar values are also used by Benigno

[27]There is, however, a quantitative effect on welfare results.

[28]The same assumption is also made in Fernández-Villaverde et al. (2015) who experiment with fiscal volatility shocks in a closed economy New Keynesian model.

[29]There is no consensus on the values of ϵ and ϵ^W in the literature. We use the calibration used in Fernández-Villaverde et al. (2015). Their discussion verifies that these parameters are not precisely identified.

[30]Values between 1 and 1.5 are common in the international real business cycle literature.

et al. (2012), who study volatility shocks in an open economy New Keynesian model.

The parameters in the RoW preference shock are calibrated by using the preference shock calibration of Basu and Bundick (2017). They calibrate the shock process using the Chicago Board Options Exchange Volatility Index (VXO), which measures S&P 100's expected volatility. Therefore, we set the persistence of the level shock, ρ^{ϑ}, to 0.936, mean volatility of the level shock to 0.3 percentage points ($100e^{-5.81}$), persistence of the stochastic volatility process, $\rho^{\sigma^{\vartheta}}$, to 0.742, and the standard deviation of the stochastic volatility shock to 0.003.

With regards to the shock process in EME interest rate, we set the persistence of the level shock, ρ^{u}, to 0.95 which is within range provided by Fernández-Villaverde et al. (2011) for the persistence of interest rate spread shocks in emerging markets. We parameterize the second-moment shock to EME interest rate based on our VAR evidence. In our Bayesian panel VAR, a one standard-deviation shock to the interbank rate volatility raises the interbank rate volatility by 0.347 units relative to the sample mean of 0.62. Thus, the shock raises the measure of interest rate volatility by 55.9 percent relative to its mean, i.e., $\eta_{\sigma} = 0.559$. The VAR evidence in Section 2 also shows that the effects volatility shocks gradually decrease over time. Specifically, in 4 quarters, interbank rate volatility falls to 29.6 percent of its weak. This implies that the persistence of the interest rate volatility shock, ρ^{σ}, is 0.738, if the volatility shock is approximated by an AR(1) process, i.e., $(0.738)^4 \approx 0.296$.

4.2 Solution Method

We solve the model by using third-order perturbation techniques.[31] As highlighted by Kim et al. (2008), solutions that use higher-order perturbation techniques tend to yield explosive time-paths due to the accumulation of terms of increasing order. To overcome this problem, Andreasen et al. (2013) use pruning of all higher order terms, and we integrate their method in our simulations.

Moreover, higher-order approximation solutions move the ergodic distribution of the model's endogenous variables away from their non-stochastic steady-state values (Fernández-Villaverde et al. (2011)). Therefore, calculating impulse responses from the non-stochastic steady state is not

[31] A first-order approximation would deliver certainty equivalence and would neglect higher-order effects. A second-order approximation would not make it possible to study the direct effects of a volatility change, as the model solution would include cross-products of exogenous volatility and level variables. Hence, a third-order approximation of the model is needed to single out the individual effects of volatility shocks (Fernández-Villaverde et al. (2011)).

informative. To overcome this difficulty, we follow the literature and calculate the impulse responses as deviations from the stochastic steady-state levels of the endogenous variables. In defining the stochastic steady state, we follow Born and Pfeifer (2014b) and Fernández-Villaverde et al. (2011), and we characterize it as the fixed point of the third-order approximated policy functions in the absence of shocks.[32]

4.3 Experiments

We study how preference SV shocks and interest rate SV shocks affect capital inflows that induce an international risk-sharing wedge. We also analyze the channels of transmission and propagation of interest rate SV shocks and identify the repercussions when it is used as a policy tool against RoW shocks that induce capital inflows into EME.

4.3.1 Capital Flows and the International Risk-Sharing Wedge

As an initial step in our analysis, we define a time-varying wedge in the traditional risk sharing condition that would tie the real exchange rate to the ratio of the marginal utilities of consumption across the border:

$$1 = \mu_{t+1}^{RS} \frac{U_{C^*,t}}{U_{C,t} rer_t}, \tag{26}$$

where $\mu_{t+1}^{RS} \equiv \frac{\mathbb{E}_t\left[\frac{U_{C,t+1}}{\Pi_{t+1}}\right] - \eta b_{t+1} U_{C,t}}{\mathbb{E}_t\left[\frac{U_{C^*,t+1}}{\Pi_{t+1} rer_{t+1}}\right] - \frac{\eta b_{t+1}^* U_{C^*,t}}{rer_t}}$.

Under complete markets, the ratio of the marginal utilities of consumption of RoW and EME agents would be equal to the real exchange rate in all histories and at all dates, implying extensive risk sharing in terms of marginal utility and a value of 1 for μ_{t+1}^{RS}. Under incomplete markets, shocks (including stochastic volatility shocks) induce fluctuations in μ_{t+1}^{RS} that depart from 1 in the short run and cause fluctuations in the real exchange rate that differ from those under complete markets. Departure from complete-market real exchange rate movements implies discrepancies in calculating the current and future values of income, and therefore, distortions in valuation of wealth.[33] Hence,

[32]This is the point in which agents choose to remain while taking future uncertainty into account. Hence, this method allows us to study the effects of an increase in the uncertainty of the future path of the interest rate without imposing any changes in the realized volatility of the interest rate *per se*.

[33]See Costinot et al. (2014) and Corsetti et al. (2018) for an extensive discussion.

the allocation of wealth across countries deviates from the complete market allocation and becomes inefficient due to movements in relative prices that are not internalized by the agents across the border.

To assess the impact of stochastic volatility shocks, we generate dynamics with one-standard-deviation shocks to the stochastic volatility processes of the RoW preference shock and the EME interest rate shock. Figure 6 plots the impulse responses of EME to a RoW preference SV shock and Figure 7 plots the impulse responses to an EME interest rate SV shock. The RoW preference SV shock triggers an inflow of capital into EME through changes in bond holdings of the agents and an outflow of capital in terms of changes in FDI.[34] Our interpretation for the RoW preference SV shock is an increase in the demand uncertainty of RoW agents.[35] The global financial crisis period exhibits significant movements in risk premia and our interpretation comes from the studies that link capital flows with movements in risk (*e.g.,* VIX) during this episode (see di Giovanni et al. (2017) and Rey (2013)). Inflows in the bond component generate a boom in consumption, investment, and output in EME. Increase in consumption pushes inflation up. With an increase in demand uncertainty in RoW, demand on EME exports go down. EME exporters lower their markups when exports are priced and sticky in the RoW currency. Lower exporter markups induce an exchange rate depreciation. The magnitude of depreciation is small because it offsets the opposite effect of declining wages on the real exchange rate. The risk-sharing wedge goes down due to the consumption boom in EME in response to capital inflows.

Figure 7 shows that dynamics in response to the EME interest rate SV shock are starkly different. First of all, EMEs display high stochastic volatility in interest rates and therefore the magnitudes of fluctuations are larger. An EME interest rate SV shock generates a drop in output, an increase in inflation, an outflow in the bond component of the current account and an inflow in the FDI component. Domestic markups go up and exporter markups go down. We explain in detail below why markups behave in this way. Absent wealth effects, real wages increase but the movement is small. Importantly, the risk-sharing wedge goes up in response to an increase in

[34]The bond component of the current account goes into negative territory, which implies inflows for the financing of the current account deficit through this component. The opposite happens for the FDI component of the current account.

[35]The size of this shock is not central to our analysis. The purpose is to derive capital inflows into the EME. The response of EME policy rate SV to capital flows will be clearer when we introduce it as a policy rule in the next subsection.

EME interest rate SV due to fall in EME consumption. The impulse responses suggest that the fluctuations in the risk-sharing wedge can be dampened in response to capital inflows that are a result of RoW preference SV shocks. We examine a related scenario in the next subsection.

We also plot the variables which are empirical counterparts of the BVAR in Figure 3 (in this figure, we define the exchange rate in EME consumption units–to be consistent with its empirical counterpart–, whereas the analysis in the model section defines it in RoW consumption units). The DSGE model and the VAR are qualitatively consistent. Quantitatively, the model exaggerates the movements in the current account and generates smaller responses for prices (our model misses many frictions in the conventional DSGE framework that would increase its quantitative fit, such as multiple lags in investment, variable capital utilization, inflation indexation, etc.).

4.3.2 Interest Rate Uncertainty as a Policy Tool (IRUPT)

Figures 6 and 7 show that μ_{t+1}^{RS} moves in opposite directions in response to two shocks that we have studied above. The next step is examining the ability of interest rate SV in improving risk-sharing across the border and an assessment of varying policy trade-offs while using it as a policy tool. We conduct the following exercise: we generate dynamics with a one-standard-deviation increase in the RoW preference SV shock (*i.e.*, $\sigma_t^{\vartheta *}$) and we replace equation (25) with the following feedback rule:

$$\sigma_t = \sigma + \iota^{\sigma}(\sigma_t^{\vartheta *} - \sigma^{\vartheta *}), \tag{27}$$

where ι^{σ} determines the intensity of the response of EME interest rate volatility to the bond component of the current account. Hence, this rule can be thought of as adjusting the size of the EME interest rate corridor to generate more volatility in EME interest rates in response to spikes in volatility in the RoW, similar to those like VIX. Figure 8 plots the responses to a one-standard deviation increase in RoW preference SV shock when interest rate uncertainty is used as a policy tool (IRUPT). Solid purple lines indicate the responses when $\iota^{\sigma} = 0$ and replicates the responses in Figure 6. Solid blue lines plot the responses with feedback parameter, ι^{σ}, equal to 0.2. Dashed blue lines indicate the responses when $\iota^{\sigma} = 0.3$ and dotted blue lines are generated after setting $\iota^{\sigma} = 0.4$.

As predicted by the dynamics available in Figures 6 and 7, we observe that increasing the volatility of interest rate shocks in response to an increase in RoW preference SV shocks shifts capital inflows into FDI and discourages bond inflows while lowering the increase in consumption and decreasing output. The shift in the current account financement indicates that EME households smooth consumption using RoW bonds in response to EME interest rate SV shock. The change in the direction of consumption fluctuations imply that movements in the risk-sharing wedge may change direction as the response of EME interest rate volatility gets larger (i.e., ι^{σ} gets larger). Future uncertainty on marginal costs forces firms to set higher prices of production for the domestic market, leading to amplification in domestic price markups. However, markups in the export market move in the opposite direction. We observe that fluctuations in price markups become more pronounced if the response of EME interest rate volatility becomes larger. As we explain below, the behavior of markups in the export market is closely related to the degree of exchange rate pass-through. Markups move because prices do not fully accommodate the changes in demand that occur under price rigidities. Markups also move due to the asymmetric shape of the profit function with respect to prices. Rising prices of goods consumed at home contribute to an increase in inflation.

From here onwards, unless otherwise indicated, for clarity of our analysis we focus on the sole effect of EME interest rate SV shock (instead of IRUPT being put in place in response to RoW preference SV shocks).

4.3.3 Decomposition of Risk in the Rest of the World Investor Portfolio

How does an increase in EME interest rate SV affect the RoW investors' portfolio? To further understand the effects of EME interest rate SV shocks, we investigate the movements in the risk premia in the RoW portfolio. Objects of interest are the expected relative excess returns between the EME and RoW assets that the RoW investor is holding. More precisely, consider the following relationships:

$$x_{t+1}^{B^*,B^*_*} \equiv \hat{r}_{t+1} - \hat{r}^*_{t+1} - \hat{s}_{t+1} + \hat{s}_t, \tag{28}$$

$$x_{t+1}^{K^*,K^*_*} \equiv \hat{r}_{K^*,t+1} - \hat{r}_{K^*_*,t+1} - r\hat{e}r_{t+1} + r\hat{e}r_t, \tag{29}$$

$$x_{t+1}^{B^*,K^*} \equiv \hat{r}_{t+1} - \hat{\pi}_{t+1} - \hat{r}_{K^*,t+1}. \tag{30}$$

The lowercase hatted variables are the percentage deviations of the respective variables from their non-stochastic steady state.[36] Certainty equivalence would imply that $\mathbb{E}_t\left[x^{B^*,B^*_*}_{t+1}\right] = \mathbb{E}_t\left[x^{K^*,K^*_*}_{t+1}\right] = \mathbb{E}_t\left[x^{B^*,K^*}_{t+1}\right] = 0$. However, given the non-linear solution of our model, endogenous fluctuations in higher-order terms lead to nonzero expected relative excess returns.[37] These terms are also nonzero (but small) when evaluated at the stochastic steady state, because the agents are taking future uncertainty into account.

Figure 9 shows the responses of the relative excess returns from their stochastic steady-state levels. We observe that the relative excess return between EME and RoW bonds decreases in response to an increase in EME interest rate SV. EME interest rate SV shock and the downturn generated by it makes EME households shift away from EME bonds. Because domestic bonds are in zero net supply, this means that RoW investors increase their EME bond holdings. However, this effect is offset by the depreciation in exchange rate (from EME perspective), reducing the return of EME bond.

The fluctuations in exchange rate affect FDI in a different manner. Depreciation (an increase in exchange rate) pushes the price of EME physical capital down (*i.e.* $q^*_t = \frac{1}{rer_t}$), increasing the associated returns with it. This is being reflected as an increase in the relative excess return of EME physical capital. Hence, we observe inflows of FDI into EME. Finally, we observe a fall in the relative excess return of EME bonds with respect to EME physical capital. With EME inflation becoming more volatile, a more volatile interest rate provides a better hedge against inflation risk.

To provide more intuition for the discouragement of bond flows into the EME, we use the assumption of log-normality to express the relative excess return between EME and RoW bonds as follows:[38]

$$\mathbb{E}_t\left[x^{B^*,B^*_*}_{t+1}\right] \approx -\frac{1}{2}\mathbb{V}ar_t(\Delta s_{t+1}) + \mathbb{C}ov_t(m^*_{t+1}, \Delta s_{t+1}), \tag{31}$$

Lowercase letters in the relations above denote logs of the respective variables. If a variable was

[36] The only exception is that $\hat{r}_{K,t+1} \equiv \frac{R_{K,t+1}-R_K}{R_K}$ where $R_{K,t+1} \equiv r_{K,t+1} + 1 - \delta$.

[37] There are several studies related to our analysis here. Among others, **?** and Itskhoki and Mukhin (2019) highlight the role of the financial sector in the movements of relative excess returns. Engel (2016) introduces long-run risk, Farhi and Gabaix (2016) and Gourio et al. (2013) introduce disaster risk, and Verdelhan (2010) proposes a model with habit persistence to account for the movements in risk premia. In contrast, we investigate the relationship between excess returns in the workhorse international macro model, in response to an increase in the stochastic volatility of the interest rate.

[38] Appendix D provides detailed derivations of this relationship, in addition to relative excess returns between other assets in the RoW investor's portfolio.

denoted by a lowercase letter in Section 2, we use a tilde to denote the log of the original variable.[39] Equation (31) shows an increase in the volatility of EME currency affects the relative excess return negatively. Moreover, the covariance between the RoW investor's stochastic discount factor and the movements in exchange rate is negative, in response to an EME interest rate SV shock. The latter implies that RoW investor does not want to hold the EME bond because they are losing value after an exchange rate depreciation in EME in response to an increase in EME interest rate SV.

4.3.4 Transmission within the Emerging Market Economy

In this subsection, we investigate how IRUPT propagates within the EME through different channels.

Consumption Smoothing Motive

First, it is useful to note that the movement of risk premium in EME household portfolio between EME and RoW bonds moves similar to RoW agent's:

$$\mathbb{E}_t\left[x_{t+1}^{B,B_*}\right] \approx \frac{1}{2}\mathbb{V}ar_t(\Delta s_{t+1}) + \mathbb{C}ov_t(m_{t+1}, \Delta s_{t+1})$$

Negative covariance of EME household stochastic discount factor with the change in nominal exchange rate is a negative incentive for the EME agent to hold EME bonds while smoothing consumption. Therefore, EME agents shift away from EME bonds to RoW bonds in response to an EME interest rate SV shock. Intuition is simple. For smoothing consumption, EME agents want to use the less risky bonds and bond component of the EME current account exhibits outflows.

Precautionary Wage and Pricing Effects

Most of the variations in our model are due nominal rigidities and we disentangle their impact in this subsection. Figure 10 and 11 show impulse responses to an EME interest rate SV shock when wages and prices flexible, respectively. The transmission of EME interest rate SV shock is

[39] We omit the terms related to the costs of adjusting bond holdings when deriving these relations. Bacchetta and van Wincoop (2019) show that delayed portfolio adjustment through high portfolio adjustment costs can account for a broad range of puzzles in international finance.

quite different under these two scenarios, although EME still attracts FDI and generates outflows in the bond component of the current account.

First, under flexible wages, we observe that EME households consume less and work more in response to an increase in volatility. Firms demand more inputs, including physical capital and labor.[40] Figure 10 shows that wages go up instantaneously, because wages are flexible. With consumption declining and output expanding the effect of producer markups is limited on inflation, which translates into an exchange rate appreciation. When we focus on Figure 11, we observe the impact of labor demand under sticky wages. Firms are willing to increase the wages to expand labor, but because wages are sticky, wage markup goes down and the increase in wages is dampened. Firms invest more than they do under sticky prices because they can decrease the price to expand revenues. Absent price stickiness, the change in investment is more pronounced. Moreover, firms demand FDI from abroad and this is reflected in the FDI component of the current account. Risk-sharing wedge moves in opposite directions in Figures 10 and 11 due to different responses of consumption under each scenario.

We see that when exchange rate appreciates the exporter markup goes up, different than under the scenario when exchange rate depreciates. This is related with the precautionary pricing channel discussed in Fernández-Villaverde et al. (2015). They studied the behavior of markups in response to uncertainty shocks in a closed economy and showed that firms move their prices upwards because profits are asymmetric in terms of prices and increasing prices as a precautionary behavior minimizes the expected future loss of profits. In our model, exporter profits are asymmetric in terms prices, but also in terms of the real exchange rate. In Figure 12, we plot the non-stochastic steady-state exporter period profits abstracting from the adjustment costs, as in Fernández-Villaverde et al. (2015). The real exchange rate adds a dimension to their analysis. When exporters price their output in the currency of the export destination (local currency pricing), steady-state period profits can be written as:

$$rer\left(\frac{P_H^*}{P}\right)^{\epsilon}\left(\frac{P_H^*(i)}{P^*}\right)^{1-\epsilon}Y_H^* - \left(\frac{\epsilon-1}{\epsilon}\right)\left(\frac{P_H^*}{P^*}\right)^{\epsilon}\left(\frac{P_H^*(i)}{P^*}\right)^{-\epsilon}Y_H^*.$$

[40] One can ask whether the positive effect on investment is whether due to the reduction of consumption generating savings to boost investment or due to the increase in FDI inflows. The answer is the latter because EME interest rate goes down in response to policy rate a SV shock.

