Interest Rate Uncertainty as a Policy Tool?*

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Abstract

We study a novel 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 output, increase in price level, an improvement in the current account, and an increase in net FDI inflows. Using a calibrated open-economy New Keynesian model, we show that the pattern from a VAR can be reproduced. We introduce a policy rule that adjusts the volatility of emerging market economy interest rate shocks in response to drivers of capital flows. We identify the trade-offs in navigating external balance and price stability. 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 uncertainty policy can be welfare improving under certain scenarios. We further investigate new channels under different assumptions about currency of export invoicing, varying degrees of risk aversion, several drivers of capital inflows, and effective-lower-bound in the rest of the world. Under every scenario, uncertainty policy is inflationary.

JEL codes: E32, F21, F32, F38, G15.

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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 innovative 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 implementation of this policy between November 2010 and August 2011.[5,6] Several studies (e.g., Kara, 2016) document

[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, 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.

[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 exper-

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, documenting the relevance of interest rate volatility on economic activity in five major emerging markets: Brazil, Chile, Indonesia, Korea, and Turkey. Particularly, we study how policy rate volatility and interbank rate volatility evolve over time in these countries and we compare their behavior with those in several advanced economies. Then, we use a structural vector autoregression (VAR) model and identify volatility shocks in the data as an exogenous increase in the volatility of interest rates. We use the VAR to show how higher interest rate volatility affects output, consumer price index (CPI), current account, and FDI.

Empirically, a volatility shock causes a decline in output, increase in consumer price index (CPI), an improvement in the current account and an increase in net FDI inflows. This empirical pattern is robust to use of both policy rate volatility and interbank rate volatility. 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 then provide a laboratory for understanding the transmission channels of interest rate volatility and how they affect the composition of the capital 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 variance of the domestic policy interest rate, which the EME's central bank uses to discourage capital 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

imental 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.

[8] We define FDI as overseas investment in physical capital, in line with the definition of FDI capturing both capital-

trace transmission and propagation of heteroskedastic 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 interest rate uncertainty 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 reproduce 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 second-order preference shock[10] 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, because movements in the real exchange rate make it 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

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.

[10] Similar to the shock in Basu and Bundick (2017).

EME bonds do not make them a good hedge for RoW investor consumption volatility. 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.[11] 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.[12]

We also provide an evaluation of the welfare consequences of the interest rate uncertainty policy. We calculate the welfare as the expected present discounted value of utility. To facilitate interpretation of results, we compare IRUPT relative to a flexible wage/price benchmark. We show that IRUPT is welfare-improving against the demand-type shocks that we consider. Specifically, IRUPT is successful in closing the wedges associated with wage stickiness and imperfect international risk-sharing.

We contribute to the literature that studies the relationship between the global financial cycle and monetary policy in EMEs.[13] We differ from this literature mainly by studying an innovative 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.[14] Instead of considering the consequences of exogenous borrowing constraints,

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

[12] The precautionary pricing motive in the presence of uncertainty is well known in the closed-economy literature on volatility shocks. See, for instance, Basu and Bundick (2017) and Ferńandez-Villaverde et al. (2015). In closed-economy, sticky-price models, a volatility shock leads to setting higher prices. In open economies, the impact on export-price setting depends on exchange rate pass-through.

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

[14] Recent contributions include Acharya and Bengui (2018), Benigno et al. (2016), Bianchi and Mendoza (2018), Dávila and Korinek (2018), Farhi and Werning (2016), Jeanne and Korinek (2019), Reyes-Heroles and Tenorio (2020) and Schmitt-Grohé and Uribe (2016). Aoki et al. (2015) and Corsetti et al. (2018) study the interplay between monetary and macroprudential policies with inefficient capital flows under perfect foresight. Reyes-Heroles and Tenorio (2020) studies macroprudential policies in a small open economy (SOE) against an increase in world interest

we focus on the propagation of heteroskedastic policy volatility 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 uncertainty shocks on economic activity.[15] We differ from this literature by studying the implications of using uncertainty as a policy tool and by focusing on an open-economy environment.[16] 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.[17] Svensson (1991) argues that narrowing exchange rate bands reduces exchange rate volatility, but the variability goes into interest rate variability. Our results indicate that the other way around takes place in our model: 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. Section 7 concludes. An appendix contains additional details and results.

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rate risk. They conduct their analysis by using Jeanne and Korinek (2019)'s model. Although the mechanism and the policy they consider is very different than in this paper, they use second-order shocks in increasing the risk in the world interest rate that the SOE is subject to. See Erten et al. (forthcoming) and Rebucci and Ma (2019) for surveys of this extensive literature.

[15] Recent contributions to the fast-growing literature that started with the seminal papers by Bloom (2009) and Justiniano and Primiceri (2008) include Basu and Bundick (2017), Ferńandez-Villaverde et al. (2015), and Leduc and Liu (2016). See Fernández-Villaverde and Guerron-Quintana (2020) for a survey. In addition to this literature, Alvarez et al. (2007) highlight importance of higher-order terms in monetary policy transmission, and Alvarez and Jermann (2001) and Alvarez et al. (2009) use limited participation in asset market to generate time-varying risk premia.

[16] 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. Ferńandez-Villaverde et al. (2011) introduce uncertainty 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).

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

2 Empirical Evidence

In this section, we provide empirical evidence for time variation in the volatility of interest rates for five emerging market economies and we estimate a vector autoregressive (VAR) model to capture the effects of volatility shocks in the data on output, consumer price index (CPI), current account, and net FDI flows. Our selection of the countries is based on data availability and their ability to represent major emerging market economies. We also conduct our analysis for several advanced economies for comparison purposes.

Our research question is motivated by the widening of the interest rate corridor, which implies higher realized volatility in shorter term rates than the policy rate volatility per se. 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.[18,19] In appendices, we also conduct similar exercises using realized policy rate volatility to present a broader analysis.

2.1 Interest rates and their volatility

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.[20] We calculate 12-month rolling standard deviations and convert them into quarterly frequency data. Figure 2 shows the evolution of the volatility of overnight interbank interest rates for EMEs in our sample. The figure clearly 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.

[18] We thank an anonymous referee for pointing out that 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.

[19] A more ideal measure of implied volatility could be calculated using interest rate options; however, to the best of our knowledge, no such data is available for emerging market economies.

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

In Figure 3, 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 1 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 2 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 advanced economies.

2.2 VAR Evidence

To empirically study the effects of interest rate volatility shocks on external accounts, we estimate a VAR with the following variables: overnight interbank interest rate volatility (as described above), real gross domestic product (GDP), consumer price index (CPI), current account to GDP ratio, and net FDI inflows to GDP ratio. Real GDP and CPI enter the VAR in log levels. The rest of the variables enter as they are. We estimate the VAR model for each of the EMEs in our sample separately. Appendix A provides further explanation on data construction and the VAR estimation.

We identify a volatility shock by using a Cholesky decomposition with the 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. Our methodology closely follows Basu and Bundick (2017) and Leduc and Liu (2016).

Figure 4 shows estimated impulse responses to an identified interbank rate volatility shock and the 95% confidence intervals. Each row indicates a country and variables are shown in columns. The movements in real GDP and CPI are in percent deviation terms, whereas movements in interest rate volatility, current account to GDP, and net FDI flows to GDP are in levels. Due to heterogeneity shown in the volatility of interest rates, a one-standard-deviation volatility shock implies various magnitudes for each EME in our sample. A one-standard-deviation increase translates into a 34.6%

change for Brazil, 26.9% for Chile, 36.3% for Indonesia, 54.4% for Korea, and 91.5% for Turkey.[21]

On impact, an increase in volatility generates a fall in real GDP, a rise in CPI, improvement in the current account, and net FDI inflows on average. Real GDP and CPI responses are qualitatively the same for all of the EMEs in our sample. The response of current account to GDP is relatively weaker on impact for Indonesia. The response of net FDI flows is quite strong for Turkey and Indonesia. The response of net FDI flows turns positive (becomes an inflow) for Brazil after four periods. Net FDI flows are negative on impact for Chile but the sign changes in the next period and stays positive for four subsequent periods. We show in the appendices that our stylized facts survive under different assumptions when estimating the VAR. In appendices, we further provide impulse responses when we estimate the VAR for advanced economies. Impulse responses for advanced economies starkly differ from those in EMEs. A decrease in CPI and a deterioration in current account to GDP are common patterns for the advanced economies in our sample. These responses are in line with the analysis provided in Basu and Bundick (2017) and Fogli and Perri (2015) whose main focus is advanced economies.

Based on this evidence, we argue that an increase in interbank rate volatility can generate a fall in output, a rise in inflation, an improvement in the current account and net FDI inflows in EMEs. In the next section we develop a New Keynesian open economy model with flows of short-term bonds and FDI. In the subsequent sections, we show that the model can reproduce the evidence documented above and we study the mechanisms through which this happens.

3 The Model

The world is composed of two regions, EME and RoW.[22] 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 assets 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.

[21] These numbers are the percent changes from the averages. For instance, for Brazil, a one-standard-deviation shock implies 34.6% increase from its mean of 2.0263. The responses of current-account-to-GDP, net-FDI-flows-to-GDP are reported in the same way.

[22] 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.

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 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 interpret the second-moment shock to the preference as the uncertainty about future demand and the second-moment shock to the monetary policy as uncertainty about future policy interest rate.

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_t^{ϑ}, follows an $AR(1)$ process:

$$\sigma_t^{\vartheta} = (1-\rho^{\sigma^{\vartheta}})\sigma^{\vartheta} + \rho^{\sigma^{\vartheta}}\sigma_{t-1}^{\vartheta} + \eta_{\sigma^{\vartheta}}\varepsilon_t^{\sigma^{\vartheta}}.$$

where $\varepsilon_t^{\sigma^{\vartheta}}$ 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.[23] 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

[23] 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.

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) 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.[24] 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:

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

[24] 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.

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

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 $rer_t \equiv \frac{S_t P_t^*}{P_t}$ is the consumption-based real exchange rate (units of EME consumption per unit of RoW). We omit the transversality conditions for bond holdings.

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.[25]

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-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

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

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:

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

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 $\alpha_1 + \alpha_2 \in (0,1)$.[26]

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

[26] 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 $b = 0$.

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:

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

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:

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

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.[27]

The monetary policy shock, u_t, represents discretionary deviations from the rule-based policy, including the EME central bank's reactions to intense capital flows. We allow this term to incorporate time-varying volatility in the form of stochastic volatility.[28]

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

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

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 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 3 summarizes the key equilibrium conditions of the model. Equations ((2), (3), (6), (7), (8), (9), (12), (13), (14), (15), (16), (17), (45), (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 the model and illustrate that its dynamics are consistent with the VAR evidence. We further study the model to identify the transmission channels of volatility shocks.

4.1 Calibration

The model is calibrated using literature on emerging markets and based on our VAR evidence. Table 4 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 3.75, 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 Gali 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.[29]

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 Gali and Monacelli (2015).[30] 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.[31]

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.[32]

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

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

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

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

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

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 the median EME in our sample. Similar values are also used by Benigno 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). 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, $\eta_{\sigma^{\vartheta}}$, to 0.003.

With regards to the shock process in EME interest rate, we set the persistence and mean volatility of level shocks using the estimation of interest rate spreads for our median EME in Ferńandez-Villaverde et al. (2011). It implies that persistence, ρ^{u}, is 0.95 and the mean volatility is 0.094 percentage points ($100e^{-6.97}$). We parameterize the second-moment shock to EME interest rate based on our VAR evidence. In our baseline VAR, a one standard-deviation shock raises the measure of uncertainty by 36.3 percent for the median EME in our sample, i.e., $\eta_{\sigma} = 0.363$. The VAR evidence in Section 2 also shows that the effects volatility shocks gradually decrease over time. Specifically, the persistence of the interest rate volatility shock, ρ^{σ}, is 0.9056 for the median EME, if the volatility shock is approximated by an AR(1) process. We also report the standard deviation and persistence of interest rate volatility shocks for other EMEs in our VAR in Table 5.

4.2 Solution Method

We solve the model by using third-order perturbation techniques.[33] 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 (Ferńandez-Villaverde et

[33] 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 (Ferńandez-Villaverde et al. (2011)).

al. (2011)). Therefore, calculating impulse responses from the non-stochastic steady state is not 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 Ferńandez-Villaverde et al. (2011), and we characterize it as the fixed point of the third-order approximated policy functions in the absence of shocks.[34]

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

[34] 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*.

the current and future values of income, and therefore, distortions in valuation of wealth.[35] Hence, 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 calibrated according to the the median EME in our VAR estimation. 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.[36] Our interpretation for the RoW preference SV shock is an increase in the demand uncertainty of RoW agents. 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 during this episode (see, e.g., 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. This confirms that our model is in line with the empirical evidence that we presented in Section 2. Domestic markups go up and exporter markups go down. We explain

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

[36] 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.

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 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 if EME interest rate uncertainty is engineered to respond to capital inflows that are a result of RoW preference SV shocks. We examine a related scenario in the next subsection.

4.3.2 Interest Rate Uncertainty as a Policy Tool (IRUPT)

Figures 6 and 7 show that μ_{t+1}^{UIP} 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 the possible consequences of 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 RoW preference volatility. The latter is usually calculated by using the VXO index (among others, see Basu and Bundick (2017)). 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 fluctuations in VXO. 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 5. Dashed blue lines indicate the responses when $\iota^{\sigma} = 10$ and dotted blue lines are generated after setting $\iota^{\sigma} = 15$.

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. Dampened

consumption fluctuations imply that movements in the risk-sharing wedge gets smaller 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, while fluctuations in wage markups become smaller in response to higher EME interest rate volatility. 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.[37] Certainty equivalence would imply that $\mathbb{E}_t\left[x_{t+1}^{B^*,B_*^*}\right] = \mathbb{E}_t\left[x_{t+1}^{K^*,K_*^*}\right] =$

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

$\mathbb{E}_t\left[x_{t+1}^{B^*,K^*}\right] = 0$. However, given the non-linear solution of our model, endogenous fluctuations in higher-order terms lead to nonzero expected relative excess returns.[38] 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 our results, we use the assumption of log-normality to express the relative excess returns as follows:[39]

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

$$\begin{aligned}\mathbb{E}_t\left[x_{t+1}^{K^*,K_*^*}\right] &\approx -\tfrac{1}{2}\left(\mathbb{V}ar_t\Delta\tilde{rer}_{t+1} + \mathbb{V}ar_t\tilde{r}_{K^*,t+1} - \mathbb{V}ar_t\tilde{r}_{K_*^*,t+1}\right)\\ &+\mathbb{C}ov_t\left(\Delta\tilde{rer}_{t+1}, \tilde{r}_{K^*,t+1}\right) - \mathbb{C}ov_t\left(log\beta_{t,t+1}^*, \tilde{r}_{K^*,t+1} - \Delta\tilde{rer}_{t+1} - \tilde{r}_{K_*^*,t+1}\right),\end{aligned} \tag{32}$$

[38] There are several studies related to our analysis here. Among others, Gabaix and Maggiori (2015) 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 heteroskedastic volatility of the interest rate.

[39] Appendix D provides detailed derivations of these relations.

$$\mathbb{E}_t\left[x_{t+1}^{B^*,K^*}\right] \approx -\frac{1}{2}\mathbb{V}ar_t\pi_{t+1} + \frac{1}{2}\mathbb{V}ar_t\tilde{r}_{K^*,t+1} + \mathbb{C}ov_t\left(\tilde{r}_{K^*,t+1} + \pi_{t+1}, log\beta^*_{t,t+1} - \Delta\tilde{rer}_{t+1}\right). \quad (33)$$

Lowercase letters in the relations above denote logs of the respective variables. If a variable was denoted by a lowercase letter in Section 2, we use a tilde to denote the log of the original variable.[40] Equation (31) shows an increase in the volatility of EME currency affects the relative excess return negatively. We also observe that EME currency is a good hedge when there is an increase in EME interest rate SV shock. The RoW investor is seeking assets whose currency negatively covaries with her stochastic discount factor (she wants assets that are valuable in bad times and vice versa). Capital outflows decrease the RoW stochastic discount factor and we observe negative covariance with exchange rate, pushing relative excess return further down.

The latter effect reveals itself in Equation (32), too. Covariance of RoW stochastic discount factor with the change in real exchange rate implies a positive effect on the relative excess return of EME physical capital. This effect offsets the opposite effects on the relative return through an increase in the variance of exchange rate and variance of rental returns.

Finally Equation (33) reveals the effect of inflation on the relative excess return of EME bond versus EME physical capital that is held by RoW agents. In response to EME interest rate SV shock, the variance of inflation, the covariance of inflation with RoW stochastic discount factor, and the covariance of inflation with real exchange rate fluctuations push the excess return of EME bond down.

4.3.4 Transmission within the Emerging Market Economy

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

[40] 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.

Consumption Smoothing Motive and Oi-Hartman-Abel Effects

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 disincentives 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.

Moreover, in the absence of nominal rigidities savings are channeled to domestic investment because firms demand more inputs from both EME and RoW to expand production. In the absence of frictions, factors of production are relatively more elastic and firms are willing to take advantage of volatility by increasing production. This is known in the literature as the Oi-Hartman-Abel effect (see Oi (1961), Hartman (1972), and Abel (1983)). This effect is very small in our model, because interest rate does not have any impact on real variables in the absence of nominal rigidities and all of the dynamics are a result of the small cross terms of the higher moments related with inflation and other variables.