Panel A shows how steady-state period profits respond to changes in prices at several levels of the real exchange rate. The blue line coincides with the closed-economy case. When the real exchange rate is equal to 1, the profit function is asymmetric in the sense that an increase in prices yields less profit loss than a decrease in prices. And in response to uncertainty, firms increase their prices due to precautionary motives. This is true in our model for the producers producing for the domestic market, because fluctuations in exchange rates do not affect their prices. However, when the exchange rate is flexible, it might not be desirable for an exporter to increase prices. Figure 12 shows that decreasing prices is more profitable in response to depreciation of the real exchange rate, whereas increasing prices is more profitable in response to appreciation.[41]

Finally, we report the variances of macro and financial aggregates when we simulate the model with EME interest rate level and SV shocks. The first four rows of Table 3 reports the variances for the baseline model and for the model versions when prices or wages flexible. We calculate the variances by simulating our model versions 200 times for 400 periods with uncorrelated shocks. We calculate cyclical components of the simulations using a Hodrick-Prescott filter with scale parameter 1600. Then we calculate the standard deviation of each simulation and we average over the replications. We use the log values of output, consumption, labor and real exchange rate whereas the components of the current account are not in logs. Absent price or wage stickiness, standard deviations of macro variables are lower than in the baseline. Combined effect of rigidities generate more volatility on macro variables and the real exchange rate.[42]

5 Welfare Analysis

Having explored how stochastic volatility shocks transmit and propagate in our model, we now evaluate IRUPT in terms of welfare. When calculating welfare, we take a third-order approximation of both the model and the utility function. We calculate welfare as the expected present discounted value of utility:

$$V_t = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t(h), L_t(h))$$

[41]In Section 6, we show that the closed economy markup implications hold under producer currency pricing.

[42]We find that the standard deviation of the real exchange rate decreases for larger values of ι^{σ} in our simulations. This is related with Svensson (1991)'s argument that narrow exchange rate variability under target zones can create larger volatility for interest rates.

We report welfare in consumption equivalent units. It is important to remind the reader that our baseline model under IRUPT (subsection 4.3.2) has three shocks: RoW preference level shock, RoW preference SV shock, and EME interest rate level shock. We calculate welfare by simulating the model using third-order approximation with uncorrelated shocks for 400 periods starting from the non-stochastic steady state. We conduct 200 replications of these simulations and average the expected discounted value of utilities (i.e., V_t, V_t^*, and $nV_t + (1-n)V_t^*$) over simulations and replications to reach our welfare metric.[43]

We start with assessing the impact of RoW preference SV shock–in consumption equivalent terms–in our baseline model without IRUPT by comparing with a model version in which there are only RoW preference level and EME interest rate level shocks. In the second part of our analysis, we focus on IRUPT and the implications of the parameter, ι^σ, on welfare. Finally, we calculate a consumption compensation value for the agent to be indifferent between living under IRUPT vis-à-vis the benchmark in which there are no SV shocks. We calculate the consumption equivalence by finding the parameter, λ_c, that would equate the welfare under two scenarios:

$$V_t^{Alternative} = V_t^{Benchmark}(\lambda_c)$$

where

$$V_t^{Benchmark}(\lambda_c) = e^{\vartheta_t} \frac{\left((1+\lambda_c) C_t^{Benchmark} - \chi \frac{\left(L_t^{Benchmark}\right)^{1+\varphi}}{1+\varphi} \right)^{1-\gamma} - 1}{1-\gamma} + \beta V_{t+1}^{Benchmark}(\lambda_c).$$

Hence, $\lambda_c > 0$ indicates that "Alternative" scenario is improving the "Benchmark" scenario.

We start by comparing EME welfare in the following two settings: baseline model without IRUPT with RoW preference level, EME interest rate level shocks and the baseline model without IRUPT with RoW preference level, RoW preference SV, and EME interest rate level shocks. This implies that policy is only conducted by the Taylor rules described in the model section.It is known that Taylor rules respond well to inefficiencies that are results of fluctuations in price markups. Our baseline model features wage rigidities and incomplete international markets in addition to

[43]Taking long simulations and averaging over long simulations does not give the same result with our methodology. We follow the methodology suggested in Born and Pfeifer (2014b)

price rigidities and Taylor rule is not able to offset all these inefficiencies simultaneously (Corsetti et al. (2010) and Gali (2008)). Therefore, it might be desirable to consider IRUPT with a Taylor rule in affecting these inefficiencies.

Table 4 shows that the permanent consumption equivalent difference is reaching -.045% between model versions with and without RoW preference SV shocks. A negative value implies that the household is worse off in the model version with RoW preference SV shocks. Therefore, EME can introduce a policy, in addition to the Taylor rule, to ameliorate the welfare losses due to RoW preference SV shocks.

In the second part of our analysis, we calculate a consumption equivalent difference between model versions that has IRUPT (with the response parameter, $\iota^{\sigma} = 0.4$) and no IRUPT. Under the shocks that we consider, IRUPT responding only to RoW preference SV shocks can generate a 0.01% permanent consumption gain vis-a-vis no IRUPT, lowering the consumption equivalent difference from the benchmark scenario of absence of SV shocks, to -.035% (third row in Table 4). This implies that approximately 22% of the consumption loss that is a result of RoW SV shocks can be ameliorated with IRUPT responding to RoW preference SV shocks.

In our final analysis, we evaluate IRUPT in the model version with the three shocks we described above (*i.e.,* RoW preference level, RoW preference SV, and EME interest rate level shocks). First, in Figure 13, we plot the EME welfare numbers when we do a grid search over ι^{σ} for several interest rate uncertainty policy rules that respond to different variables.[44] Not all capital inflows are created equal: when IRUPT is designed to respond only to the RoW preference SV shocks, the rule is welfare improving for $\iota^{\sigma} \in (0, 0.73)$. The welfare gains peak around $\iota^{\sigma} = 0.4$. However, when IRUPT is designed to respond to RoW preference level shocks, or EME interest rate level shocks, it generates lower values than the model version that does not include IRUPT. We find that the source of capital inflows (whether they are due to level or SV shocks) is very important for IRUPT to be effective. We further look at several macro variables as natural candidates for IRUPT to target. However, the movements in the endogenous macro variables in the model are significantly driven by the level shocks when we simulate our model with both level and SV shocks to calculate the welfare.[45] Therefore, targeting endogenous macro variables, such as the bond inflows, leads to

[44]We plot the welfare when $\iota^{\sigma}$is moving between 0 and 1. Extending the grid for higher values of ι^{σ} does not change our results.

[45]It is required to hit the system with level shocks to be able to turn on the associated SV shocks.

lower welfare than targeting the SV shocks only.

We end this section by highlighting that although IRUPT can generate positive welfare gains when designed against RoW SV shocks, albeit the numbers are small.[46] We also find it important to highlight that drivers of capital inflows have different implications for recipient countries. In a broader policy context, designing IRUPT to respond to spikes in VIX vs. designing it to respond to macro variables such as bond inflows have opposite welfare consequences from the perspective of an open economy NK model.[47]

6 Additional Results

In this section, we discuss the effects of modifying our model in several directions. First, we study the effects of a tax on RoW bonds (capital controls) in our model and compare its implications with IRUPT. Second, we assess the effectiveness of IRUPT when capital flows are generated by RoW preference level shocks, rather than RoW preference SV shocks. Third, we show how our model would work if we introduced a Taylor rule in EME that does not respond to fluctuations in exchange rate. Fourth, we study the impact of bond adjustment cost parameter in generating our results. Fifth, due to the central role played by exchange rate pass-through in our results, we study the dynamics when firms engage in producer currency pricing. Sixth, we consider the implications of using Epstein-Zin-Weil preferences as commonly done in the macro-finance literature. Finally, we study IRUPT when there is an effective lower bound (ELB) in RoW interest rate setting; we do so because the recent episodes of large capital inflows into emerging economies coincided with periods of constrained conventional monetary policy in advanced economies. In appendices, we also introduce another extension in which we introduce a time-to-build requirement for the physical capital that will be used in overseas production. By doing so, we capture the long-run nature of FDI.

[46]This is in line with the previous literature that confirmed SV shocks generate smaller responses. Among others, see Born and Pfeifer (2014a).

[47]Some of the literature which uses preference SV shocks interprets them as spikes in VXO/VIX (e.g., Basu and Bundick, 2017).

6.1 Capital Controls

Capital controls have been studied in the literature in terms of their role as a prudential policy tool for smoothing aggregate demand. We assess whether a version of capital controls can affect the composition of capital inflows similar the way that IRUPT does. We modify the EME household's budget constraint as follows:

$$
\begin{aligned}
&P_tC_t(h) + \tfrac{B_{t+1}(h)}{R_t} + \tfrac{S_tB_{*,t+1}(h)}{R_t^*} + \tfrac{\eta}{2}P_t(\tfrac{B_{t+1}(h)}{P_t})^2 + \tfrac{\eta}{2}S_tP_t^*(\tfrac{B_{*,t+1}(h)}{P_t^*})^2 + P_tI_t(h) + S_tP_t^*I_{*,t}(h) \\
&\quad = B_t(h) + S_t(1-\tau_{t-1})B_{*,t}(h) + P_tr_{K,t}K_t(h) + S_tP_t^*r_{K,*,t}K_{*,t}(h) + W_t(h)L_t(h) \\
&\qquad - \tfrac{\kappa^W}{2}\left(\tfrac{W_t(h)}{W_{t-1}(h)} - 1\right)^2 W_t(h)L_t(h) + d_t(h) + T_t(h) + T_t^{\tau}(h).
\end{aligned}
$$

The new variables are highlighted in red. τ is a capital-inflow tax in EME and the proceeds from this tax are rebated back to EME households period by period.

With capital-inflow taxes in place, the international bond Euler equation of the EME household is modified accordingly:

$$
\frac{1}{R_t^*} = (1-\tau_t)\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}^*}\frac{rer_{t+1}}{rer_t}\right] - \eta b_{*,t+1}.
$$

We let τ_t to respond to the bond component of the current account with a response parameter ι^τ: $\tau_t = \iota^\tau\left(CA_t^{Bond} - \overline{CA}^{Bond}\right)$. In Figure 14, we plot impulse responses to a RoW preference SV shock when capital controls are in place and lack thereof. It is seen that capital controls work as intended by decreasing inflows in the bond component of the current account. Mildening the impact of capital inflows, consumption and inflation responds less than the case in which there is no capital control policy (but there is still a Taylor rule without stochastic volatility shocks). International risk-sharing wedge moves less with dampened fluctuations in consumption.

We highlight that we do not study optimal capital controls and their performance in comparison to IRUPT. It is furthermore important to note that our model does not feature any occasionally binding collateral or leverage constraints. Inclusion of large nonlinearities along these dimensions can change the relative impact of capital controls.[48]

[48]FX intervention is another type of policy that is used to ameliorate the disruptions in the FX market, and therefore, affects capital flows. The literature focuses on FX interventions' ability to overcome financial frictions that our model does not incorporate. However, changing the relative supply of currency and manipulating the real exchange rate can affect markups and the FDI, in our model.

6.2 Capital Flows Generated by RoW Preference Level Shock

In this subsection, we focus on the impact of RoW preference shock in generating inflows into EME. Purple lines in Figure 15 indicate impulse responses to a one-standard deviation decrease in the RoW preference level shock when EME Taylor rule does not exhibit stochastic volatility.[49] This shock makes RoW agents more impatient and in response to it, they increase consumption. Demand on EME exports rises and EME exporters want to lower their prices in response to an appreciation of exchange rate. Because prices are sticky, export prices stay higher than where they would stay under flexible prices and this pushes exporter markups up. Incoming FDI boosts production and prices fall due to an expansion in supply.

RoW preference level shock generates more amplified fluctuations than the RoW preference SV shock. It also generates an inflow in the bond component and an outflow in the FDI component of the current account. However, it is still possible for IRUPT to alter the composition of the capital account. We know that, in response to an increase in EME interest rate SV, export markup goes down and risk sharing wage goes up. This is the opposite of what is being generated by a RoW preference level shock. Hence, IRUPT can be effective in closing these margins. To see the impact of IRUPT, we simulate our model with $\sigma_t = \sigma - \iota^{\sigma}(\vartheta_t^* - \vartheta^*)$, with $\iota^{\sigma} = 4$ and $\iota^{\sigma} = 6$. Figure 15 shows that IRUPT affects the fluctuations in export price and risk-sharing wedge in the opposite direction, but amplifies the fluctuations in the price markup.

6.3 Standard Taylor Rule

We introduced a Taylor rule in EME that responds to fluctuations in output, inflation, and exchange rate. Although this type of Taylor rule is commonly suggested in the literature that focuses on EMEs, we study how a more standard Taylor rule impacts dynamics against capital inflows generated by RoW preference SV shocks:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho} \left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho)\rho_{\Pi}} \left(\frac{Y_t}{Y}\right)^{(1-\rho)\rho_{Y}}. \tag{32}$$

Figure 16 plots impulse responses. Purple lines indicate dynamics from the baseline model in which the Taylor rule is described by equation (23) and $\iota^{\sigma} = 0$. Blue lines show impulse responses

[49]This corresponds to $\iota^{\sigma} = 0$ as in our previous exercises.

from the model in which Taylor rule is described by equation (32). A Taylor rule responding to fluctuations to exchange rate performs better against RoW preference SV shocks in terms dampening the fluctuations in inefficient wedges. Bond inflows are dampened and fluctuations in all the distortions affecting EME (price, wage markups and international risk-sharing wedge) are dampened under the Taylor in the baseline model. Our analysis in the previous sections shows that IRUPT can still improve the better rule (the one that is also responding to the exchange rate) along the dimensions we previously described.

6.4 Impact of Bond Adjustment Cost Parameter

Table 4's fourth row shows the effect of parameter η on bond adjustment costs. The table shows that the value of η has welfare implications. EME household benefits from a permanent 2.651% consumption equivalent when adjustment costs are ten times smaller than in our baseline model. A very small value of η implies that bonds adjust very quickly and the magnitude of cross-border financial flows can get larger without significant costs in order to improve international risk-sharing. Table 4's sixth row confirms that under a smaller adjustment parameter, standard deviation of the current account is amplified whereas the standard deviations of consumption and labor are lower vis-a-vis the version with $\eta = 0.0025$.[50,51]

6.5 Currency of Trade Invoicing

In our baseline setting, we assume that prices of output for domestic sale are always set in domestic currency and export prices are set in RoW currency. Now, we investigate the consequences of setting export prices in the currency of the producer, referred to as producer currency pricing (PCP). In appendices, we provide the details of the firms' problem under PCP.

Figure 17 shows impulse responses after an increase in EME interest rate uncertainty when exports use RoW currency (DCP) or producer currency (PCP) in invoicing exports. Our impulse responses are generated by SV shocks to the EME interest rate.

[50] Senay and Sutherland (2019) use endogenous discount factors to pin down the steady state for bond holdings. They also report a significant change in welfare under different endogenous discount factor adjustment parameter variation.

[51] de Groot et al. (2019) show that stationarity-inducing mechanisms generate important differences in the long-run net foreign asset positions in models that are solved by employing global methods, when compared with those in models that are solved by local methods. Very small values for adjustment parameters (e.g., 0.00025) may impact the response of consumption to stochastic volatility shocks, even qualitatively.

EME bonds are riskier and there is an outflow in the bond component of the capital account as in the baseline model. Real exchange rate depreciates and the price of physical capital becomes lower from RoW perspective. This is being reflected again as FDI inflows into EME. However, international risk-sharing and exporter markups move significantly different under PCP. Under PCP, exporters benefit from depreciating exchange rate and they want to expand production. This is being reflected as higher demand on inputs of production. Sticky wages pressure labor because firms cannot move wages up on impact. This is being reflected as a big decline in wage markups (which is subsequently reflected as a fall in output due to inefficiency costs).

As discussed in our main results section, the reason why export price markups rise is partly because of the shape of the profit function under PCP. To see this, we write the steady-state period export profits abstracting from the adjustment costs as follows:

$$\left(rer\frac{P_H^*}{P}\right)^{\epsilon}\left(\frac{P_H^{*h}(i)}{P}\right)^{1-\epsilon}Y_H^* - \left(\frac{\epsilon-1}{\epsilon}\right)\left(rer\frac{P_H^*}{P}\right)^{\epsilon}\left(\frac{P_H^{*h}(i)}{P}\right)^{-\epsilon}Y_H^*.$$

The real exchange rate enters revenue and cost sides of this expression symmetrically. Figure 18 shows how the profit function changes in response to movements of the real exchange rate. In the left panel, the blue line shows the closed-economy case. The profit function is asymmetric, as the profit loss from price increases is smaller than when prices are lowered. The right panel of Figure 18 shows the curvature of the profit function in three dimensions. Fluctuations of the real exchange rate do not change the profit function asymmetry in relative prices; hence, precautionary pricing behavior implies increasing prices in response to an increase in uncertainty. Therefore, exporter markups rise.

6.6 Epstein-Zin-Weil Preferences

Here, we explore the consequences of recursive preferences that break the link between relative risk aversion and the elasticity of intertemporal substitution (EIS). Because the source of fluctuations is an increase in the volatility of interest rates, it is informative to disentangle the trade-offs between the agents' incentives toward smoothing consumption across states versus time. Therefore, we extend our analysis by assuming different degrees of risk aversion.

We follow the literature and generalize equation (1) to an Epstein-Zin-Weil (Epstein and Zin

(1989) and Weil (1989)) specification:

$$V_t \equiv \left\{ (1-\beta)\left(C_t(h) - \frac{L_t(h)^{1+\varphi}}{1+\varphi}\right)^{1-\gamma} + \beta\left[\mathbb{E}_t\left(V_{t+1}^{1-\sigma}\right)\right]^{\frac{(1-\gamma)}{(1-\sigma)}} \right\}^{\frac{1}{1-\gamma}}. \tag{33}$$

The discount factor, $\beta_{t,t+1}$, becomes

$$\beta^*_{t,t+1} \equiv \frac{\beta U_{C,t+1}}{U_{C,t}} \left(\frac{V_{t+1}^{1-\sigma}}{\left(\mathbb{E}_t\left[V_{t+1}^{1-\sigma}\right]\right)} \right)^{\frac{\gamma-\sigma}{1-\sigma}}. \tag{34}$$

With Epstein-Zin-Weil preferences, the discount factor now has an additional term that reflects the early resolution of uncertainty. With plausible calibration, any unfavorable changes in utility imply a higher discount factor for RoW agents. One property of recursive preferences is that they induce deviations from UIP even under internationally complete markets and perfect foresight.

Figure 25 in appendices compares the impulse responses to a one-standard deviation EME interest rate SV shock. To highlight the role of risk aversion, without loss of generality, we consider the cases in which σ is equal to 5 and 10 while $\gamma = 0.9$.

Higher degrees of risk aversion magnifies the responses of the variables to an EME interest rate SV shock. Qualitatively, Figure 25 exhibits the same type dynamics with Figure 7 except the response of the domestic price markup. This is because the contractionary effect of the EME interest rate SV shock offsets the precautionary pricing behavior. With demand falling more intensely, firms push markups down on impact. We conclude that higher degrees of risk aversion do not affect our results qualitatively.

6.7 Effective Lower Bound in the Rest of the World

The historical episode that motivated our exercise coincided with a period in which the central banks of key advanced economies were constrained in using their conventional monetary policy tool, the nominal interest rate. Here, we study the implications of these countries' interest rate policy being tied in a liquidity trap situation.