Precautionary Wage and Pricing Effects

Most of the variations in our model are due nominal rigidities and we isolate 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 quite different under these two scenarios, although EME still attracts FDI and generates outflows in the bond component of the current account.

First, 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. Figure 10 shows that wages go up instantaneously, because wages are flexible. Increase in wages generates an exchange rate appreciation. When exchange rate appreciates, we also observe that exporter markup goes

up, different than in our baseline scenario. When we focus on Figure 11, we observe the impact of willingness to work under sticky wages. Firms are willing to increase the wages to expand labor, but because of stickiness wages hardly move and wage markup goes down. 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 Ferńandez-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 Ferńandez-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:

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

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. Table 6 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] Volatility of the current account indicates that opposing forces are in effect. This is in line with our discussion how rigidities affect the real exchange rate its role on the current account. The effects of price and wage stickiness do not add up, but instead, they affect each other through different channels. It is important to keep in mind that these standard deviations are also generated by interest rate level shocks in addition to SV shocks. Therefore, we rely more on our impulse response analysis for the transmission of volatility shocks.

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:

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

We report welfare for EME, RoW, and a weighted average of both regions which we call Joint Welfare. It is important to remind the reader that our baseline model under IRUPT (subsection

[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.

4.3.2) has three shocks: RoW preference level shock, RoW preference SV shock, EME interest rate level shock. We turn on and off several shocks and several ingredients in our model in order to account for the effects of each component.

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. By doing so, we capture transitional dynamics when comparing two welfare numbers of different model versions.[43]

We start by comparing welfare with and without stochastic volatility shocks (i.e., only RoW preference and EME interest rate shocks). This implies that policy is conducted by the Taylor rules described in the model section.[44] Table 7 shows the welfare numbers for this exercise. Left column reports numbers from our baseline model simulation with the three shocks (EME interest rate level, RoW preference level, and RoW preference SV) when IRUPT is off (i.e., $\iota^\sigma = 0$) and right column reports numbers after simulation of the baseline model with two level shocks (EME interest rate level and RoW preference level shocks). We see that introducing second-order RoW preference shocks reduces EME welfare. We also observe that joint welfare is reduced after introducing RoW preference SV shocks although RoW welfare improves by little.

To facilitate interpretation of results, we also report welfare numbers from the model version with flexible wages and prices in Table 8. We use the model under IRUPT, but shut down its impact by setting $\iota^\sigma = 0$, so that the previously discussed three shocks affect the model without a change in EME interest rate shock volatility. The last column indicates numbers from this model version. In the absence of price rigidities, demand shocks, such as the interest rate and preference shocks, affect the natural rate of interest without having any effect on the natural level output (movements in the interest rates is also ineffective in making an impact to real variables). Therefore, fluctuations in real variables are minimized. Moreover, extensive risk sharing generates very close welfare numbers for each region. These well-known effects are being reflected by high welfare numbers in the fourth

[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)

[44] It is known that Taylor rules respond well to inefficiencies due to fluctuations in price markups. Our baseline model features wage rigidities and incomplete international markets in addition to 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.

column. When we introduce price and wage rigidities, we see that welfare is being reduced under simulations with the same shocks. The effects of rigidities on welfare are reported in second and third columns. Welfare decreases more under sticky wages than under sticky prices.

In Table 9, we report the welfare numbers when IRUPT is on and the feedback parameter is set to 10. We see that IRUPT generates higher welfare (although small) vis-a-vis the baseline model without IRUPT (when monetary policies are only set by Taylor rules, i.e. $\iota^{\sigma} = 0$). The small welfare gains are present in the model version without wage or price rigidities.

In our impulse response analysis, we conducted experiments against second-order RoW preference shocks and we showed that IRUPT deployed against second-order preference shocks can do a good job in the sense of dampening the fluctuations in international risk-sharing wedge and the wage markup. However, we also showed that fluctuations in price markups are increasing in response to IRUPT. Therefore, the effects on welfare were not clear. Comparing the third columns of Tables 8 and 9 shows that IRUPT is reducing the welfare loss from wage stickiness. Comparing the second columns also indicate a welfare gain in the presence of price rigidities under IRUPT. However, this gain is coming from improving risk-sharing rather than dampening the fluctuations in markups. Indeed, we observe improvements in welfare when comparing joint welfare numbers in Tables 8 and 9.

To see how IRUPT affects this tradeoff (i.e., improving fluctuations in wage markup and international risk-sharing vs. deteriorating the fluctuations in price markups), we run simulations with increasing the feedback parameter in IRUPT. Table 10 reports our simulations for $\iota^{\sigma} = 10$, $\iota^{\sigma} = 100$, $\iota^{\sigma} = 200$, and $\iota^{\sigma} = 2000$, and Figure 13 plots the welfare numbers when we do a grid search over ι^{σ}. We observe that a value of ι^{σ} close to 110 maximizes the EME welfare while a value of ι^{σ} close to 120 maximizes the Joint Welfare. Under higher values than these, deterioration in fluctuations of price markups offset the welfare gain and IRUPT becomes welfare deteriorating. Welfare numbers indicate ι^{σ} should be set to a much higher number than in our impulse response analysis, because the majority of fluctuations are generated by level shocks, instead of second-moment shocks.

The analysis in this section shows that capital flow cycles can be costly from the perspective of EMEs, and policy is desirable from the EME perspective of policymakers. Although the quantitative effects are small, IRUPT is welfare-improving against the shocks we consider.

6 Additional Results

In this section, we discuss the effects of modifying our baseline 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 first-moment RoW preference shocks, rather than second-moment RoW preference 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.[45]

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. It is a natural question to ask how do they perform vis-a-vis IRUPT.

We modify the EME household's budget constraint to introduce capital controls as in the previous literature:

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

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.

[45] 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.

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: $\tau_t = \iota^\tau\left[(b_t - b_{t+1}) + rer_t\left(b_{*,t} - b_{*,t+1}\right)\right]$. 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 still a Taylor rule without stochastic volatility shocks). International risk-sharing wedge moves less with dampened fluctuations in consumption.

Table 11 reports the welfare numbers for capital controls. Strikingly, welfare under capital controls is less than welfare under the model version with only Taylor rule (without Taylor rule SV shock). It is important to remind the reader that when calculating welfare, we hit the model with RoW preference level, RoW preference SV, and EME interest rate level shocks. Although capital control taxes do a good job against RoW preference SV shocks, it worsens the model outcome when level shocks are considered. Therefore, we see lower welfare numbers than absent capital controls.[46]

6.2 Capital Flows Generated by RoW Preference Level Shock

In this subsection, we comment on how different drivers of capital flows might affect EME. Particularly, 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.[47] 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.

[46] It is 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 welfare impact of capital controls.

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

RoW preference level shock generates more amplified fluctuations than the RoW preference second-order shock. However, it is still possible for IRUPT to improve the situation. We know that, in response to an increase in EME interest rate SV, wage markup and export markup go down whereas domestic price markup 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 assess the impact on IRUPT we replace equation (25) with the following feedback rule.

$$\sigma_t = \sigma - \iota(\vartheta_t^* - \vartheta^*), \tag{34}$$

This rule implies that volatility of EME Taylor rule shock responds to changes in RoW preference level shock with a scale parameter ι. Of course, discount factor shocks are not observable in reality and it would be hard to design such rule. But for the purpose of exposition, this rule is indicative in understanding responses to changes in RoW discount factor.[48] It is clearly seen from Figure 15 that IRUPT designed to respond RoW discount factor shocks dampens the fluctuations in wage and price markups, but amplifies the fluctuations in the international risk-sharing wedge. In doing so, capital inflows are channeled into FDI and bond inflows are discouraged. Hence, we conclude that IRUPT is also effective against RoW discount factor level shocks.

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 impact dynamics against capital inflows generated by RoW preference SV shocks:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho} \left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho)\rho_\Pi} \left(\frac{Y_t}{Y}\right)^{(1-\rho)\rho_Y}. \tag{35}$$

Figure 16 plots impulse responses. Purple lines indicate dynamics from the baseline model in which Taylor follow is described by equation (23) and $\iota^\sigma = 0$. Blue lines show impulse responses from the model in which Taylor rule is described by equation (35). A Taylor rule responding to

[48] It is straightforward to replace equation (34) with a rule in which EME Taylor rule shock volatility responds to an observable variable that strongly correlates with RoW discount factor, such as the bond inflows into EME: $\sigma_t = \sigma + \iota((b_t - b_{t+1}) + rer_t\,(b_{*,t} - b_{*,t+1}))$. This would only change the impact of the scale parameter, ι.

fluctuations to exchange rate performs better against RoW preference SV shocks. 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. Therefore, we conclude that IRUPT can further improve this scenarios along the dimensions described in the previous sections.