We capture this by assuming that the RoW interest rate is pegged at a fixed level. Although we do not impose an explicit effective lower bound on the RoW nominal interest rate, the exercise allows us to capture the key effects of the constraint for our purposes. What matters in our analysis is to have a RoW interest rate that is unresponsive to economic conditions when the EME central bank engages in its use of interest rate uncertainty.[52]

We assume that the RoW nominal interest rate is pegged at its steady-state value for four periods, and we induce dynamics with a one standard deviation increase in the EME interest rate SV shock in period one (shock process is calibrated according to our VAR estimation for median EME). The impulse responses from our experiment are in Figure 19. We observe that the responses are magnified. In response to an increase in EME interest rate SV shock, consumption in EME goes down. EME households borrow. RoW bond returns cannot respond to additional demand, because the RoW interest rate is stuck. This makes RoW bonds highly attractive given relatively high returns. Hence, we observe large inflows into EME. Risk sharing implies EME returns increase in response. This is being reflected as a fall in EME inflation.

7 Conclusions

We examined adjusting interest rate volatility in response to capital inflows as an unconventional policy tool. Our interest was spurred by the experience of the Central Bank of the Republic of Turkey (CBRT), which used it with the goal of dampening capital inflows and affecting their composition. We studied how this policy would work and whether it would accomplish its goals in a standard New Keynesian open-economy model, augmented by explicitly modeling bond versus FDI flows.

Interest rate uncertainty can achieve the objective of dampening short-term bond inflows and channel inflows towards foreign direct investment in the benchmark scenario we studied: internationally incomplete markets, sticky prices, and trade invoicing in dominant currency. In this environment, higher interest rate uncertainty in the emerging economy makes its debt riskier and causes foreign investors to shift away from emerging economy bonds. Depreciation of the real exchange rate decreases asset prices in the emerging economy while increasing the returns associated with them. Precautionary price setting ensures that this effect is strong enough to incentivize FDI flows into the emerging economy. Importantly, under all scenarios we studied, IRUPT is inflationary. We also show that IRUPT may be welfare-improving against the demand-type stochastic

[52] Sims and Wolff (2018) use a similar methodology to study the effects of government spending shocks during zero-lower-bound episodes.

volatility shocks that we consider. Fluctuations in inefficient wedges related with international imperfect risk sharing are dampened when IRUPT is deployed against these shocks. However, IRUPT is welfare reducing when deployed against level shocks and against macro variables that fluctuate in response to level shocks. Thus, IRUPT is a narrow tool.

These results are relevant for emerging economy central banks tasked with multiple mandates and concerned with the impact of swings in capital flows. We take no stand on whether the CBRT's choice to implement its policy experiment was desirable for Turkey or on the design of optimal interest rate uncertainty policy. Our analysis provides a roadmap for under what conditions this unorthodox tool might work.

A natural extension of our model would include financial intermediation and frictions in the banking sector. When these are included, increased uncertainty in the policy rate may aggravate financial frictions, introducing an additional channel through which the policy would affect capital flows, macroeconomic outcomes, and welfare. We leave this extension for future work.

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Tables

Table 1: Model Summary (Baseline)

Euler equation, domestic bonds	$\frac{1}{R_t} = \mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\right] - \eta b_{t+1}$
Euler equation, RoW bonds	$\frac{1}{R_t^*} = \mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}^*}\frac{rer_{t+1}}{rer_t}\right] - \eta b_{*t+1}$
Law of motion of capital (Home)	$K_{t+1}(h) = (1-\delta)K_t(h) + I_t(h)$
Law of motion of capital (FDI)	$K_{*,t+1}(h) = (1-\delta)K_{*,t}(h) + I_{*,t}(h)$
Euler equation, Home capital	$1 = \mathbb{E}_t\left[\beta_{t,t+1}\left(r_{K,t+1} + 1 - \delta\right)\right]$
Euler equation, FDI	$1 = \mathbb{E}_t\left[\beta_{t,t+1}\frac{rer_{t+1}}{rer_t}\left(r_{K,*,t+1} + 1 - \delta\right)\right]$
Real wage	$w_t = \mu_t^W\left(\frac{\chi L_t^{\varphi}}{C_t^{-\rho}}\right)$
Demand functions	$Y_{E,t} = a\left(\frac{P_{E,t}}{P_t}\right)^{-\omega} Y_t$ $Y_{R,t} = (1-a)\left(\frac{P_{R,t}}{P_t}\right)^{-\omega} Y_t$
Price index	$1 = \left(a \cdot rp_{E,t}^{1-\omega} + (1-a)rp_{R,t}^{1-\omega}\right)^{\frac{1}{1-\omega}}$
Marginal cost of intermediate good production	$mc_t = \frac{w_t^{1-\alpha_1-\alpha_2} r_{K,t}^{\alpha_1}\left(r_{K,t}^*\right)^{\alpha_2}}{(1-\alpha_1-\alpha_2)^{1-\alpha_1-\alpha_2}\alpha_1^{\alpha_1}\alpha_2^{\alpha_2}}$
Relative price of goods sold at Home	$rp_{E,t} = \mu_{E,t} mc_t$
Relative price of exports	$rp_{E,t}^* = \frac{\mu_{E,t}^* mc_t}{rer_t}$
Intermediate good production	$Y_{E,t} + \left(\frac{1-n}{n}\right) Y_{E,t}^* = K_t^{\alpha_1} K_t^{*\alpha_2} L_t^{1-\alpha_1-\alpha_2}$
Factors of production	$\alpha_1 w_t L_t = \left(1-\alpha_1-\alpha_2\right) r_{K,t} K_t$ $\alpha_2 r_{K,t} K_t = \alpha_1 r_{K,t}^* K_t^*$
Resource constraint	$Y_t = C_t + I_t + I_t^* + \frac{\kappa^W}{2}\left(\Pi_t^W - 1\right)^2 w_t L_t$ $+\frac{\kappa}{2}\left(\Pi_{E,t} - 1\right)^2 rp_{E,t} Y_{E,t}$ $+\left(\frac{1-n}{n}\right)\frac{\kappa^*}{2}\left(\Pi_{E,t}^* - 1\right)^2 rp_{E,t}^* Y_{E,t}^*$
Net foreign assets	$\frac{b_{t+1}}{R_t} + \frac{rer_t b_{*,t+1}}{R_t^*} + \left(\frac{1-n}{n}\right) rer_t K_{*,t+1} - K_{t+1}^*$ $= \frac{b_t}{\Pi_t} + \frac{rer_t b_{*,t}}{\Pi_t^*} + \left(\frac{1-n}{n}\right) rer_t \left(r_{K,*,t} + 1 - \delta\right) K_{*,t}$ $-\left(r_{K,t}^* + 1 - \delta\right) K_t^* + TB_t$
Monetary policy	$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho}\left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho)\rho_\Pi}\left(\frac{Y_t}{Y}\right)^{(1-\rho)\rho_Y}\left(\frac{S_t}{S_{t-1}}\right)^{(1-\rho)\rho_S} e^{u_t}$

Table 2: Calibration

Parameter		*Value*
Discount factor	β	0.9914
Relative risk aversion	ρ	2
Relative weight of labor in utility	χ	1
Inverse Frisch elasticity	φ	3.79
Bond adjustment	ψ	0.0025
Rotemberg wage adjustment	κ^W	2513
Elasticity of substitution of differentiated labor	ϵ^W	21
Home bias	a	0.65
Share of domestic capital	α_1	0.30
Share of foreign capital	α_2	0.15
Rotemberg domestic price adjustment	κ	237.48
Elasticity of substitution between Home and Foreign goods	ω	1.2
Rotemberg export price adjustment	κ^*	237.48
Elasticity of substitution of differentiated goods	ϵ	21
Interest rate smoothing coefficient	ρ_R	0.7
Steady state response to inflation	ρ_Π	1.5
Steady state response to output	ρ_Y	0.5/4
Steady state response to exchange rate	ρ_S	0.03
Persistence of EME policy rate level shock	ρ^u	0.95
Mean volatility of policy rate level shock	σ	-6.46
Persistence of EME policy rate stochastic volatility shock	ρ^σ	0.73
Standard deviation of EME policy rate stochastic volatility shock	η^σ	0.56

Table 3: Standard deviations of macro and financial aggregates

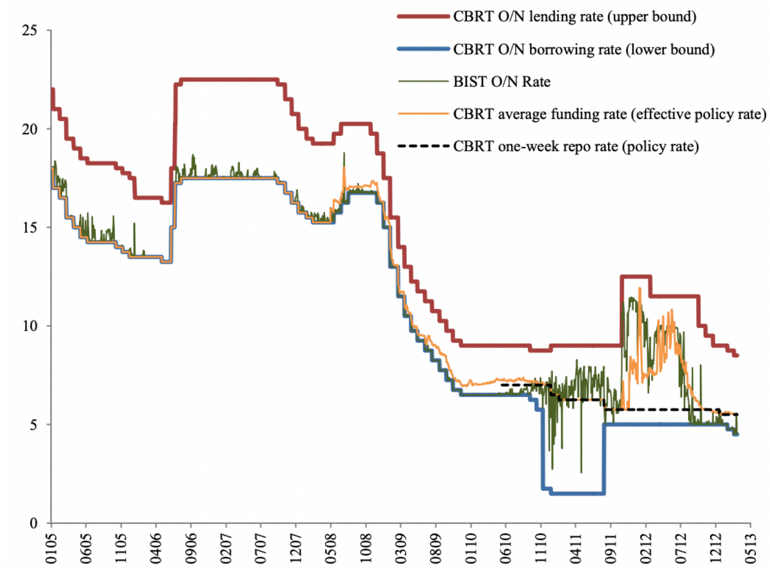
Model version	σ_Y	σ_C	σ_L	σ_{rer}	$\sigma_{CA^{Bond}}$	$\sigma_{CA^{FDI}}$
Business cycle drivers: ε_t,ε_t^{σ} Nominal rigidities: Sticky prices, sticky wages Monetary policy: Taylor rule with $\sigma_t = (1-\rho^{\sigma})\sigma + \rho^{\sigma}\sigma_{t-1} + \eta_{\sigma}\varepsilon_t^{\sigma}$ Standard parameterization	4.61	5.98	6.40	2.12	5.87	9.68
Business cycle drivers: ε_t,ε_t^{σ} Nominal rigidities: Flexible prices, sticky wages Monetary policy: Taylor rule with $\sigma_t = (1-\rho^{\sigma})\sigma + \rho^{\sigma}\sigma_{t-1} + \eta_{\sigma}\varepsilon_t^{\sigma}$ Standard parameterization	4.16	5.73	7.12	1.07	6.68	11.06
Business cycle drivers: ε_t,ε_t^{σ} Nominal rigidities: Sticky prices, flexible wages Monetary policy: Taylor rule with $\sigma_t = (1-\rho^{\sigma})\sigma + \rho^{\sigma}\sigma_{t-1} + \eta_{\sigma}\varepsilon_t^{\sigma}$ Standard parameterization	3.62	4.25	3.66	2.08	6.78	17.95
Business cycle drivers: ε_t,ε_t^{σ} Nominal rigidities: Flexible prices, flexible wages Monetary policy: Taylor rule with $\sigma_t = (1-\rho^{\sigma})\sigma + \rho^{\sigma}\sigma_{t-1} + \eta_{\sigma}\varepsilon_t^{\sigma}$ Standard parameterization	0.00	0.00	0.00	0.00	0.00	0.00
Business cycle drivers: $\varepsilon_t^{\vartheta}$, $\varepsilon_t^{\sigma^{\vartheta}}$,$\varepsilon_t$ Nominal rigidities: Sticky prices, sticky wages Monetary policy: Taylor rule with $\sigma_t = \sigma + 0.4(\sigma_t^{\vartheta *} - \sigma^{\vartheta *})$ Standard parameterization	3.78	4.81	5.22	1.71	4.41	7.74
Business cycle drivers: $\varepsilon_t^{\vartheta}$, $\varepsilon_t^{\sigma^{\vartheta}}$,$\varepsilon_t$ Nominal rigidities: Sticky prices, sticky wages Monetary policy: Taylor rule with $\sigma_t = \sigma + 0.4(\sigma_t^{\vartheta *} - \sigma^{\vartheta *})$ Standard parameterization except $\eta = 0.00025$	3.14	4.36	5.07	2.30	10.40	11.81

Table 4: EME Welfare Under Different Versions of the Model

Model version	Consumption equivalent, λ_c
Business cycle drivers: $\varepsilon_t^{\vartheta}$, ε_t Interest rate uncertainty rule: Absent Standard parameterization	0
Business cycle drivers: $\varepsilon_t^{\vartheta}$, $\varepsilon_t^{\sigma^{\vartheta}}$,$\varepsilon_t$ Interest rate uncertainty rule: Absent Standard parameterization	-0.045
Business cycle drivers: $\varepsilon_t^{\vartheta}$, $\varepsilon_t^{\sigma^{\vartheta}}$,$\varepsilon_t$ Interest rate uncertainty rule: $\sigma_t = \sigma + 0.4(\sigma_t^{\vartheta *} - \sigma^{\vartheta *})$ Standard parameterization	-0.035
Business cycle drivers: $\varepsilon_t^{\vartheta}$, $\varepsilon_t^{\sigma^{\vartheta}}$,$\varepsilon_t$ Interest rate uncertainty rule: $\sigma_t = \sigma + 0.4(\sigma_t^{\vartheta *} - \sigma^{\vartheta *})$ Standard parameterization except $\eta = 0.00025$	2.616

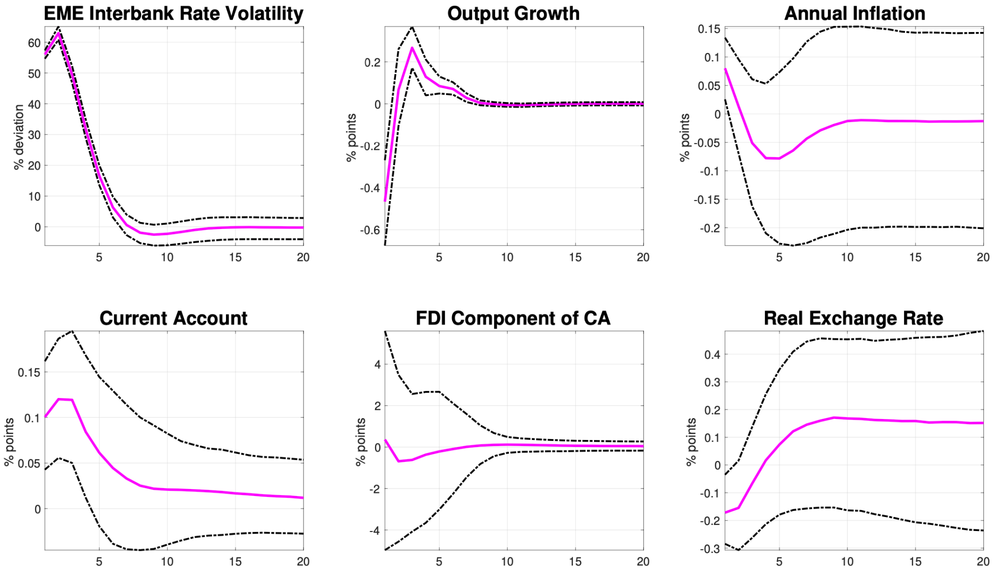
Figures

Figure 1: Interest Rate Corridor and Average Funding Cost, Turkey



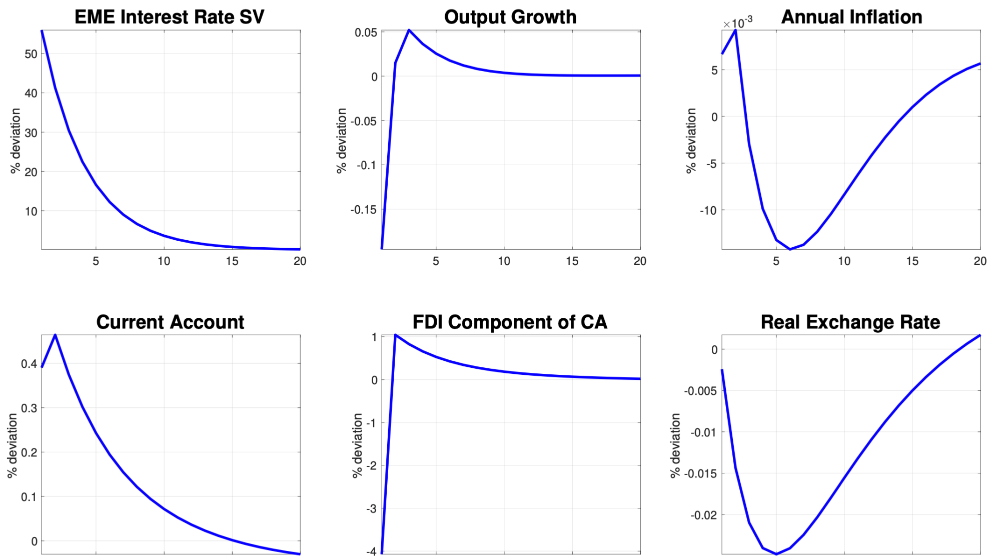
Source: Kucuk et al. (2014) Notes: The horizontal axis indicates dates and the vertical axis are percentage rates in levels. Horizontal axis documents month-year in four digits, first two digits indicating the month and the last two indicating year.

Figure 2: Impulse Responses to an Interbank Rate Volatility Shock in the BVAR Model



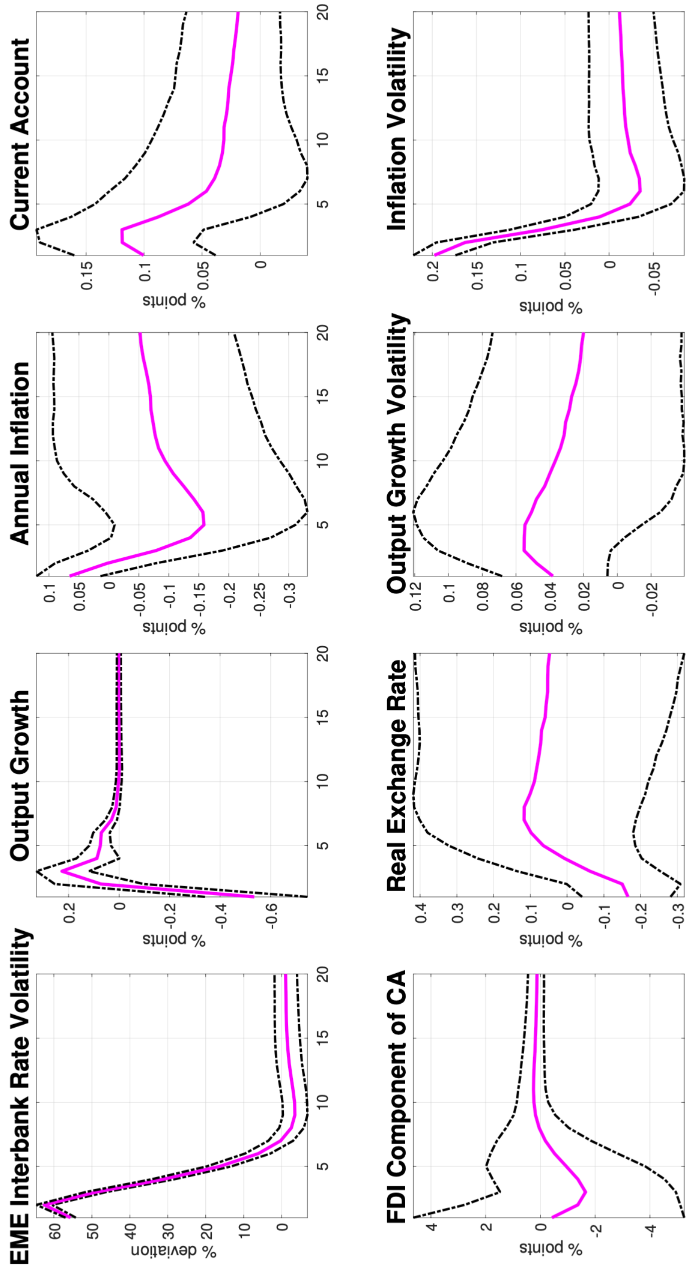
Notes: Purple lines indicate responses to a one-standard deviation interbank rate volatility shock in the panel BVAR with the interbank rate volatility ordered first. One-standard deviation shock translates into a 56% deviation from its average. Black dashed lines around the solid purple lines indicate 68% confidence intervals for the estimated impulse responses. A fall in the real exchange rate indicates depreciation.

Figure 3: Impulse Responses to an Interest Rate Stochastic Volatility (SV) Shock in the DSGE Model



Notes: Blue lines indicate responses to a one-standard deviation Emerging Market Economy interest rate stochastic volatility shock in the DSGE model. The shock magnitude replicates the shock magnitude in the panel BVAR estimated impulse responses. DSGE model variables are translated into panel BVAR variables for comparison purposes.A fall in the real exchange indicates depreciation. Exchange rate is defined in EME consumption units for comparison purposes with the panel BVAR.

Figure 4: Impulse Responses to an Interbank Rate Volatility Shock in the extended panel BVAR



Notes: Purple lines indicate responses to a one-standard deviation interbank rate volatility shock in the panel BVAR with the interbank rate volatility ordered first. One-standard deviation shock translates into a 56% deviation from its average. Black dashed lines around the solid purple lines indicate 68% confidence intervals for the estimated impulse responses. A fall in the real exchange rate indicates depreciation.

Figure 5: Model Architecture

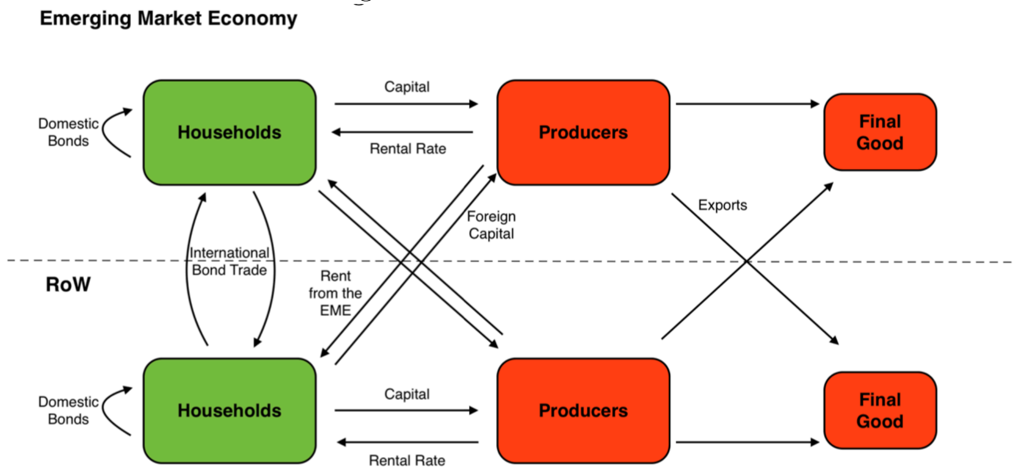
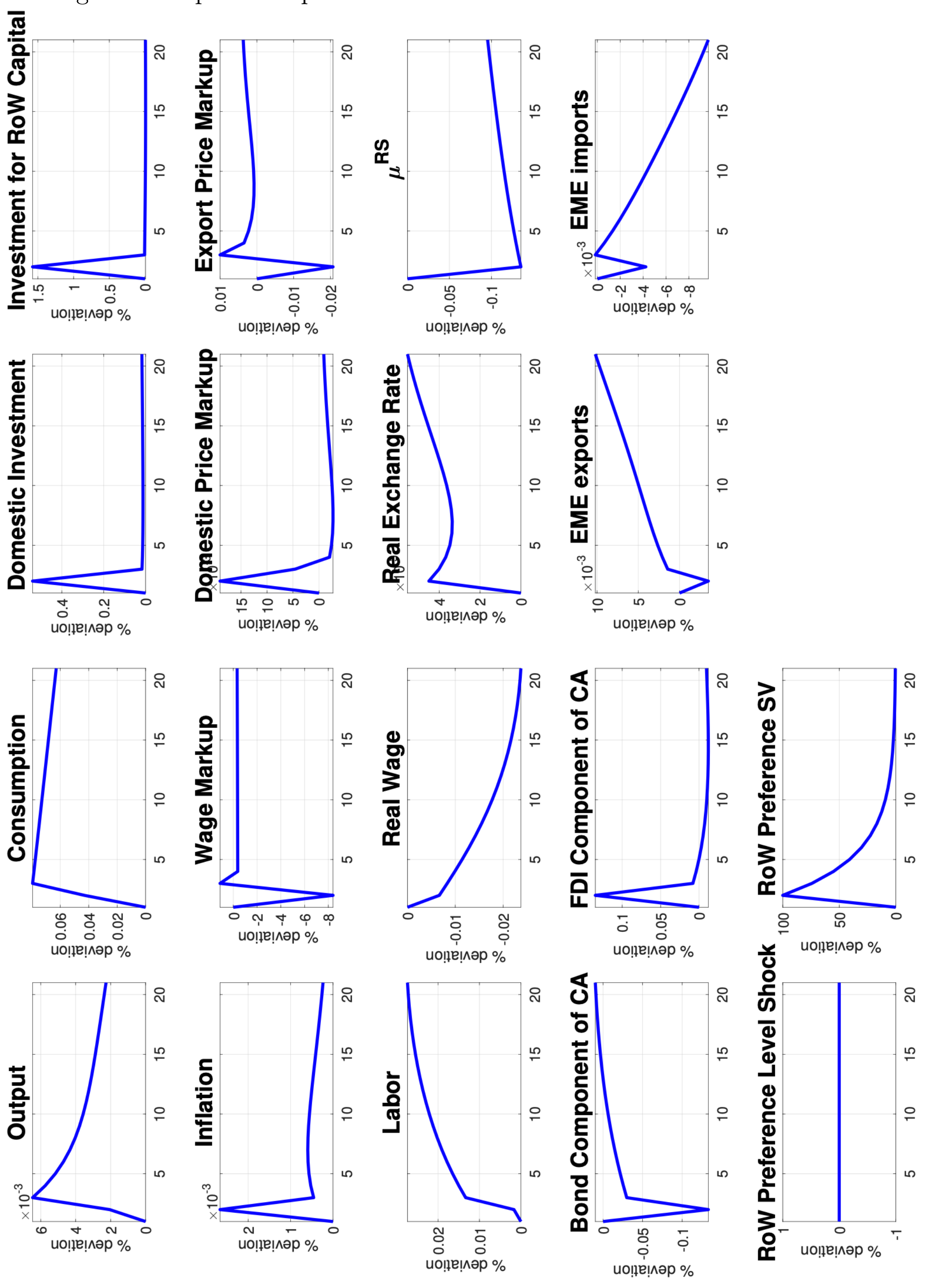
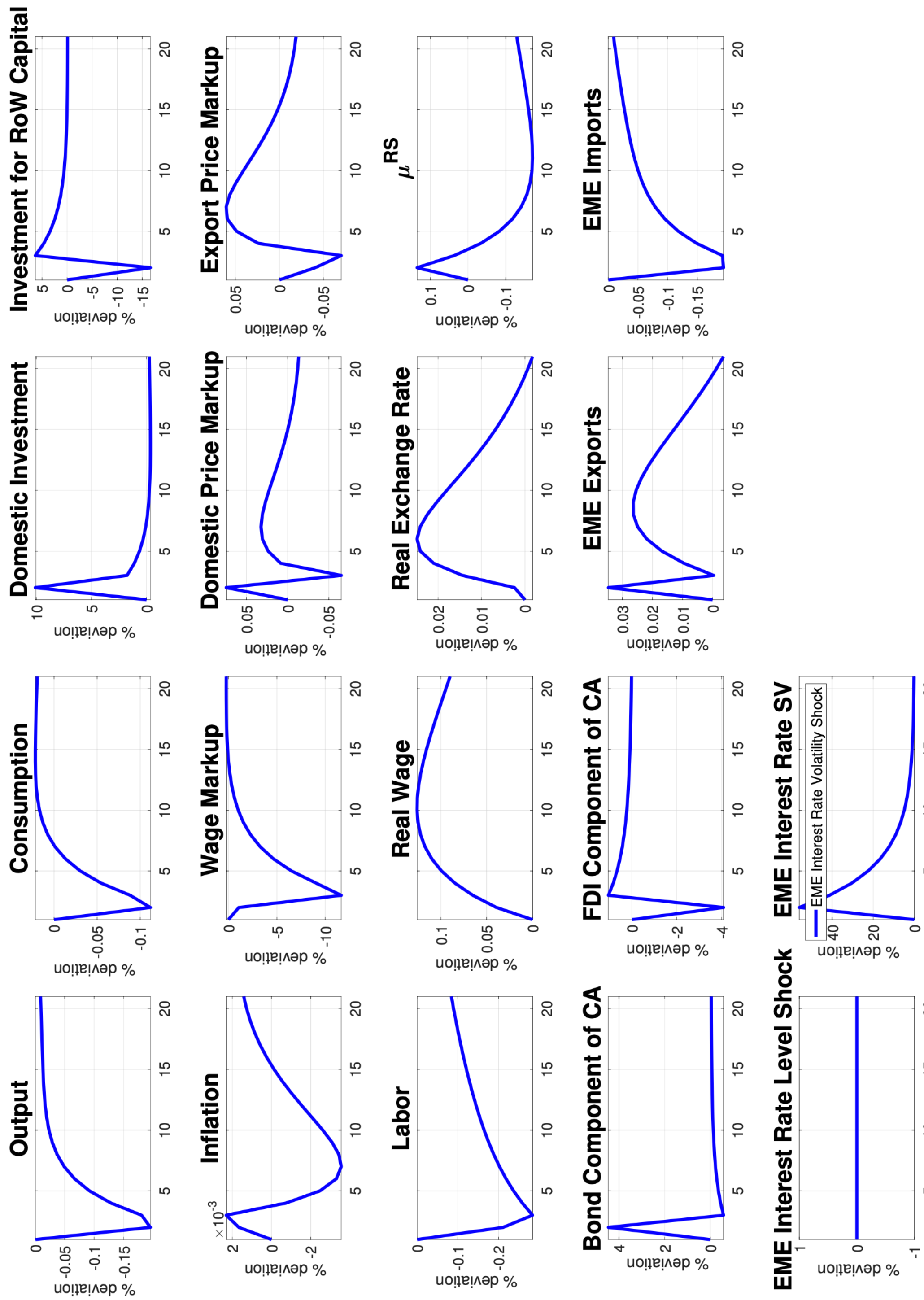


Figure 6: Impulse Responses to an Increase in RoW Preference SV Shock



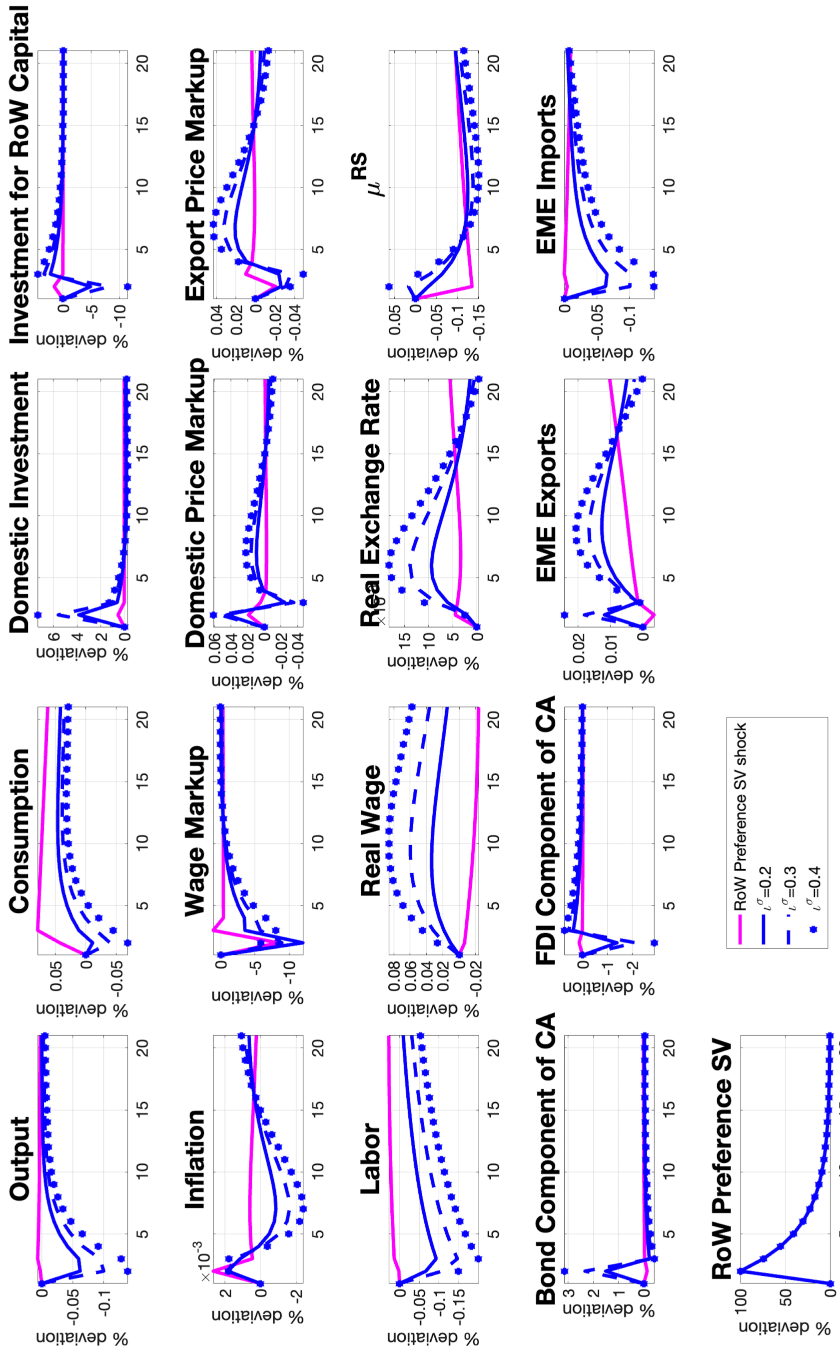
Notes: Impulse responses to a RoW preference stochastic volatility shock as deviations from the stochastic steady state. Upward movement in the real exchange rate implies depreciation from the EME perspective.

Figure 7: Impulse Responses to an Increase in EME Interest Rate SV Shock



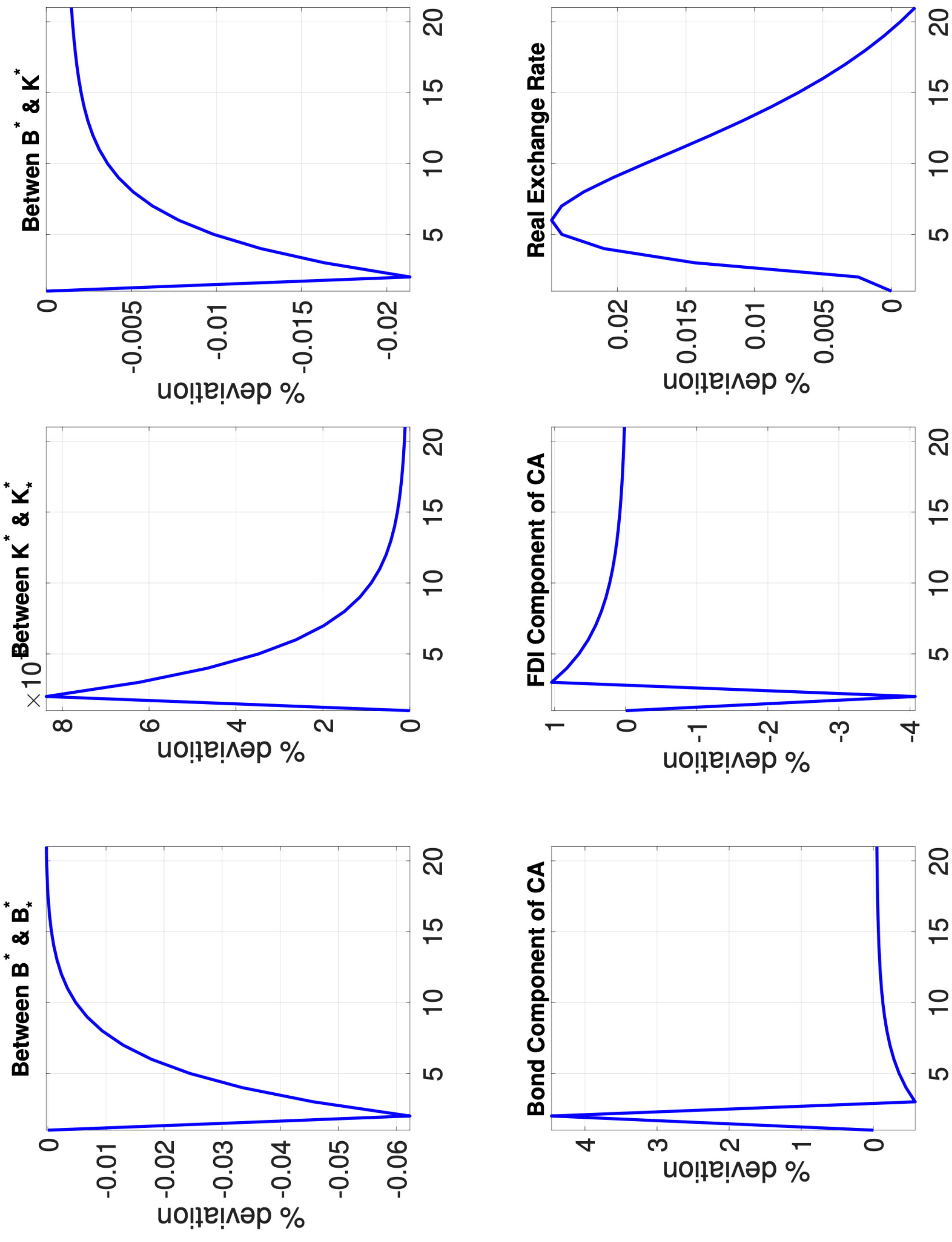
Notes: Impulse responses to an EME interest rate stochastic volatility shock as deviations from the stochastic steady state. Upward movement in the real exchange rate implies depreciation from the EME perspective.