6.4 Impact of Bond Adjustment Cost Parameter

Table 12 shows the effect of varying parameter η on bond adjustment costs. The table shows that varying η has welfare implications. 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 13 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.[49] Although we calibrate this parameter to a widely used value in the literature, we highlight that this parameter plays a role in generating our welfare results.[50]

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 using median EME calibration from VAR estimation.

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

[50] 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. We solve a small open economy RBC model with stochastic volatility shocks to account for the impact of this parameter. For the established values in the literature, between the range 0.001 and 0.0025, we observed that the differences between model dynamics are small when comparing impulse responses. However, very small values for adjustment parameters (e.g., 0.00025) can 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 price-wage 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 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:

$$V_t \equiv \left\{ (1-\beta) \left(C_t(h) - \frac{L_t(h)^{1+\varphi}}{1+\varphi} \right)^{1-\gamma} + \beta \left[\mathbb{E}_t \left(V_{t+1}^{1-\sigma} \right) \right]^{\frac{(1-\gamma)}{(1-\sigma)}} \right\}^{\frac{1}{1-\gamma}}. \tag{36}$$

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

$$\beta^*_{t,t+1} \equiv \frac{\beta U_{C,t+1}}{U_{C,t}} \left(\frac{V_{t+1}^{1-\sigma}}{\left(\mathbb{E}_t \left[V_{t+1}^{1-\sigma} \right] \right)} \right)^{\frac{\gamma-\sigma}{1-\sigma}}. \tag{37}$$

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. We conclude that higher degrees of risk aversion do not affect our results significantly.

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. Capital flows in an interdependent world economy are significantly impacted by the monetary policy of advanced economies. Here, we study the implications of these countries' interest rate policy being tied in a liquidity trap situation. Unless explicitly noted, we study the consequences of introducing one model departure from baseline at a time.

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, because 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.[51]

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 heavily 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 flows 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 is an effective tool (in the sense of achieving the objectives for which the CBRT used it) 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.

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

Importantly, under all scenarios we studied, IRUPT is inflationary. We also show that IRUPT is welfare-improving against the demand-type shocks that we consider. Fluctuations in inefficient wedges related with wage stickiness and international imperfect risk sharing are dampened when IRUPT is deployed against shocks that we consider.

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. We think of this policy as a tool to be deployed only in special circumstances. With this perspective, our analysis provides a roadmap for how 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: 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

Table 2: 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

Notes: Data from Haver, FRED, and Eurostat.

Table 3: 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	$\alpha_1 w_t L_t = (1-\alpha_1-\alpha_2) r_{K,t} K_t$ $\alpha_2 r_{K,t} K_t = \alpha_1 r_{K,t}^* K_t^*$
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 4: 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	3.75
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

Table 5: Interest Rate Volatility Shock Process

		Brazil	Chile	Indonesia	Korea	Turkey
Persistence	ρ^σ	0.9056	0.9326	0.9235	0.8988	0.8661
Av. std. dev. of SV shock	η_σ	0.346	0.269	0.363	0.544	0.915

Table 6: Standard deviation of macro and financial aggregates

	Baseline	Flexible Price	Flexible Wage	Absent Nominal Rigidities
σ_Y	2.81	2.49	2.23	0.00
σ_C	3.70	3.45	2.61	0.00
σ_L	3.91	4.43	2.26	0.00
σ_{rer}	1.32	0.65	1.28	0.00
$\sigma_{CA(Bond)}$	2.22	2.03	3.29	0.00
$\sigma_{CA(FDI)}$	5.21	6.08	10.79	0.00

Table 7: Welfare with and without SV shocks

	Baseline with $\iota^\sigma = 0$	Baseline without RoW SV Shocks
EME Welfare	15.6418	15.6709
RoW Welfare	16.0954	16.0759
Joint Welfare	15.8686	15.8734

Table 8: Welfare under $\iota^\sigma = 0$

	Baseline	Flexible Wages	Flexible Prices	Flexible Wages and Prices
EME Welfare	15.6418	57.4115	15.4068	82.6272
RoW Welfare	16.0954	58.1625	12.4148	82.6327
Joint Welfare	15.8686	57.7870	13.9108	82.6299

Table 9: Welfare under $\iota^\sigma = 10$

	Baseline	Flexible Wages	Flexible Prices
EME Welfare	15.6427	57.4119	15.4077
RoW Welfare	16.0948	58.1623	12.4143
Joint Welfare	15.8688	57.7871	13.9110

Table 10: Welfare (Baseline Model)

	$\iota^\sigma = 10$	$\iota^\sigma = 100$	$\iota^\sigma = 200$	$\iota^\sigma = 2000$
EME Welfare	15.6427	15.6471	15.6442	14.2024
RoW Welfare	16.0948	16.0921	16.0941	17.0448
Joint Welfare	15.8688	15.8696	15.8692	15.6236

Table 11: Welfare Comparison (Baseline with $\iota^{\sigma} = 0$ vs. Tax on RoW Bonds)

	$\tau = 0$	$\tau = 0.05$
EME Welfare	15.6418	15.6191
RoW Welfare	16.0954	16.0065
Joint Welfare	15.8686	15.8128

Table 12: Welfare Comparison ($\eta = 0.0025$ vs. $\eta = 0.00025$ when $\iota^{\sigma} = 10$)

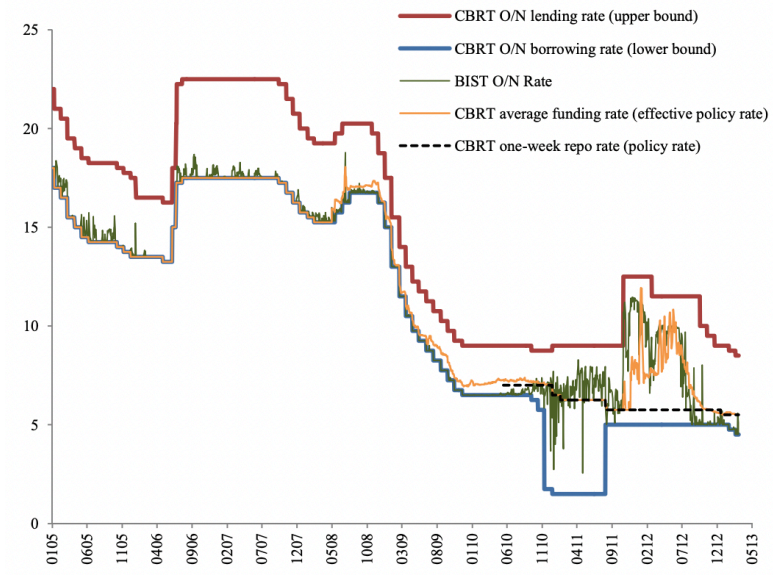
	$\eta = 0.0025$	$\eta = 0.00025$
EME Welfare	15.6427	16.6993
RoW Welfare	16.0948	18.9890
Joint Welfare	15.8688	17.8442

Table 13: Standard deviation of macro and financial aggregates ($\eta = 0.0025$ vs. $\eta = 0.00025$ when $\iota^{\sigma} = 10$)

	$\eta = 0.0025$	$\eta = 0.00025$
σ_Y	1.70	1.39
σ_C	2.20	1.94
σ_L	2.37	2.27
σ_{rer}	0.79	1.06
$\sigma_{CA(Bond)}$	1.14	3.79
$\sigma_{CA(FDI)}$	3.09	4.49
σ_{Π}	0.39	0.47

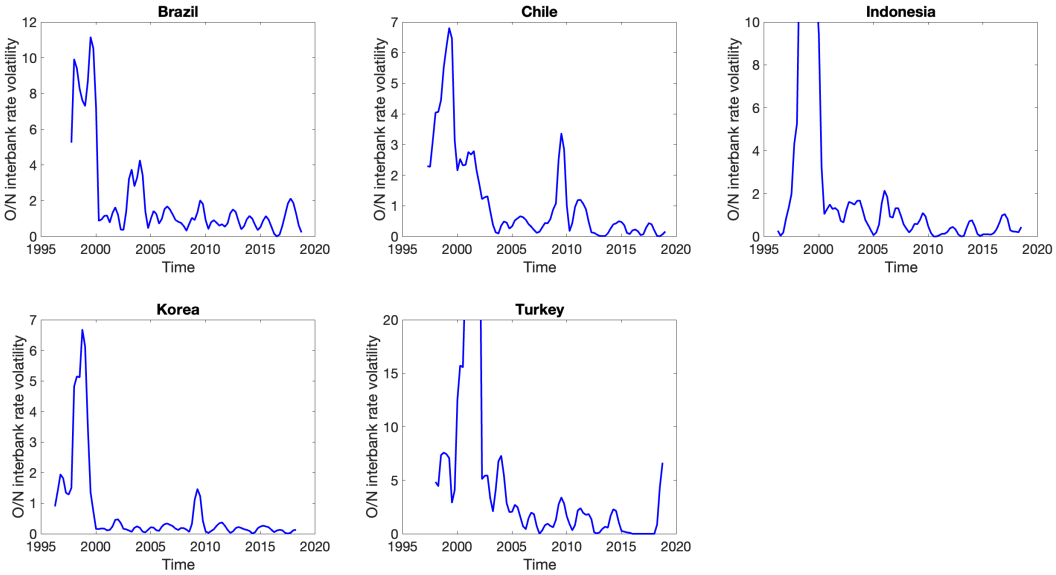
Figures

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



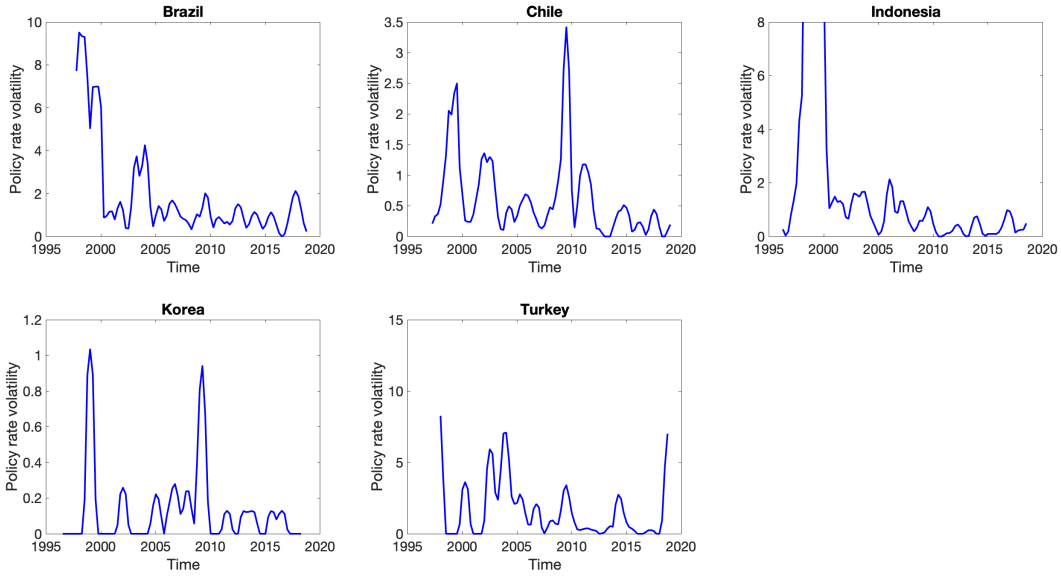
Source: Kucuk et al. (2014)

Figure 2: 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 3: 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 4: Impulse Responses to an Interest Rate Volatility Shock