Figure 8: Interest Rate Uncertainty as a Policy Tool (IRUPT)



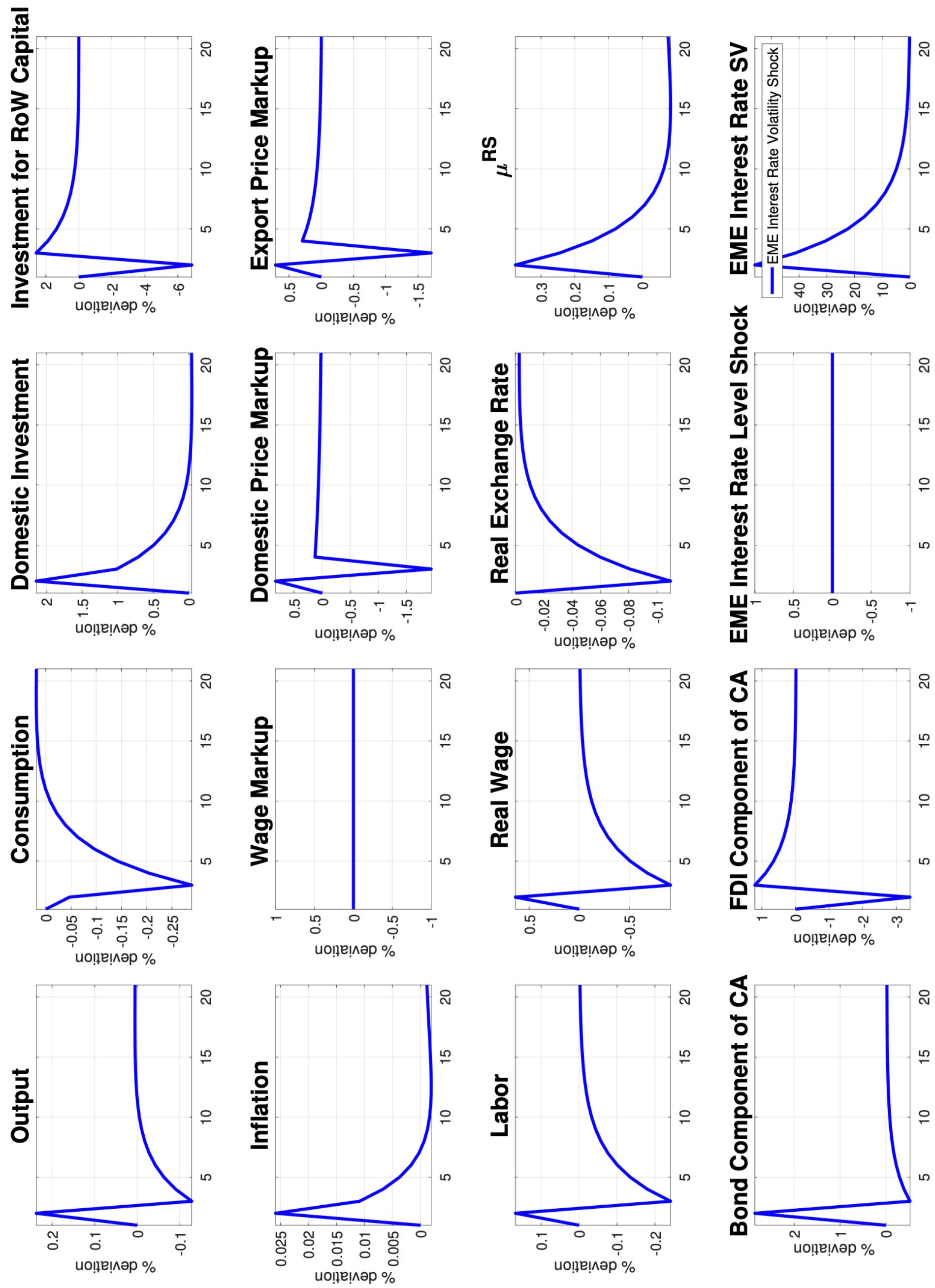
Notes: Purple lines indicate responses to a RoW preference SV shock. Solid blue responses indicate IRUPT with $\iota^\sigma = 0.2$, dashed blue responses indicate IRUPT with $\iota^\sigma = 0.3$, and dotted blue responses indicate IRUPT with $\iota^\sigma = 0.4$. Upward movement in the real exchange rate implies depreciation from the EME perspective.

Figure 9: Relative Excess Returns and the Composition of the External Account



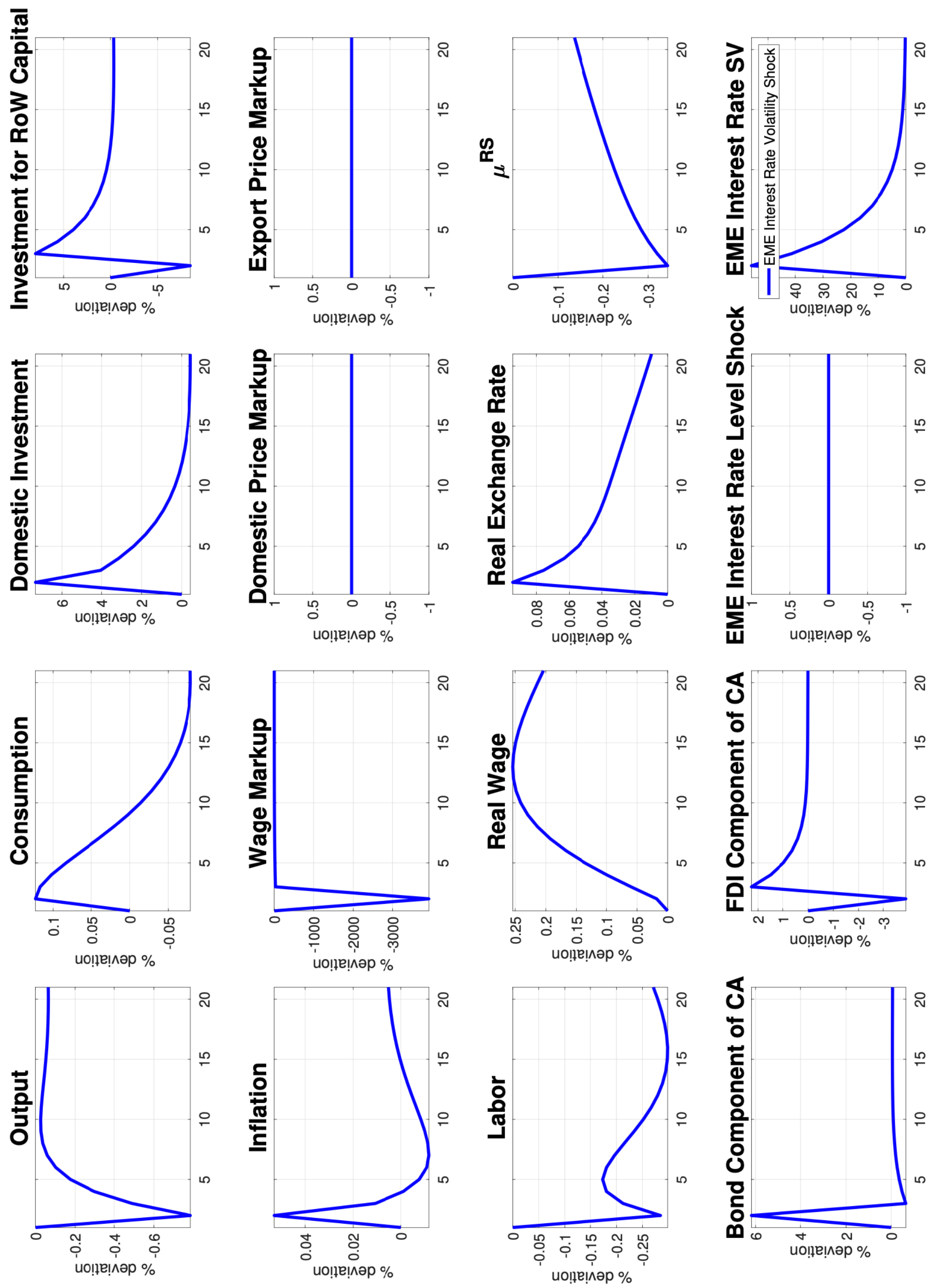
Notes: The figure plots impulse responses to a one-standard deviation increase in EME interest rate SV. Deviations from the stochastic steady state.

Figure 10: Impulse Responses When Wages are Flexible ($\kappa^W = 0$)



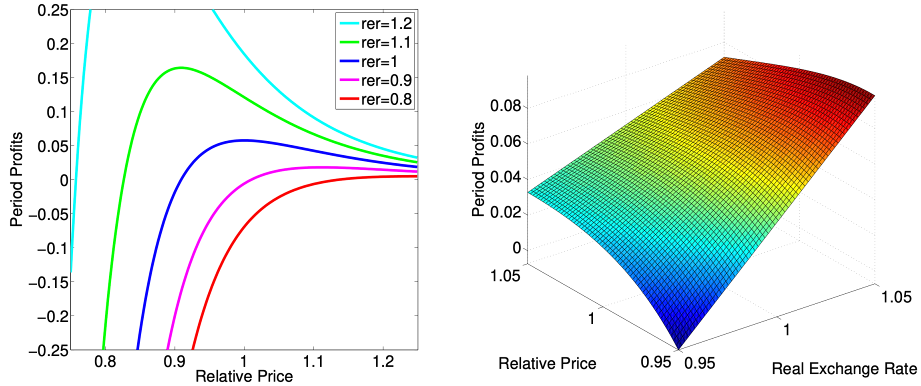
Notes: The figure plots impulse responses to a one-standard deviation increase in EME interest rate SV. Deviations from the stochastic steady state.

Figure 11: Impulse Responses When Prices are Flexible ($\kappa = \kappa^* = 0$)



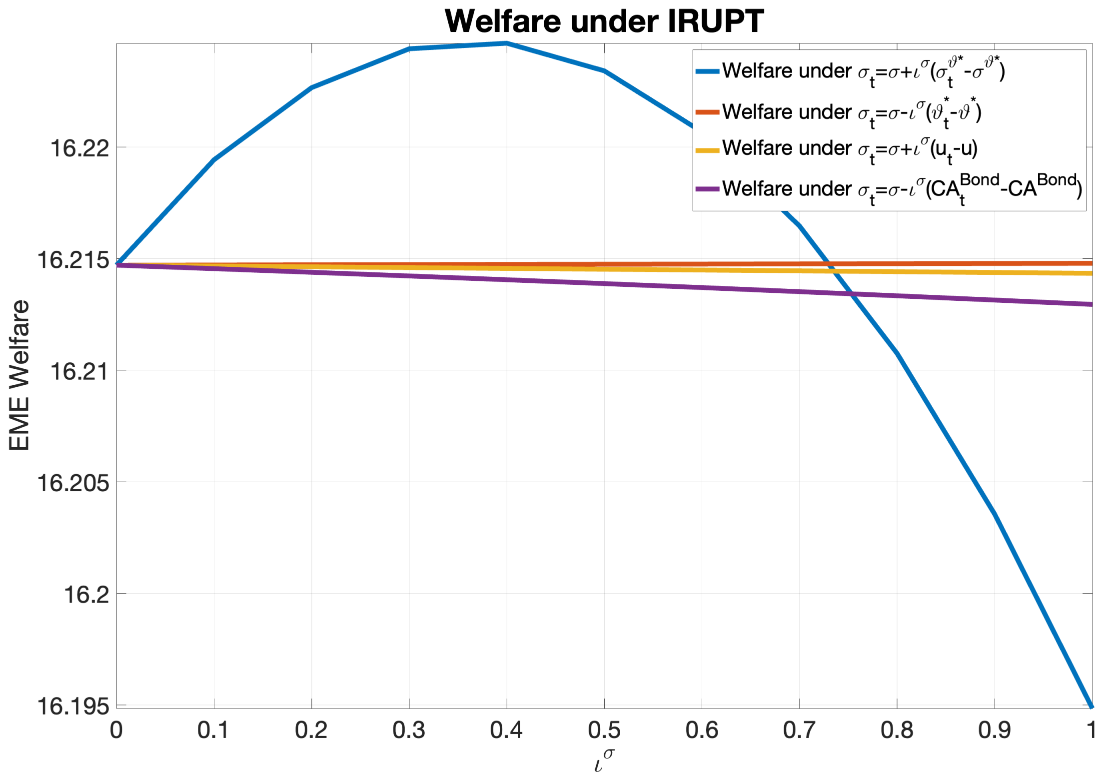
Notes: The figure plots impulse responses to a one-standard deviation increase in EME interest rate SV. Deviations from the stochastic steady state.

Figure 12: Period Profit (LCP)



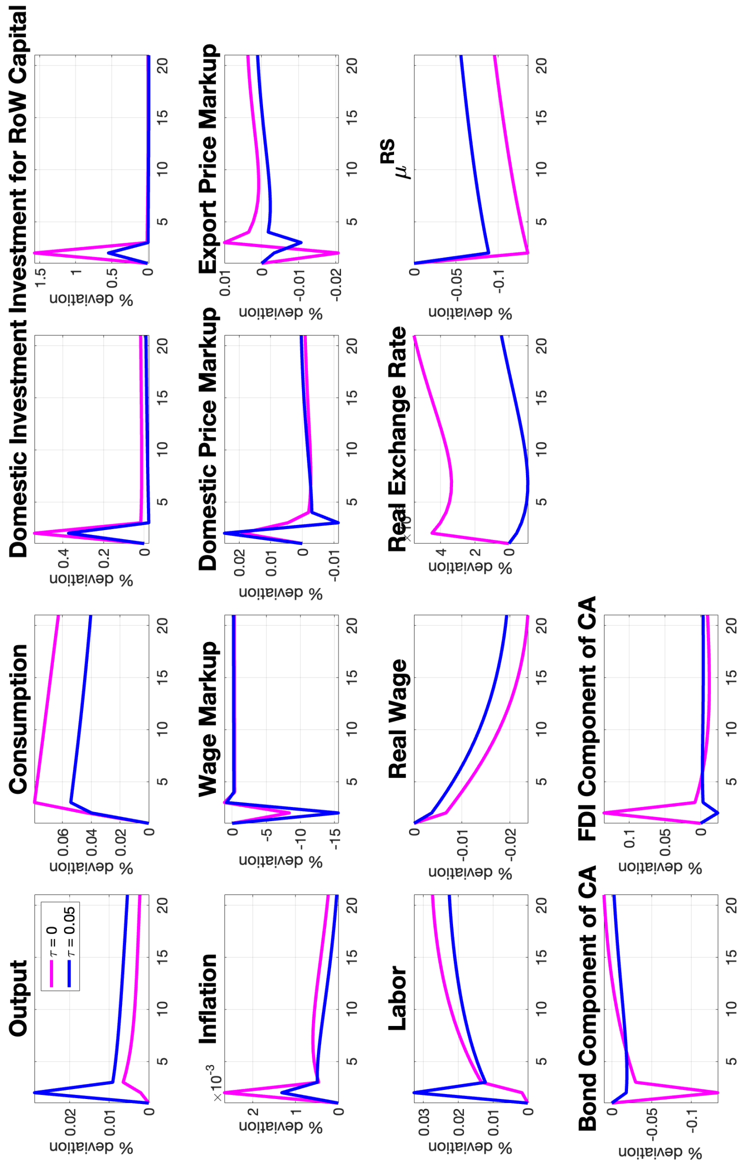
Notes: The figure plots period profits for different levels of relative prices and real exchange rate.

Figure 13: Welfare (Baseline Model)



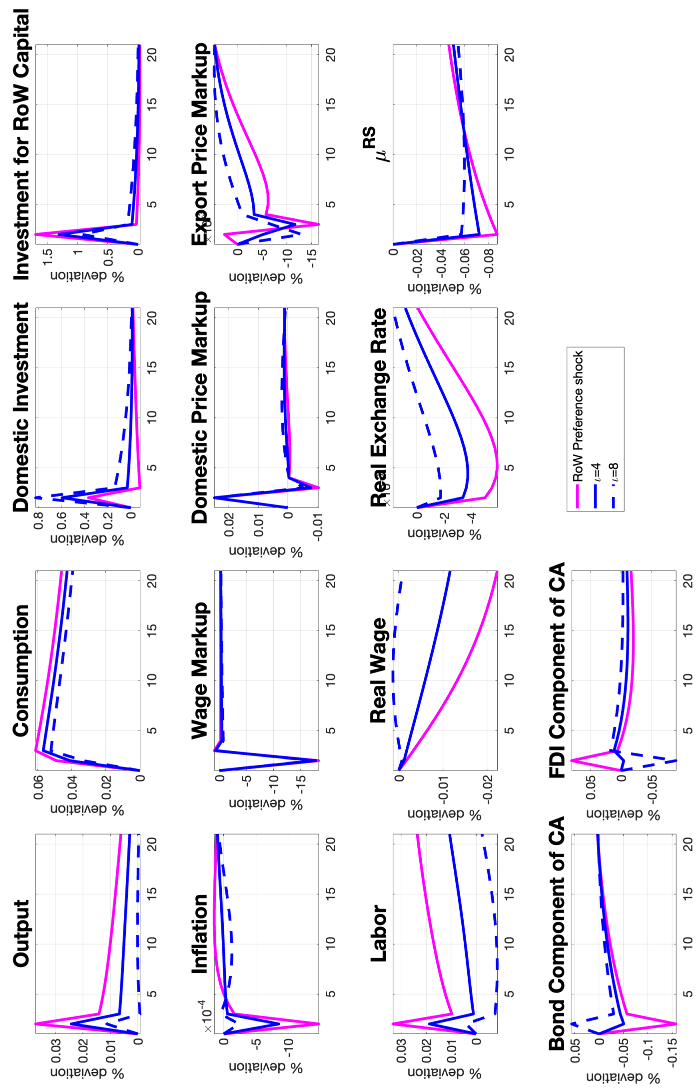
Notes: The figure plots EME welfare for different rules for the interest rate uncertainty rule. If the interest rate uncertainty rule responds to the rest-of-the-world stochastic volatility shocks, it is possible to improve welfare for certain response parameters. Designing interest rate uncertainty rule against macro variables may not be welfare improving as macro variables move more in response to level shocks, rather than stochastic volatility shocks.

Figure 14: Impulse Responses to RoW Preference SV Shock under Tax on RoW bonds



Notes: The figure plots impulse responses to a one-standard deviation increase in RoW preference SV. Deviations from the stochastic steady state.

Figure 15: Impulse Responses to RoW Preference Level Shock



Notes: The figure plots impulse responses to a one-standard deviation decrease in RoW preference level shocks. Deviations from the stochastic steady state.