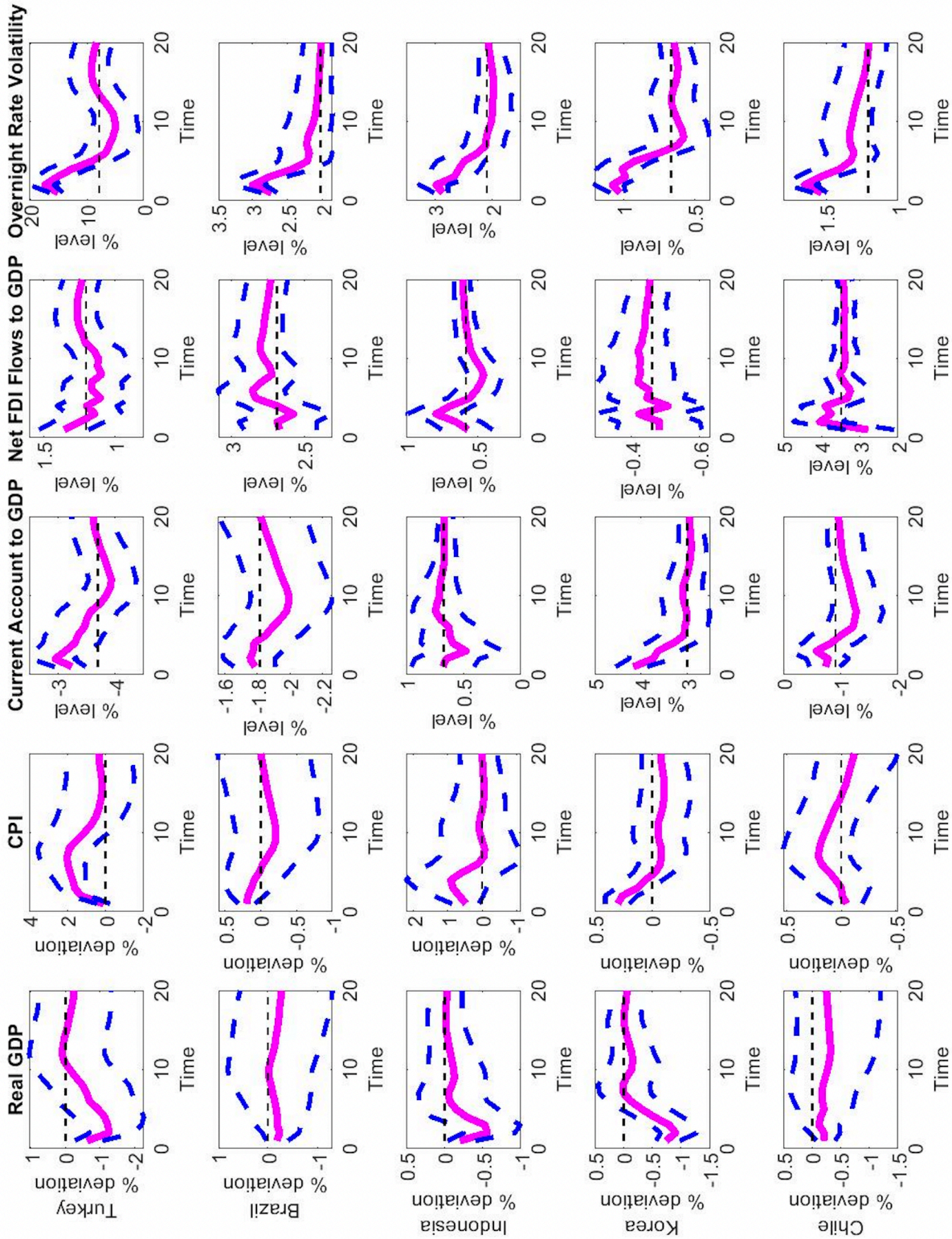


Figure 5: Model Architecture

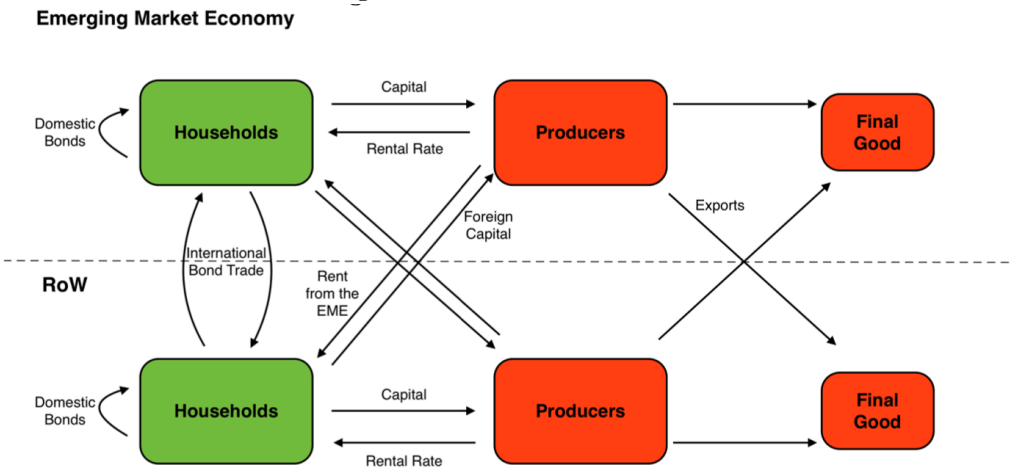


Figure 6: Impulse Responses to an Increase in RoW Preference SV Shock

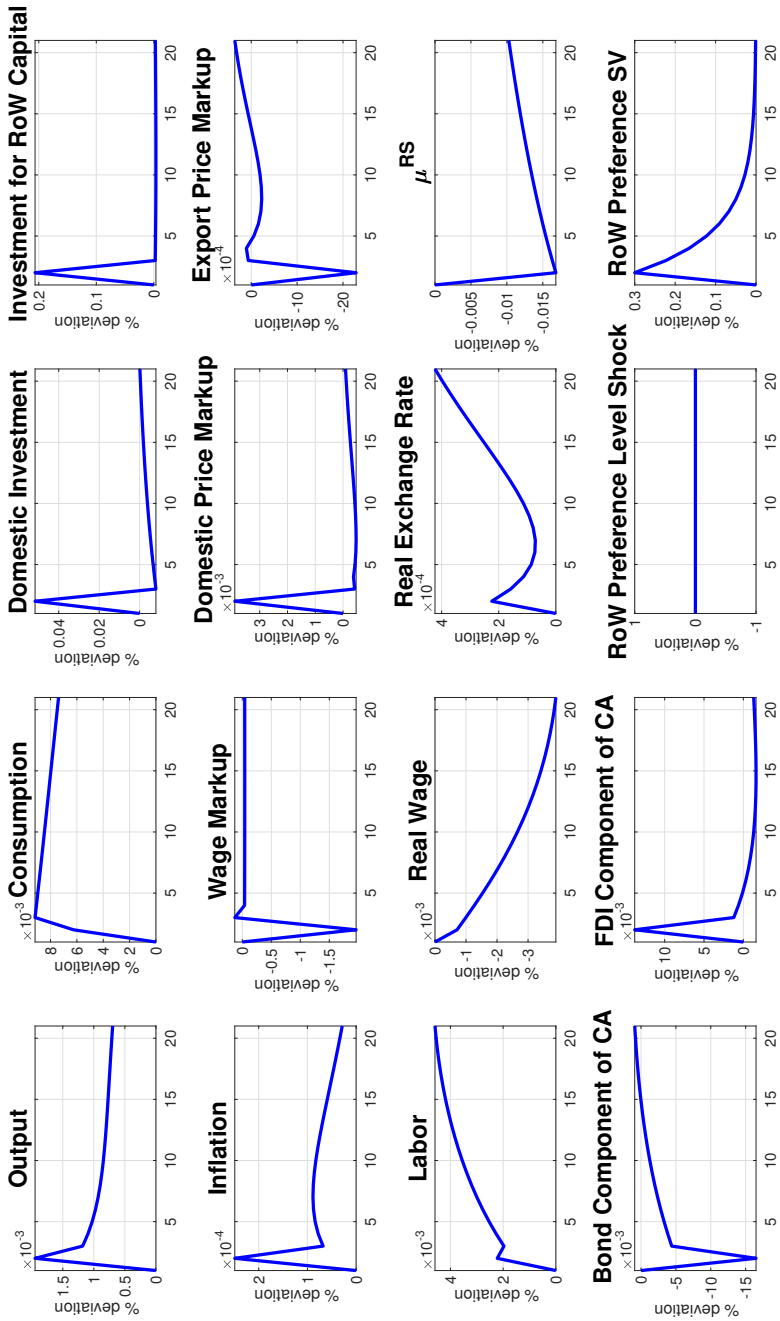


Figure 7: Impulse Responses to an Increase in EME Interest Rate SV Shock

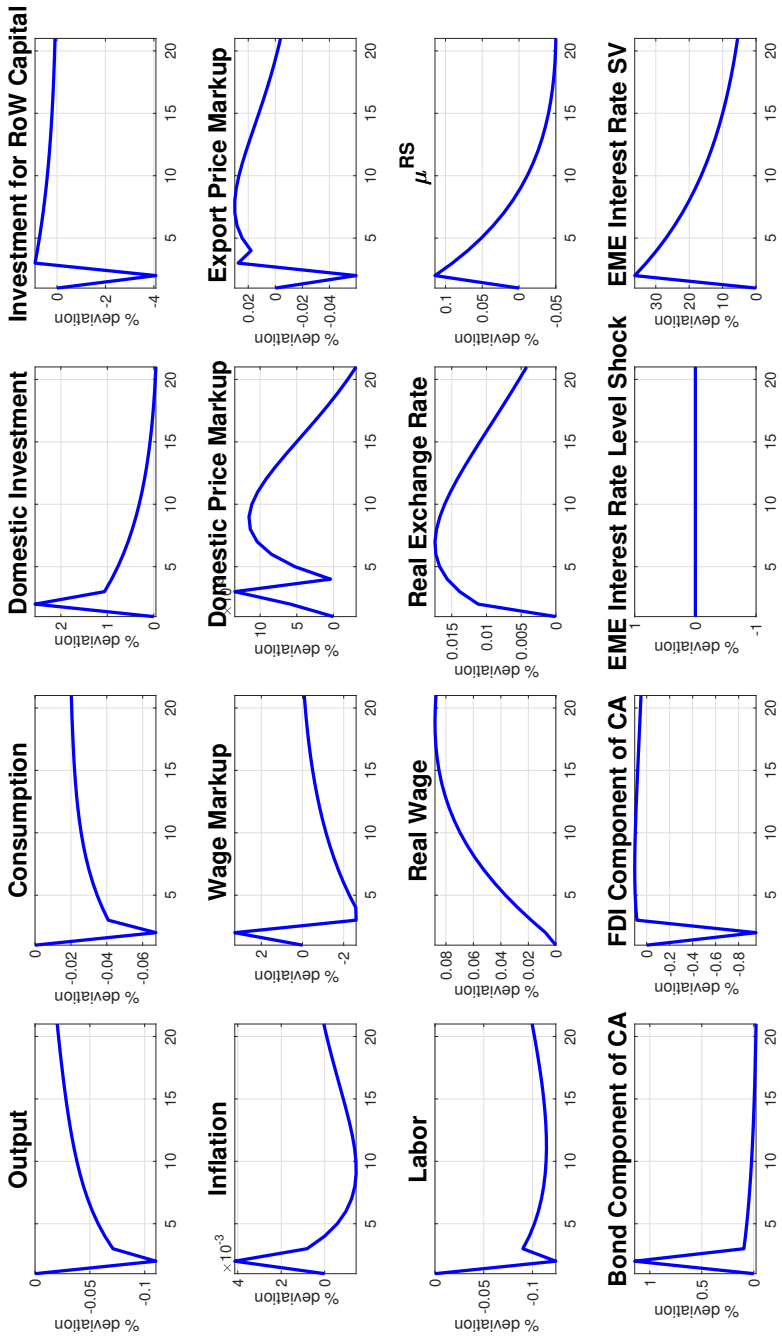
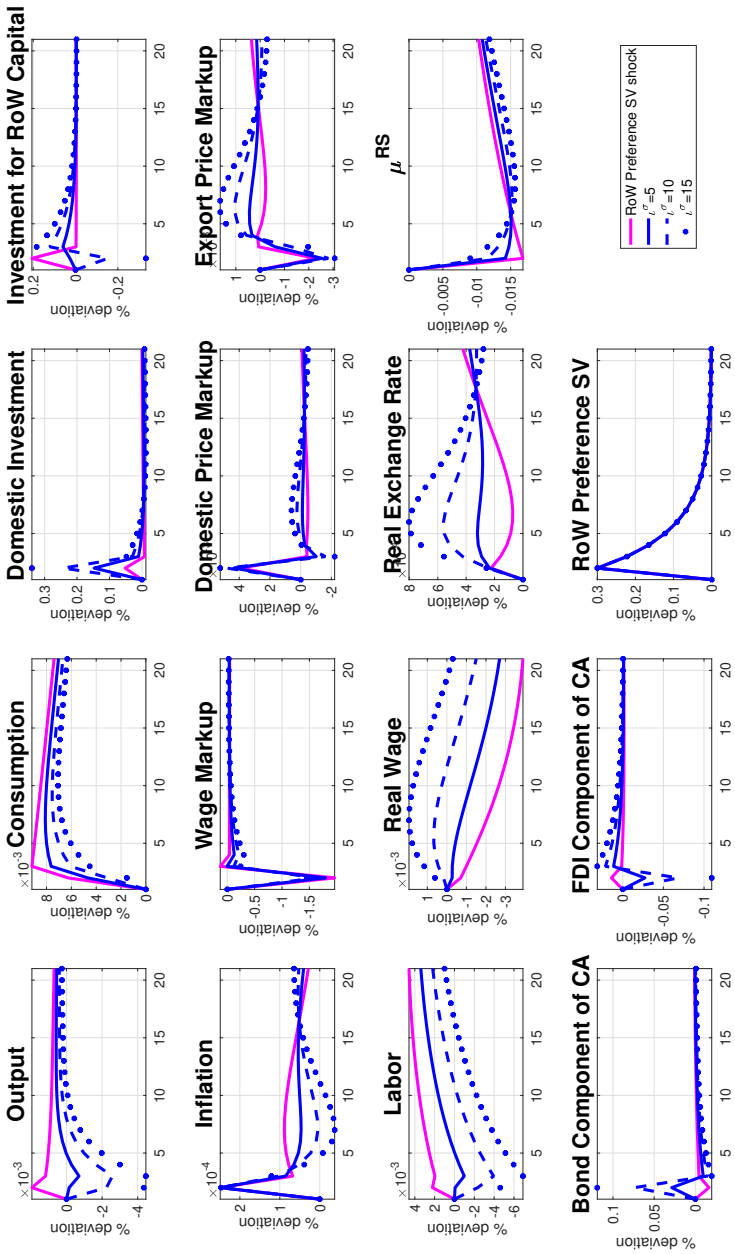
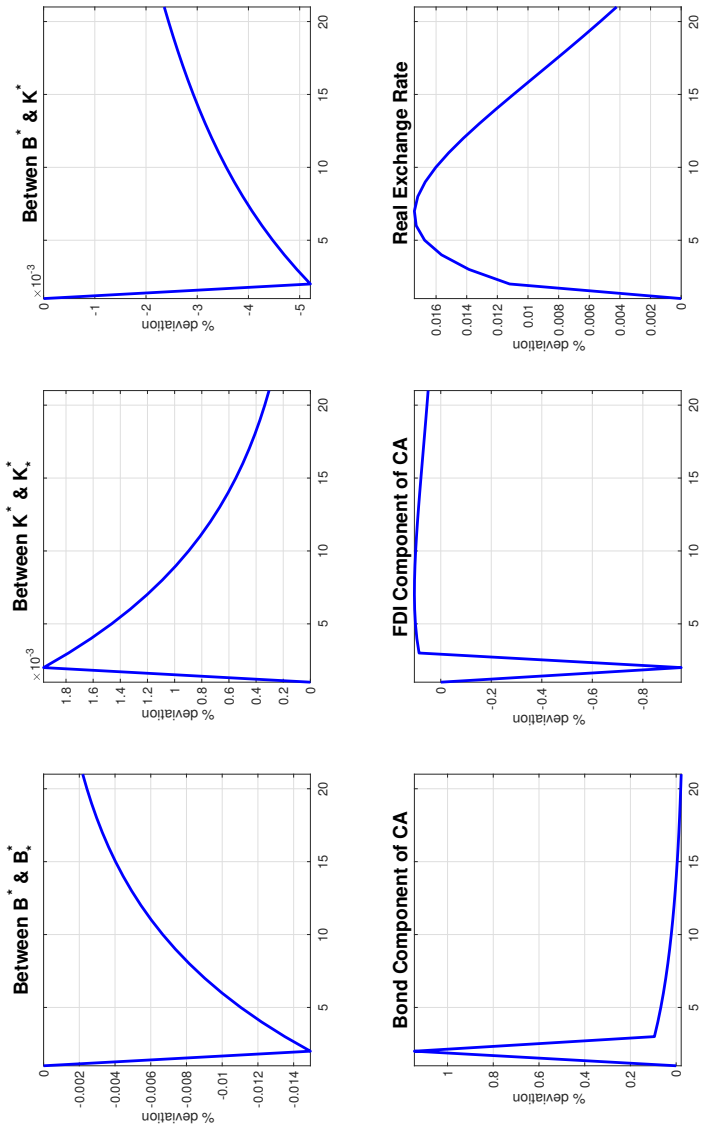