Figure 16: Impulse Responses to RoW Preference SV Shock (Taylor rule comparison)

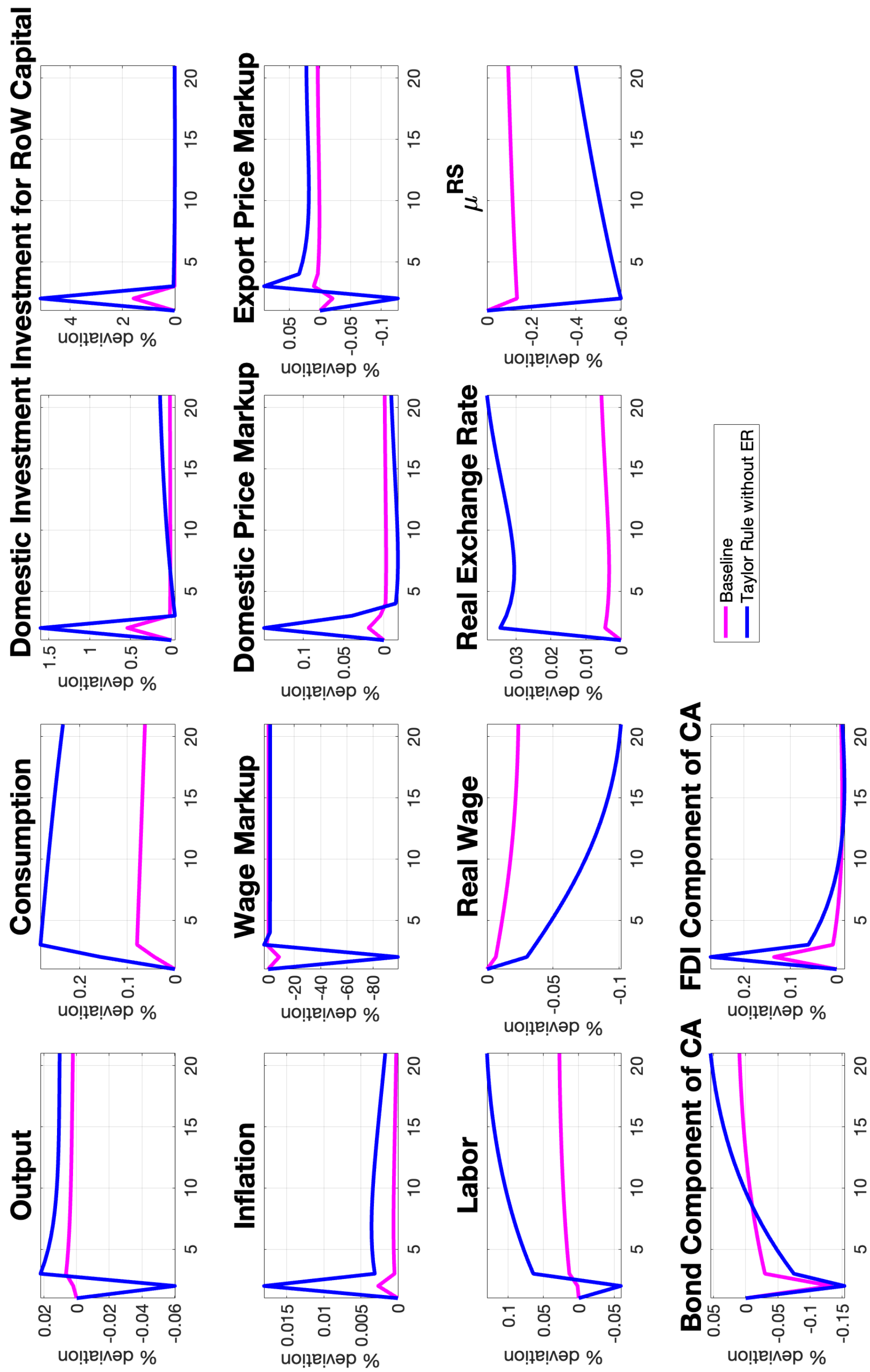


Figure 17: Impulse Responses to EME SV Shock (DCP vs. PCP)

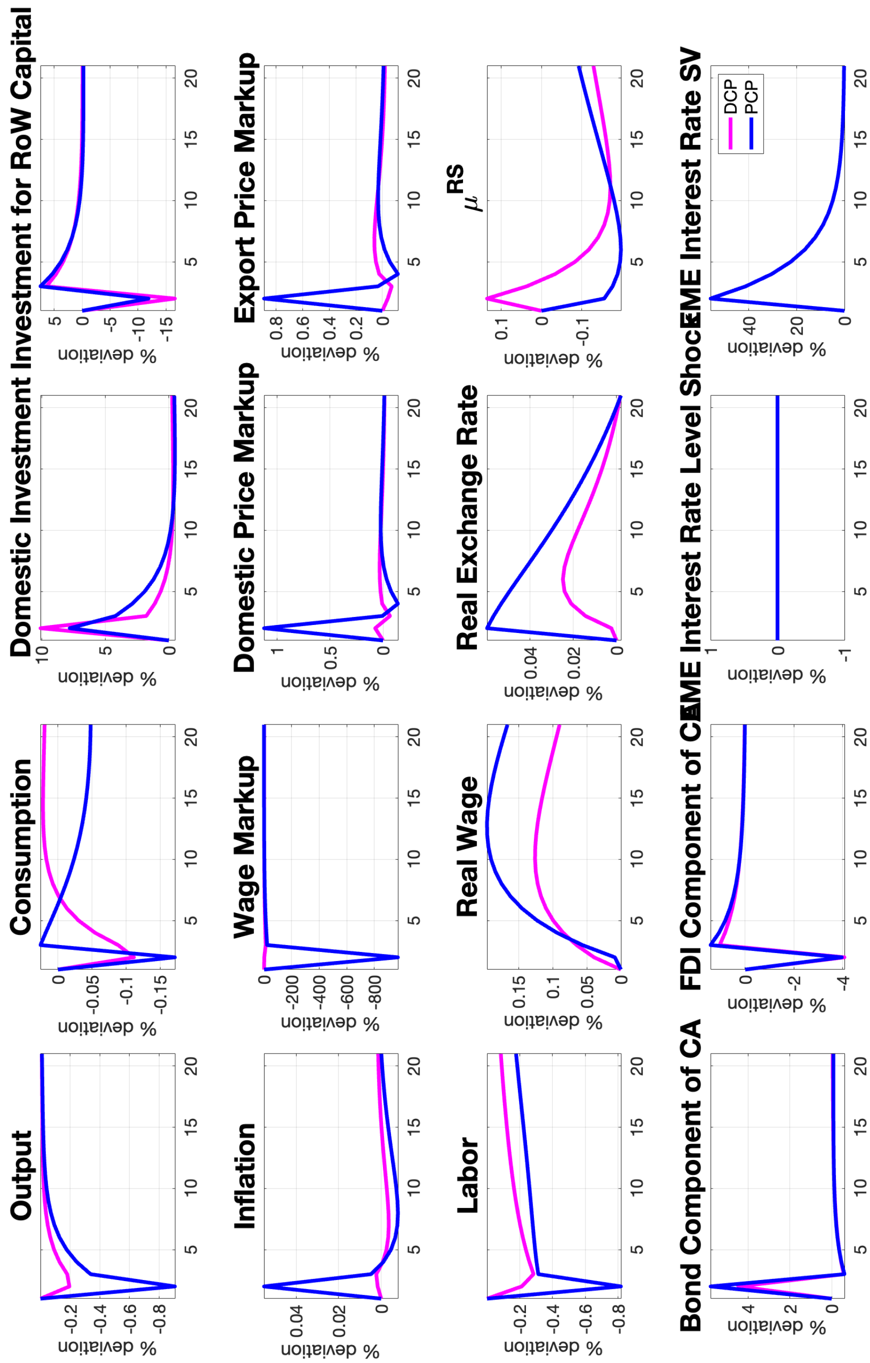


Figure 18: Period Profit (PCP)

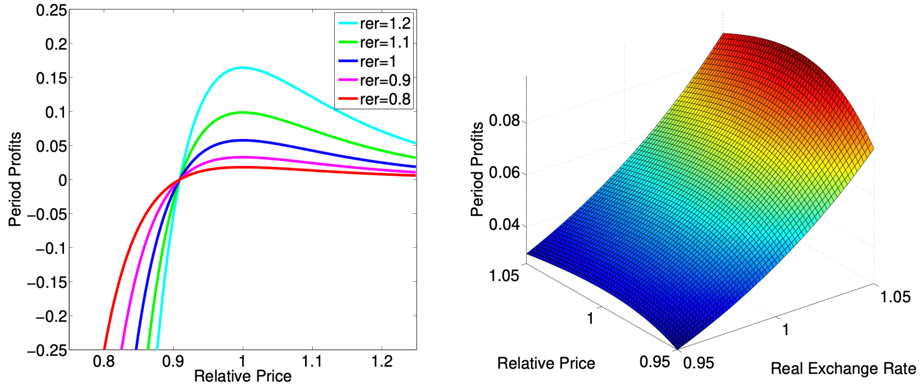
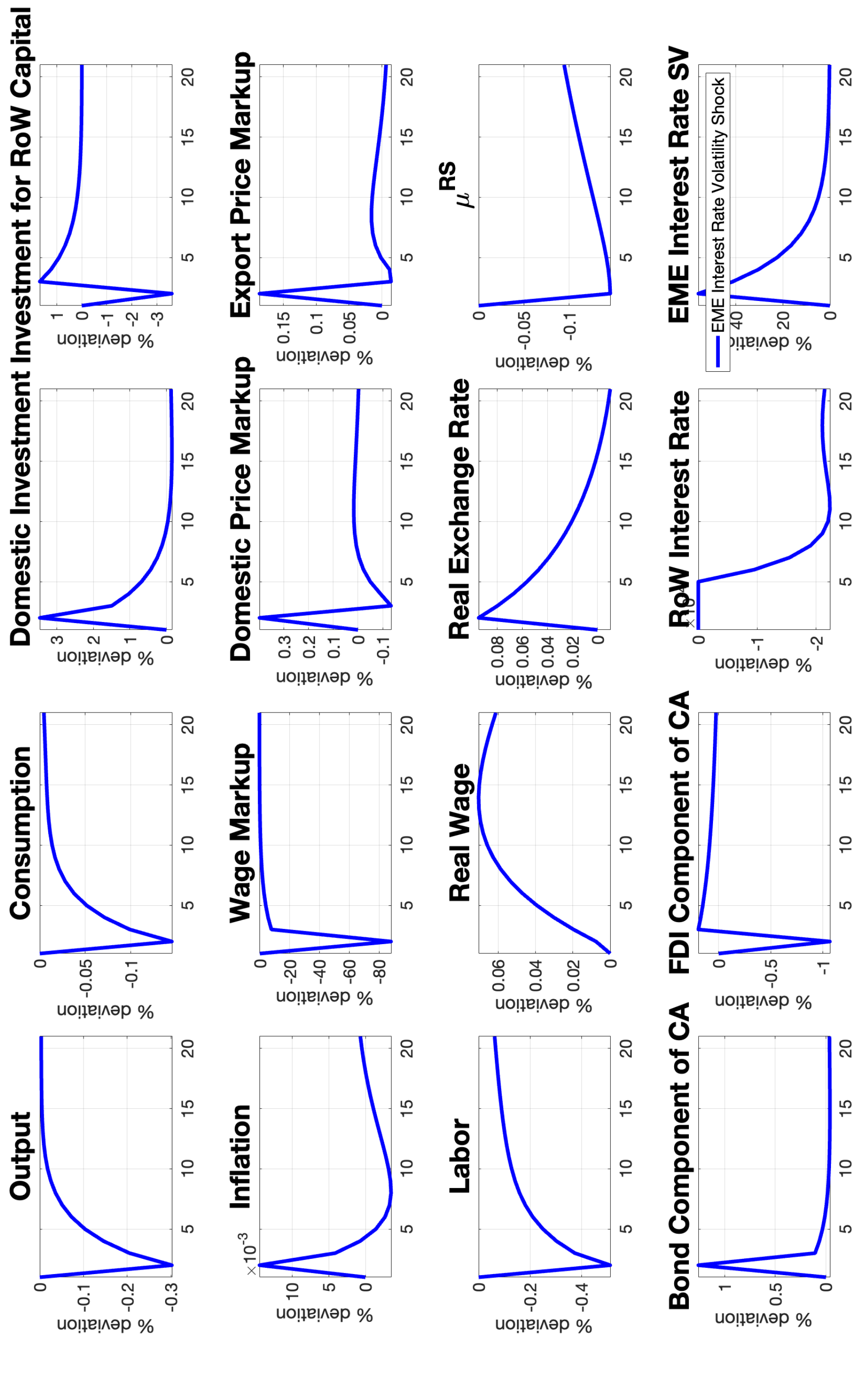


Figure 19: Impulse Responses to EME SV Shock (ELB in RoW)



Interest Rate Uncertainty as a Policy Tool?

Online Appendix

Fabio Ghironi & Galip Kemal Ozhan

July 21, 2023

A: Additional Details on the Empirical Analysis

Interest rates and their volatility

In this section, we provide empirical evidence for time variation in the volatility of interest rates for five emerging market economies. We start by documenting time-varying volatility in the interest rates for our selected emerging market economies: Brazil, Chile, Indonesia, Korea, and Turkey. We collect overnight interbank rate data from Haver Analytics, which is provided in monthly frequency.[53] We calculate 12-month rolling standard deviations and convert them into quarterly frequency data. Figure 20 shows the evolution of the volatility of overnight interbank interest rates for EMEs in our sample. The figure exhibits time-varying volatility in the interest rates. The effects of 1997 Asian crisis and its transmission to other emerging countries are seen as the biggest spikes in the volatility of interbank market rates for Brazil (samba effect), Chile, Indonesia, and Korea. A milder spike is seen during the Global Financial Crisis of 2008-2009. Turkey's interbank rate volatility jumps during the 2001 banking crisis and stays relatively more volatile on average than the other EMEs in our group. In Figure 21, we present the volatility of policy rates for these countries. A similar behavior can be seen in the policy rate volatility graphs. As expected, the policy rate is less volatile than the overnight interbank market rates. Moreover, the impact of 1997 Asian crisis is not as pronounced as on interbank rate volatility. Table 5 provides further evidence for the significance of interest rate volatility in our group of EMEs. Although average policy rate levels are close to average interbank rate levels, average volatility of interbank rates is much higher than average policy rate volatility in these countries. For comparison purposes, Table 6 provides the averages for several advanced economies. It is clearly seen that both policy rate volatility and interbank rate volatility are much lower than those in EMEs. Moreover, average policy rate volatility and average interbank rate volatility are very close to each other in these

[53] This is the shortest frequency we were able to reach.

advanced economies.

Additional Details on the VAR

We provide additional details about data construction and estimation procedure in this section. For comparison purposes and robustness, we also run several other country-by-country estimations.

We estimate our panel VAR using data on overnight interbank interest rates, real gross domestic product (GDP) growth, annual inflation in quarterly frequency, current-account-to-GDP, net-FDI-inflows-to-GDP, and real exchange rate. Overnight interbank interest rates are in monthly frequency. We calculate 12-month rolling standard deviations and convert monthly frequency standard deviations to quarterly standard deviations by taking averages. Thus, our measure of interest rate uncertainty captures the volatility within a quarter. We obtain data on FDI, GDP growth, CPI, Current-Account-to-GDP, and Real Effective Exchange Rates from Haver. We collect the FDI data from IMF's International Financial Statistics. Indian CPI data has gaps in Haver and we fill those from data in FRB St. Louis's FRED database. We focus on a balanced panel, because emerging market economy observations are generally absent during economic turbulences and an unbalanced data may bias our estimates. To prevent that our results being a result of huge fluctuations in interbank rate volatility, we also start from 2002:QII to abstract from the 1997 Asian Crisis and 2001 Turkish Crisis. We include two lags in the estimation of the panel BVAR.[54] In the robustness analysis, we calculate inflation volatility and GDP growth volatility by calculating the standard deviation in the last 4 quarters.

In this appendix, we also estimate a country-by-country VAR for several advanced economies. Second, we estimate country-by-country VARs by replacing net-FDI-to-GDP with net-equity-flows-to-GDP. We obtain the equity flows data from Sander (2019)'s dataset. We collect overnight interbank interest rates and real GDP from Haver Analytics. We also conduct some analysis using policy rates. We collect policy rates from BIS database and if any part of the series is missing, we utilize from the data in Haver Analytics. CPI, current-account-to-GDP and net-FDI-inflows-to-GDP are obtained from the dataset of Sander (2019). His dataset is a collection of winsorized data from IMF International Statistics. If some values of particular dates are missing, we complete the dataset by using values from FRED and Haver.

[54] We employ BEAR toolbox that is developed by Dieppe et al. (2016) to conduct estimations.

Figure 22 shows estimated impulse responses to an identified interbank rate volatility shock for several advanced economies. We see that the behavior of inflation, current-account-to-GDP and net-FDI-flows-to-GDP are different than those for EMEs. An increase in interbank rate volatility decreases CPI and deteriorates current account on average. These results are in line with the papers whose focus is advanced economies. For instance, Fogli and Perri (2015) show macroeconomic volatility affects accumulation of net foreign assets for several OECD economies. The decline in inflation in response to uncertainty is shown in Basu and Bundick (2017), among others.

Finally, Figure 23 plots estimated impulse responses after we replace net-FDI-inflows-to-GDP with net-equity-flows-to-GDP. Equity flows are more in shorter term nature than FDI flows. Hence, we have mixed evidence on the response of net-equity-flows. Turkey, Brazil, and Chile exhibit outflows of equities in response to an increase in interbank rate volatility.

Table 5: Descriptive Statistics (Emerging Market Economies)

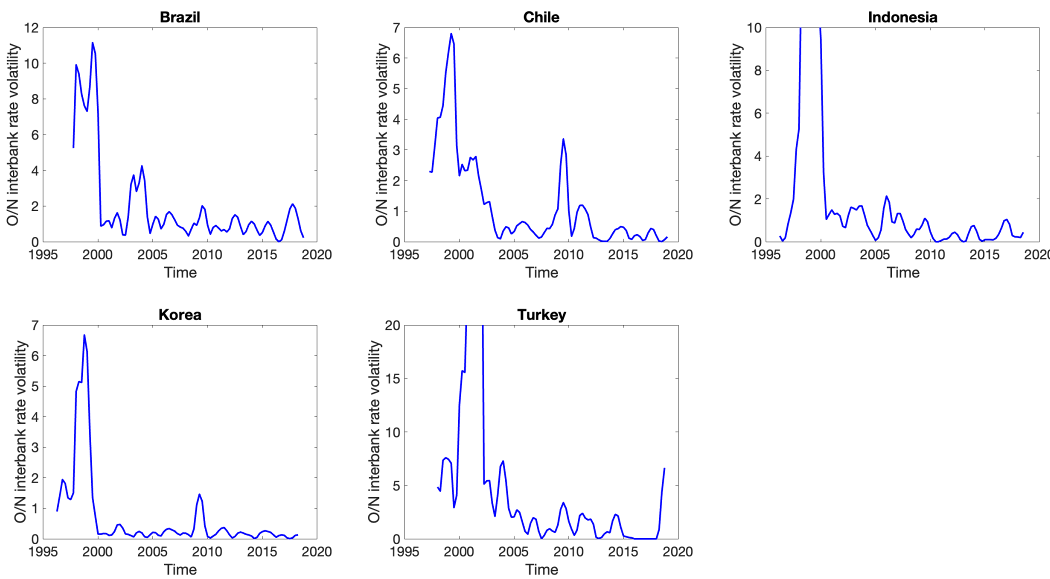
	Sample	Average Interbank Rate	Average Interbank Rate Volatility	Average Policy Rate	Average Policy Rate Volatility
Brazil	1997QIV:2018QIV	15.5516	2.0263	15.4513	1.9086
Chile	1997QII:2019QI	5.3065	1.2068	4.4305	0.6357
Indonesia	1996QII:2018QIII	11.4671	2.0976	11.9215	2.0945
South Korea	1996QII:2018QII	4.5459	0.6648	3.3085	0.2132
Turkey	1998QI:2018QIV	25.6643	7.84911	25.9902	1.6018
Average		12.5071	2.7689	12.2204	1.2908

Notes: Data from Haver, FRED, and Eurostat.

Table 6: Descriptive Statistics (Advanced Economies)

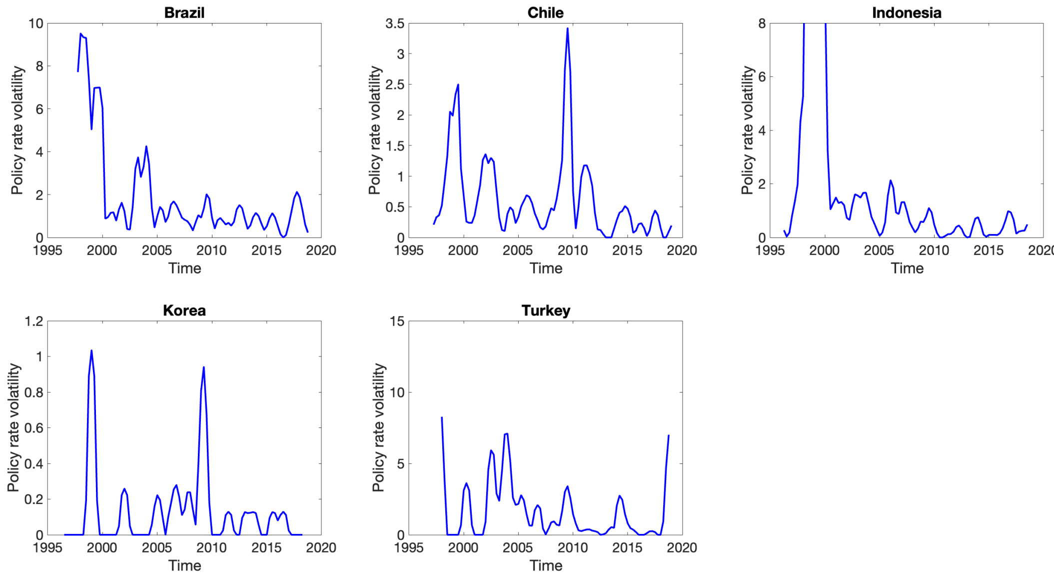
	Sample	Average Interbank Rate	Average Interbank Rate Volatility	Average Policy Rate	Average Policy Rate Volatility
Australia	1996QII:2018QIV	4.3328	0.2667	4.5888	0.2691
Canada	1996QII:2018QIII	2.4422	0.3121	2.6700	0.3158
France	1996QII:2019QI	1.8268	0.2428	2.6465	0.2236
United Kingdom	1996QII:2018QIV	3.0828	0.2699	3.3772	0.2429
Average		2.9212	0.2729	3.3206	0.2628

Figure 20: Overnight Interbank Rate Volatility



Notes: Figures plot the 12-month rolling standard deviation of the interest rates in quarterly frequency. Source: Haver Analytics and FRED.

Figure 21: Policy Rate Volatility



Notes: Figures plot the 12-month rolling standard deviation of the interest rates in quarterly frequency. Source: Haver Analytics and FRED.

Figure 22: Impulse Responses to an Increase in Interest Rate Volatility (Advanced Economies)

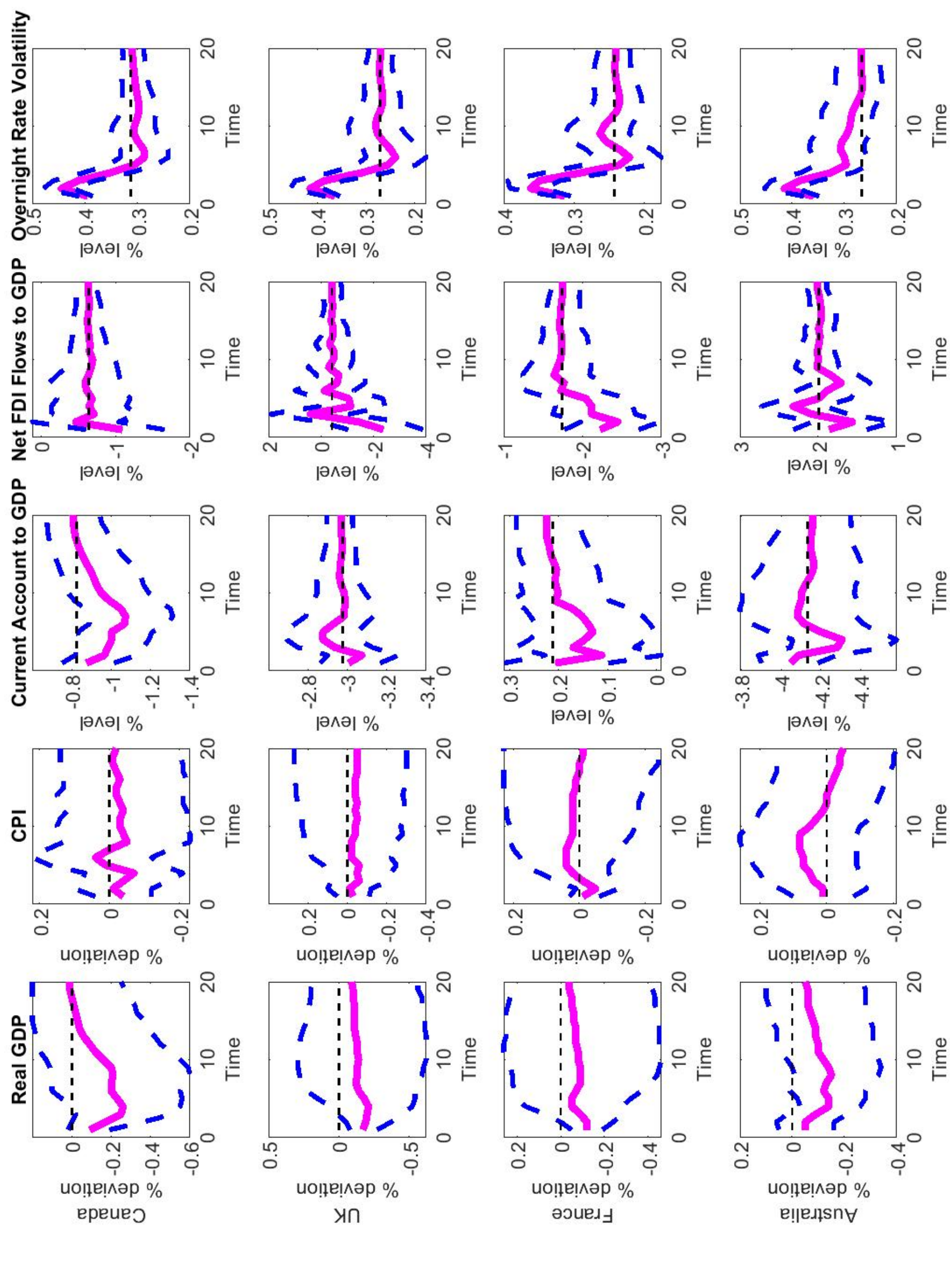
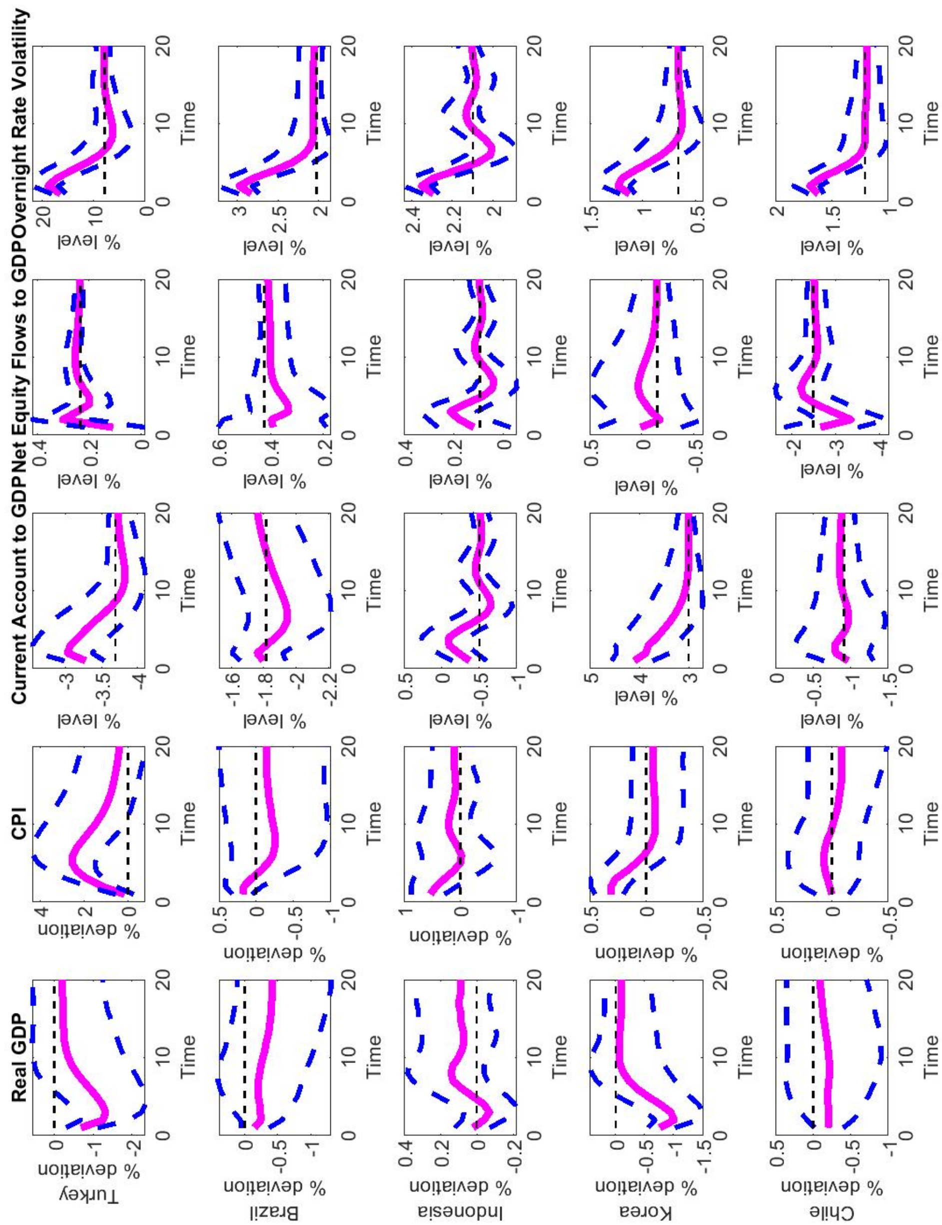


Figure 23: Impulse Responses to an Increase in Interest Rate Volatility (Portfolio Equity instead of FDI)



B: Derivation of Net Foreign Assets

Start with EME households' budget constraint, equation (5), divide it by P_t, and impose $T_t = \frac{\eta}{2}\left[P_t(\frac{B_{t+1}(h)}{P_t})^2 + S_t P_t^*(\frac{B_{*,t+1}(h)}{P_t^*})^2\right]$ and equation (21) to obtain:

$$\begin{aligned}\frac{b_{t+1}}{R_t} + \frac{rer_t b_{*,t+1}}{R_t^*} + \left(\frac{1-n}{n}\right) rer_t I_{*,t} = \frac{b_t}{\Pi_t} + \frac{b_{*,t}}{\Pi_t^*} rer_r + w_t L_t + r_{K,t}K_t + \left(\frac{1-n}{n}\right) rer_t r_{K,*,t}K_{*,t} + I_t^* \\ + \left(\mu_{E,t} - 1\right) mc_t Y_{E,t} + \left(\frac{1-n}{n}\right)\left(\mu_{E,t}^* - 1\right) mc_t Y_{E,t}^* - Y_t.\end{aligned}$$

Now, use $w_t L_t + r_{K,t}K_t = mc_t\left(Y_{E,t} + \left(\frac{1-n}{n}\right) Y_{E,t}^*\right) - r_{K,t}^* K_t^*$ to get:

$$\begin{aligned}\frac{b_{t+1}}{R_t} + \frac{rer_t b_{*,t+1}}{R_t^*} + \left(\frac{1-n}{n}\right) rer_t I_{*,t} - I_t^* = \frac{b_t}{\Pi_t} + \frac{b_{*,t}}{\Pi_t^*} rer_r \\ + \left(\frac{1-n}{n}\right) rer_t r_{K,*,t}K_{*,t} - r_{K,t}^* K_t^* + \left(\frac{1-n}{n}\right) \mu_{E,t}^* mc_t Y_{E,t}^* - rer_t \mu_{R,t} mc_t^* Y_{R,t}.\end{aligned} \tag{35}$$

Use isomorphic equations for RoW to obtain:

$$\begin{aligned}\frac{b_{*,t+1}^*}{R_t^*} + \frac{b_{t+1}^*}{rer_t R_t} + \left(\frac{n}{n-1}\right)\frac{I_t^*}{rer_t} - I_{*,t} = \frac{b_{*,t}^*}{\Pi_t^*} + \frac{b_t^*}{rer_t \Pi_t} \\ - r_{K,*,t}K_{*,t} + \left(\frac{n}{1-n}\right)\left(\frac{r_{K,t}^* K_t^*}{rer_t}\right) + \left(\frac{n}{1-n}\right) mc_t^* \mu_{R,t} Y_{R,t} - \frac{mc_t}{rer_t}\mu_{E,t}^* Y_{E,t}^*.\end{aligned} \tag{36}$$

Now, multiply equation (36) with $rer_t(1-n)$, subtract it from equation (35) and impose the bond market clearing conditions, $nb_{t+1} + (1-n)b_{t+1}^* = 0$ and $nb_{*,t+1} + (1-n)b_{*,t+1}^* = 0$:

$$\begin{aligned}2n\left(\frac{b_{t+1}}{R_t} + rer_t\frac{b_{*,t+1}}{R_t^*}\right) + 2((1-n)rer_t I_{*,t} - nI_t^*) = 2n\left(\frac{b_t}{\Pi_t} + \frac{rer_t b_{*,t}}{\Pi_t^*}\right) \\ + 2(1-n)rer_t r_{K,*,t}K_{*,t} - 2nr_{K,t}^* K_t^* + 2(1-n)\mu_{E,t}^* mc_t Y_{E,t}^* - 2nrer_t\mu_{R,t} mc_t^* Y_{R,t}.\end{aligned} \tag{37}$$

Finally, divide the above equation with $2n$, and impose law of motion of capital for K^* and K_* to obtain equation (22):

$$\begin{aligned}\frac{b_{t+1}}{R_t} + rer_t\frac{b_{*,t+1}}{R_t^*} + \left(\frac{1-n}{n}\right) rer_t K_{*,t+1} - K_{t+1}^* \\ = \frac{b_t}{\Pi_t} + \frac{rer_t b_{*,t}}{\Pi_t^*} + \left(\frac{1-n}{n}\right) rer_t\left(r_{K,*,t} + 1 - \delta\right) K_{*,t} - \left(r_{K,t}^* + 1 - \delta\right) K_t^* + TB_t,\end{aligned}$$

where $TB_t \equiv \left(\frac{1-n}{n}\right)\mu_{E,t}^* mc_t Y_{E,t}^* - rer_t \mu_{R,t} mc_t^* Y_{R,t}$.

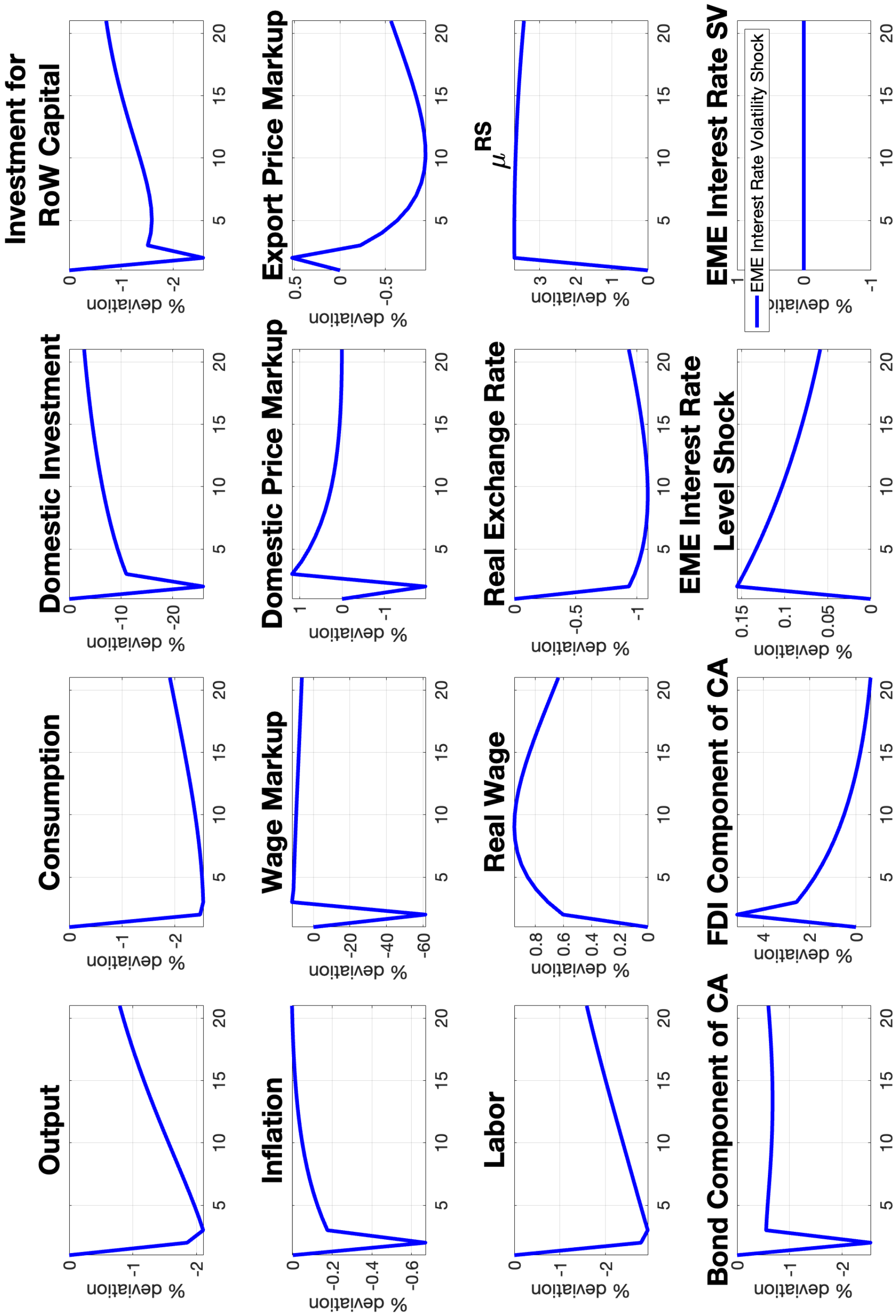
C: Interest Rate Level Shock

The model delivers responses to a one-time exogenous increase in the interest rate as expected. Our model further helps us to track the dynamics of FDI that are usually not considered in the previous literature. The upward movement in the level of the interest rate causes contraction. Most of the decline in output is due to a decrease in investment in domestic physical capital. There is downward pressure on prices, and domestic price markups fall accordingly. Under DCP, exporter markups go up in response to an appreciation in real exchange rate. The fall in household demand for goods is followed by a fall in labor supply. Firms lower their demand for both types of physical capital. A decrease in the demand for physical capital from the RoW contributes to net FDI outflows from EME. EME bonds are offering higher return and this generates inflows in the bond component of the current account. Real exchange rate appreciates and the price of investment into EME rises. Hence, the RoW agents' investment in capital for EME production falls, and this leads to stronger FDI outflows.