Figure 8: Interest Rate Uncertainty as a Policy Tool (IRUPT)



Notes: Purple lines indicate responses to a RoW preference SV shock. Solid blue responses indicate IRUPT with $\iota^{\sigma} = 5$, dashed blue responses indicate IRUPT with $\iota^{\sigma} = 10$, and dotted blue responses indicate IRUPT with $\iota^{\sigma} = 15$.

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 ($\kappa^W = 0$)

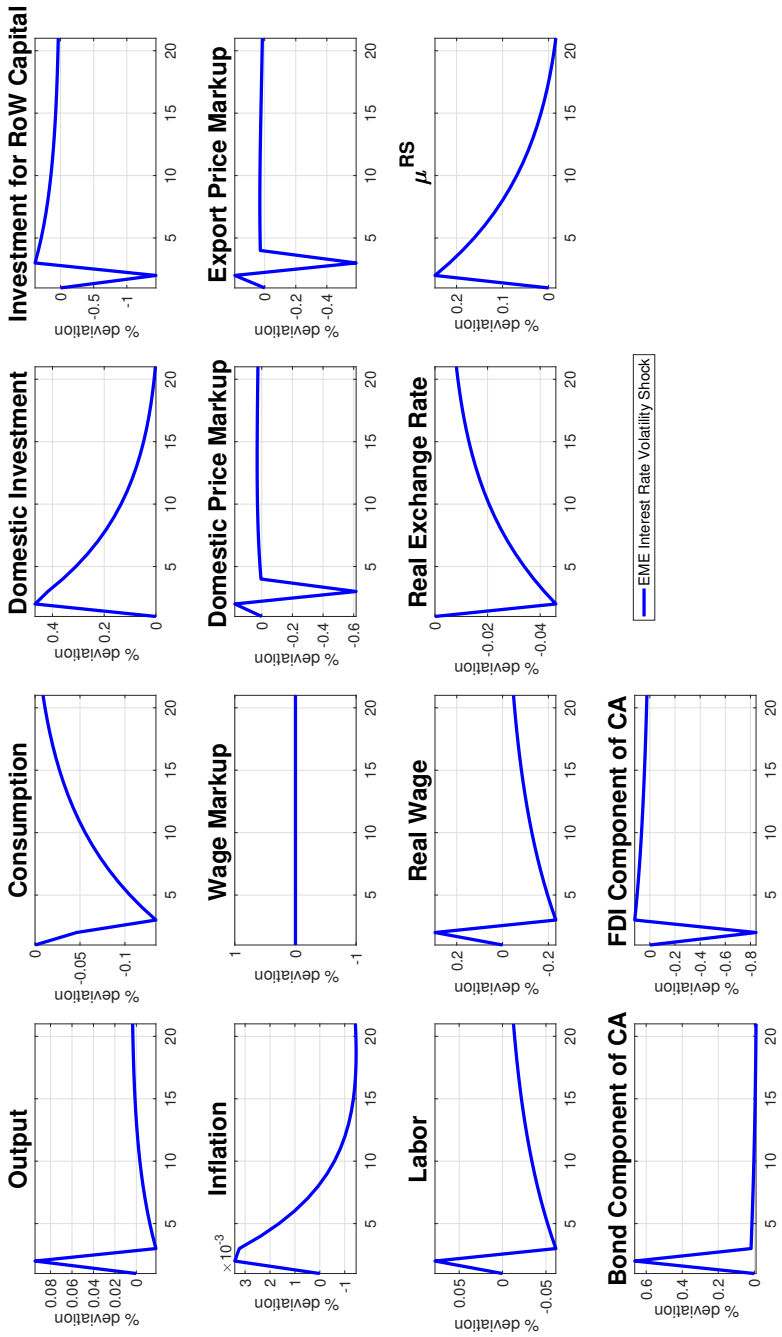


Figure 11: Impulse Responses When Prices are Flexible ($\kappa = \kappa^* = 0$)