The impulse responses in Figure 24 are also informative for the impact of a negative level shock. A negative shock to the EME interest rate level would work against capital inflows generated by the RoW preference SV shocks shown in Figure 6. It would be helpful to channel inflows into FDI while discouraging bond inflows. However, it would create extensive inflation in EME. One of the reasons why Turkish central bank deployed the interest rate corridor policy was because inflation was above its target and they did not want to lower the rates. Policy papers from Turkish central bank indicate that the corridor policy would create better trade-offs among the objectives (among others, see Başçı (2012) and Kucuk et al. (2014)).

Our analysis shows that IRUPT is also inflationary; however, IRUPT's effect on inflation is much lower than an expansionary level shock for generating the same level of bond outflows.

Figure 24: Impulse Responses to EME Interest Rate Level Shock



D: Derivation of the Relative Excess Returns in the RoW Portfolio

Using the Euler equations of bond holdings and capital accumulation, we derive relative risk of each asset from the RoW portfolio problem. The equations we focus are as follows:

$$\frac{1}{R^*_{t+1}} = \mathbb{E}_t\left[\frac{\beta^*_{t,t+1}}{\Pi^*_{t+1}}\right] - \eta b^*_{*,t+1}, \tag{38}$$

$$\frac{1}{R_{t+1}} = \mathbb{E}_t\left[\frac{\beta^*_{t,t+1}}{\Pi_{t+1}}\frac{rer_t}{rer_{t+1}}\right] - \eta b^*_{t+1}, \tag{39}$$

$$1 = \mathbb{E}_t\left[\beta^*_{t,t+1}\left(\underbrace{r_{K^*_*,t+1} + 1 - \delta}_{\equiv R_{K^*_*,t+1}}\right)\right], \tag{40}$$

$$1 = \mathbb{E}_t\left[\beta^*_{t,t+1}\frac{rer_t}{rer_{t+1}}\left(\underbrace{r_{K*,t+1} + 1 - \delta}_{\equiv R_{K^*,t+1}}\right)\right]. \tag{41}$$

First, let's focus on the relative excess return between RoW bonds held by RoW agents and EME bonds held by RoW agents. Using the assumption of log-normality, one can express equations (38) and (39) as follows:

$$-log(R^*_{t+1}) \approx \mathbb{E}_t log\underbrace{\left(\frac{\beta^*_{t,t+1}}{\Pi^*_{t+1}}\right)}_{\equiv M^*_{t+1}} + \frac{1}{2}Var_t\left(\frac{\beta^*_{t,t+1}}{\Pi^*_{t+1}}\right),$$

$$\begin{aligned}-log(R_{t+1}) \approx \quad & \mathbb{E}_t log M^*_{t+1} + \mathbb{E}_t log\left(\tfrac{S_t}{S_{t+1}}\right) \\ & + \tfrac{1}{2}\left[Var_t log(M^*_{t+1}) + Var_t log\left(\tfrac{S_t}{S_{t+1}}\right) + 2Cov_t\left(log M^*_{t+1}, log\left(\tfrac{S_t}{S_{t+1}}\right)\right)\right].\end{aligned}$$

The latter can be further written as:

$$
\begin{aligned}
-\underbrace{log(R_{t+1})}_{r_{t+1}} \approx & \underbrace{\mathbb{E}_t log M^*_{t+1}}_{\equiv \mathbb{E}_t m^*_{t+1}} + \underbrace{log\left(S_t\right)}_{\equiv s_t} - \mathbb{E}_t log\left(S_{t+1}\right) \\
& + \tfrac{1}{2}\left[Var_t m^*_{t+1} + Var_t\left(s_t - s_{t+1}\right)\right] + Cov_t\left(m^*_{t+1}, s_t - s_{t+1}\right).
\end{aligned}
$$

So, we can express the relative excess return as:

$$
r_{t+1} - r^*_{t+1} \approx \mathbb{E}_t s_{t+1} - s_t - \frac{1}{2} Var_t\left(s_t - s_{t+1}\right) - Cov_t\left(m^*_{t+1}, s_t - s_{t+1}\right).
$$

To derive the relative excess return between K^* and K^*_*, we write down the equations (40) and (41) as follows:

$$
\begin{aligned}
0 = \; & \mathbb{E}_t log \beta^*_{t,t+1} + \mathbb{E}_t log R_{K^*_*,t+1} \\
& + \tfrac{1}{2}\left[Var_t log \beta^*_{t,t+1} + Var_t log R_{K^*_*,t+1} + 2Cov_t(log\beta^*_{t,t+1}, log R_{K^*_*,t+1})\right],
\end{aligned}
$$

and

$$
\begin{aligned}
0 = \; & \mathbb{E}_t log \beta^*_{t,t+1} + \mathbb{E}_t log \tfrac{rer_t}{rer_{t+1}} R_{K^*,t+1} \\
& + \tfrac{1}{2} Var_t log \beta^*_{t,t+1} + \tfrac{1}{2} \underbrace{Var_t log \frac{rer_t}{rer_{t+1}} R_{K^*,t+1}}_{\substack{= Var_t log \frac{rer_t}{rer_{t+1}} + Var_t log R_{K^*,t+1} \\ +2Cov_t\left(log \frac{rer_t}{rer_{t+1}}, log R_{K^*,t+1}\right)}} \underbrace{+ Cov_t(log\beta^*_{t,t+1}, log \frac{rer_t}{rer_{t+1}} R_{K^*,t+1})}_{\substack{= Cov_t(log\beta^*_{t,t+1}, log\frac{rer_t}{rer_{t+1}}) \\ + Cov_t(log\beta^*_{t,t+1}, log R_{K^*,t+1})}}.
\end{aligned}
$$

Hence, the relative excess return is:

$$
\begin{aligned}
& \mathbb{E}_t log \tfrac{rer_t}{rer_{t+1}} + \mathbb{E}_t log R_{K^*,t+1} - \mathbb{E}_t log R_{K^*_*,t+1} = \\
& -\tfrac{1}{2}\left(Var_t log \tfrac{rer_t}{rer_{t+1}} + Var_t log R_{K^*,t+1} - Var_t log R_{K^*_*,t+1}\right) - Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log R_{K^*,t+1}\right) \\
& -Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log \beta^*_{t,t+1}\right) - Cov_t\left(log \beta^*_{t,t+1}, log R_{K^*,t+1}\right) + Cov_t\left(log \beta^*_{t,t+1}, log R_{K^*_*,t+1}\right).
\end{aligned}
$$

Finally, for the relative excess return between the assets B^* and K^*, we proceed as follows:

$$
-r_{t+1} \approx \mathbb{E}_t log \frac{\beta^*_{t,t+1}}{\Pi_{t+1}} \frac{rer_t}{rer_{t+1}} + \frac{1}{2} Var_t log \frac{\beta^*_{t,t+1}}{\Pi_{t+1}} \frac{rer_t}{rer_{t+1}},
$$

and therefore,

$$
\begin{aligned}
&-r_{t+1} = \mathbb{E}_t log \tfrac{rer_t}{rer_{t+1}} - \mathbb{E}_t log \Pi_{t+1} + \mathbb{E}_t log \beta^*_{t,t+1} \\
&-\tfrac{1}{2}\left(Var_t log \tfrac{rer_t}{rer_{t+1}} + Var_t log \beta^*_{t,t+1} + Var_t log \Pi_{t+1}\right) - Cov_t\left(log \beta^*_{t,t+1}, log \Pi_{t+1}\right) \\
&+Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log \beta^*_{t,t+1}\right) - Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log \Pi_{t+1}\right).
\end{aligned}
$$

Similarly, using (41):

$$
\begin{aligned}
&0 \approx \mathbb{E}_t log \tfrac{rer_t}{rer_{t+1}} + \mathbb{E}_t log R_{K^*,t+1} + \mathbb{E}_t log \beta^*_{t,t+1} \\
&+ \qquad \underbrace{\frac{1}{2}\left[Var_t\left(log \frac{rer_t}{rer_{t+1}} + log \beta^*_{t,t+1} + log R_{K^*,t+1}\right)\right]} \qquad . \\
&\quad = \tfrac{1}{2}\left(Var_t log \tfrac{rer_t}{rer_{t+1}} + Var_t log \beta^*_{t,t+1} + Var_t log R_{K^*,t+1}\right) \\
&\quad +Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log \beta^*_{t,t+1}\right) + Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log R_{K^*,t+1}\right) + Cov_t\left(log \beta^*_{t,t+1}, log R_{K^*,t+1}\right)
\end{aligned}
$$

Subtracting the above identity from r_{t+1}, we obtain:

$$
\begin{aligned}
&r_{t+1} - \mathbb{E}_t log \Pi_{t+1} - \mathbb{E}_t log R_{K^*,t+1} \approx -\tfrac{1}{2} Var_t log \Pi_{t+1} + \tfrac{1}{2} Var_t log R_{K^*,t+1} \\
&+Cov_t\left(log \beta^*_{t,t+1}, log \Pi_{t+1}\right) + Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log \Pi_{t+1}\right) \\
&+Cov_t\left(log \beta^*_{t,t+1}, log R_{K^*,t+1}\right) + Cov_t\left(log \tfrac{rer_t}{rer_{t+1}}, log R_{K^*,t+1}\right).
\end{aligned}
$$

E: Producer Currency Pricing

The export price is set in the producer currency. The cost of adjusting the export price is given as follows:

$$\left(\frac{1-n}{n}\right)\frac{\kappa^*}{2}\left(\frac{P^{*e}_{E,t+s}(i)}{P^{*e}_{E,t+s-1}(i)}-1\right)^2\frac{P^{*e}_{E,t+s}(i)}{P_{t+s}}Y^*_{E,t+s}(i).$$

The monopolistic producer i chooses a rule $(P_{E,t}(i), P^{*e}_{E,t}(i), Y_{E,t}(i), Y^*_{E,t}(i))$ to maximize the expected discounted profit:

$$\mathbb{E}_t\left[\sum_{s=t}^{\infty}\beta_{t,t+s}\left(\begin{array}{c}\left(1-\frac{\kappa}{2}\left(\frac{P_{E,t+s}(i)}{P_{E,t+s-1}(i)}-1\right)^2\right)\frac{P_{E,t+s}(i)}{P_{t+s}}Y_{E,t+s}(i)\\ +\ \left(\frac{1-n}{n}\right)\left(1-\frac{\kappa^*}{2}\left(\frac{P^{*e}_{E,t+s}(i)}{P^{*e}_{E,t+s-1}(i)}-1\right)^2\right)\frac{P^{*e}_{E,t+s}(i)}{P_{t+s}}Y^*_{E,t+s}(i)\\ -mc_t\left(Y_{E,t+s}(i)+\left(\frac{1-n}{n}\right)Y^*_{E,t+s}(i)\right)\end{array}\right)\right].$$

From the first-order-conditions with respect to $P_{E,t+s}(i)$ and $P^{*e}_{E,t+s}(i)$ evaluated under symmetric equilibrium, we obtain the real price of EME output for domestic sales ($i.e.$ $rp_E \equiv \frac{P_E}{P}$) as a time-varying markup, $\mu_{E,t}$ over the marginal cost:

$$rp_{E,t} = \mu_{E,t}mc_t,$$

and the real price of EME output for export sales (in units of RoW consumption) as a time-varying markup, $\mu^*_{E,t}$, over the marginal cost

$$rp^*_{E,t} = \frac{\mu^*_{E,t}mc_t}{rer_t}, \tag{42}$$

where

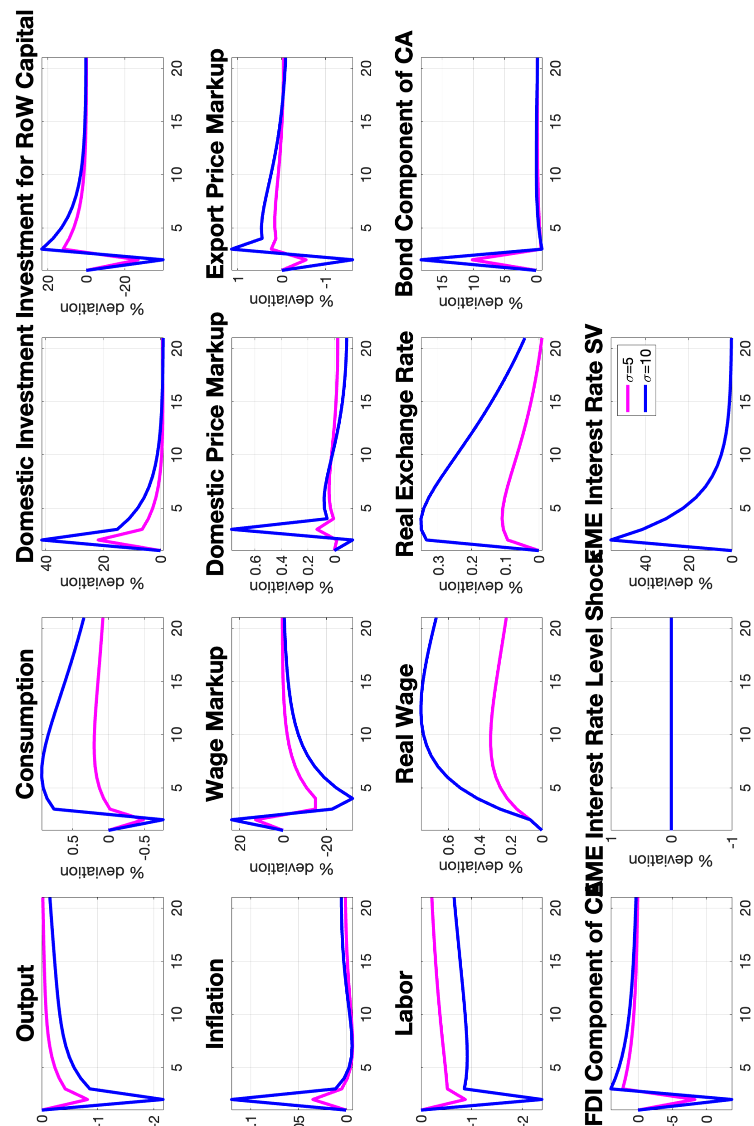
$$\mu_{E,t} \equiv \frac{\epsilon}{(\epsilon-1)\left(1-\frac{\kappa}{2}(\Pi_{E,t}-1)^2\right)+\kappa\left(\Pi_{E,t}(\Pi_{E,t}-1)-\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}(\Pi_{E,t+1}-1)(\Pi_{E,t+1})^2\frac{Y_{E,t+1}}{Y_{E,t}}\right]\right)},$$

$$\mu^*_{E,t} \equiv \frac{\epsilon}{(\epsilon-1)\left(1-\frac{\kappa^*}{2}(\Pi^{*e}_{E,t}-1)^2\right)+\kappa^*\left(\Pi^{*e}_{E,t}(\Pi^{*e}_{E,t}-1)-\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}(\Pi^{*e}_{E,t+1}-1)(\Pi^{*e}_{E,t+1})^2\frac{Y^*_{E,t+1}}{Y^*_{E,t}}\right]\right)},$$

with $\Pi^{*e}_{E,t} \equiv \frac{rp^*_{E,t}}{rp^*_{E,t-1}}\frac{rer_t}{rer_{t-1}}\Pi_t$.

F: Epstein-Zin-Weil Preferences

Figure 25: Impulse Responses to EME SV Shock (Epstein-Zin-Weil Preferences)



G: Time-to-build FDI

Given the long-run nature of FDI, we study the dynamics when multiple periods are required for EME and RoW agents to build the physical capital that will be used in overseas production processes. To do so, we replace equation (3) with the following conditions:

$$\begin{aligned} K_{*,t+1}(h) &= (1-\delta)K_{*,t}(h) + I_{*,1,t}(h), \\ I_{*,j-1,t+1}(h) &= I_{*,j,t}(h); \qquad j = 2, ..., J. \\ I_{*,t}(h) &= \textstyle\sum_{j=1}^{J} \frac{1}{J} I_{*,j,t}(h), \end{aligned} \tag{43}$$

where $\frac{1}{J}$ determines the fixed fraction of the total investment expenditures allocated to projects that are j periods away from completion. $I_{*,j,t}(h)$ is the project that is initiated in period t and is j periods away from completion.[55]

The conditions in (43) imply that, in each period, households initiate projects that will be completed within J periods and will complete partially finished projects that were initiated in previous periods. The EME household's optimization problem subject to the above constraints leads to following Euler equation for EME capital that will be used in the RoW and the respective pricing equation for the outgoing FDI:

$$q_{*,t+J-1} = \mathbb{E}_{t+J-1}\left[\beta_{t+J-1,t+J}\left(rer_{t+J} r_{K,*,t+J} + q_{*,t+J}\left(1-\delta\right)\right)\right], \tag{44}$$

$$\mathbb{E}_t\left[\beta_{t,t+J-1} q_{*,t+J-1}\right] = \frac{1}{J}\left(rer_t + \mathbb{E}_t\left[\beta_{t,t+1} rer_{t+1}\right] + ... + \mathbb{E}_t\left[\beta_{t,t+J-1} rer_{t+J-1}\right]\right). \tag{45}$$

Equations (44) and (45) show that the investment for overseas capital depends on the rental rate (in foreign consumption units) and the expected fluctuations of the real exchange rate during the periods in which the physical capital is built. Equation (45) links the sum of discounted marginal costs of projects (*i.e.* the fluctuations of the real exchange rate) with the expected discounted one-period-beforehand price of investment.

[55] This is the same modeling of time to build as in Kydland and Prescott (1982).

In this case, the current account can be written as:

$$\underbrace{(b_{t+1} - b_t) + rer_t\,(b_{*,t+1} - b_{*,t})}_{\text{Bond component}} + \underbrace{\frac{1}{J}\left[\left(\frac{1-n}{n}\right) rer_t\,(K_{*,t+J} - K_{*,t}) - \left(K^*_{t+J} - K^*_t\right)\right]}_{\text{FDI component}} \equiv CA_t$$

The irreversibility of FDI dampens fluctuations in the FDI component of the capital account. EME households cannot expand intermediate goods production on impact. The dampening of net FDI inflows when FDI is subject to time-to-build is related to the "real options" argument that Bernanke (1983) highlighted when he noted that agents can evaluate their options as uncertainty increases. Time to build implies that agents can prefer to wait for the resolution of uncertainty before changing the supply and demand for FDI.[56] The policy remains inflationary.

[56] See also Stokey (2016) for a more recent analysis.