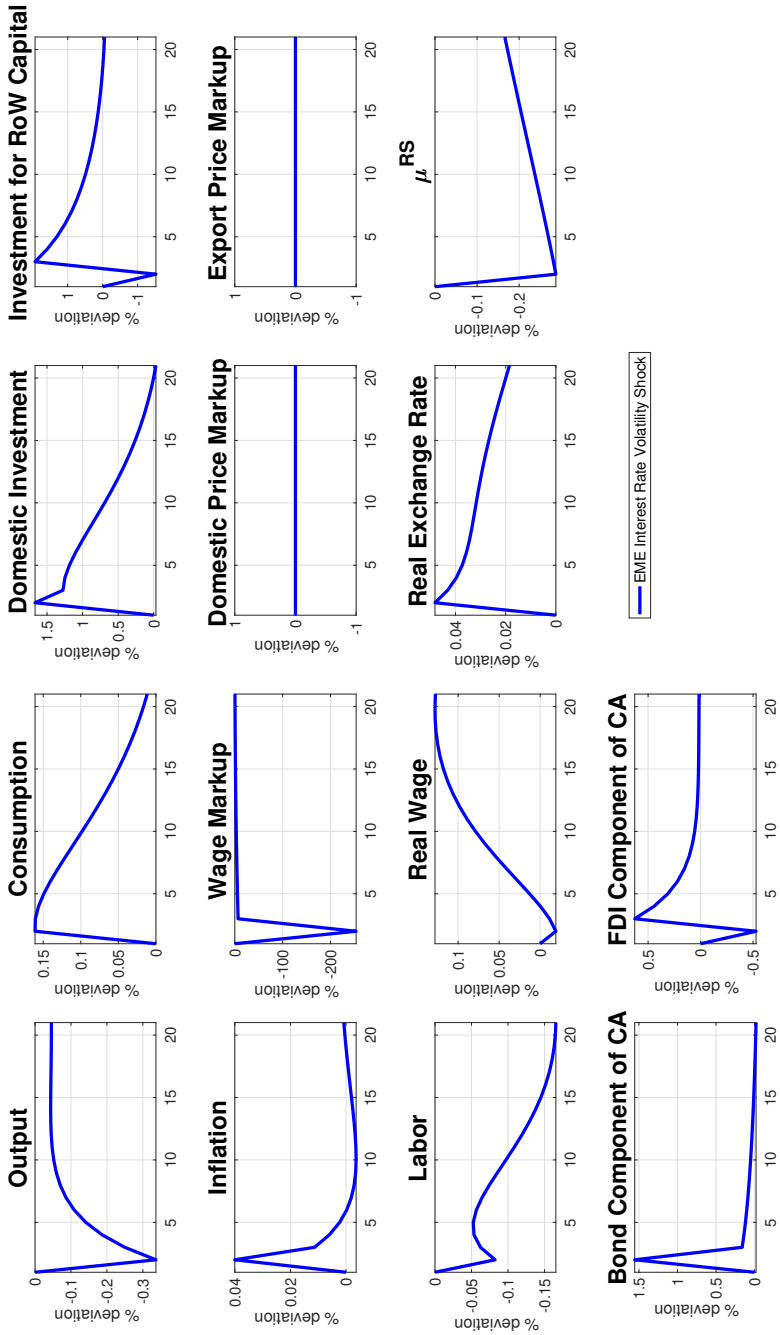


Figure 12: Period Profit (LCP)

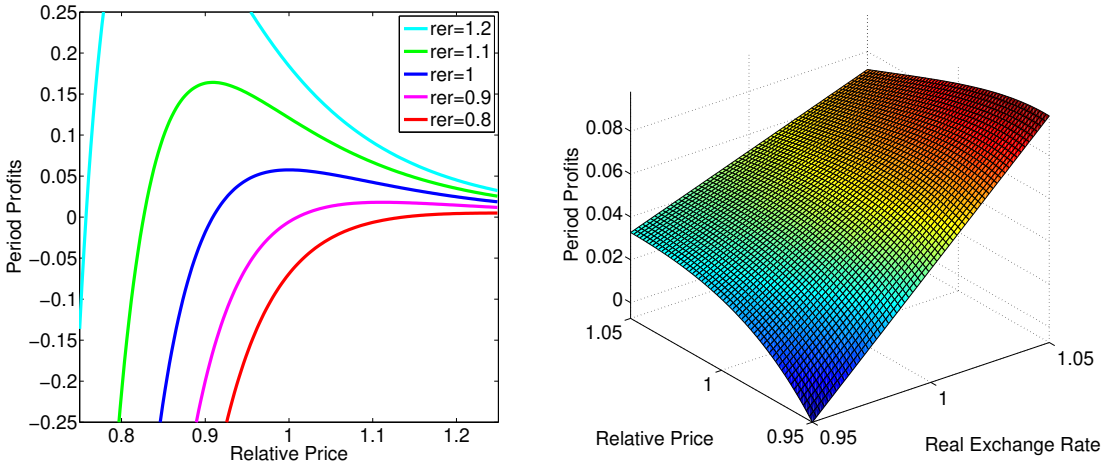


Figure 13: Welfare (Baseline Model)

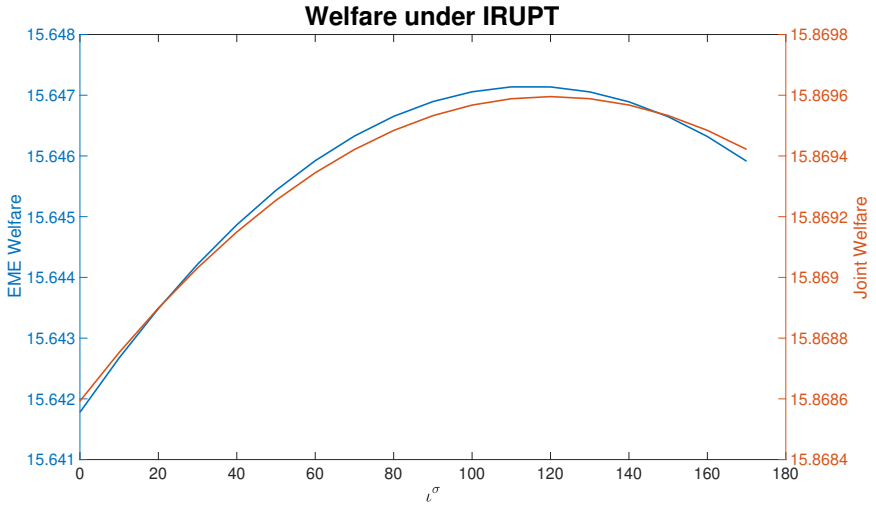


Figure 14: Impulse Responses to RoW Preference SV Shock under Tax on RoW bonds

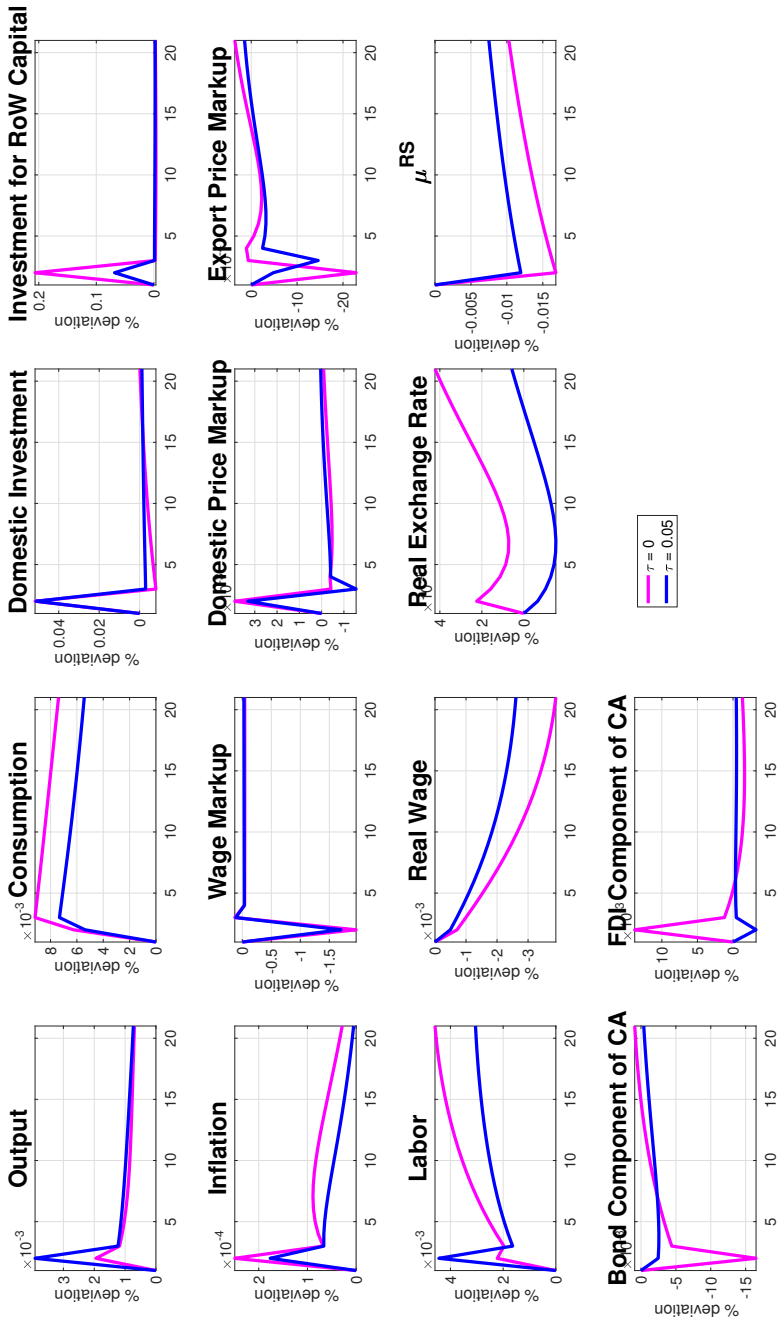


Figure 15: Impulse Responses to RoW Preference Level Shock

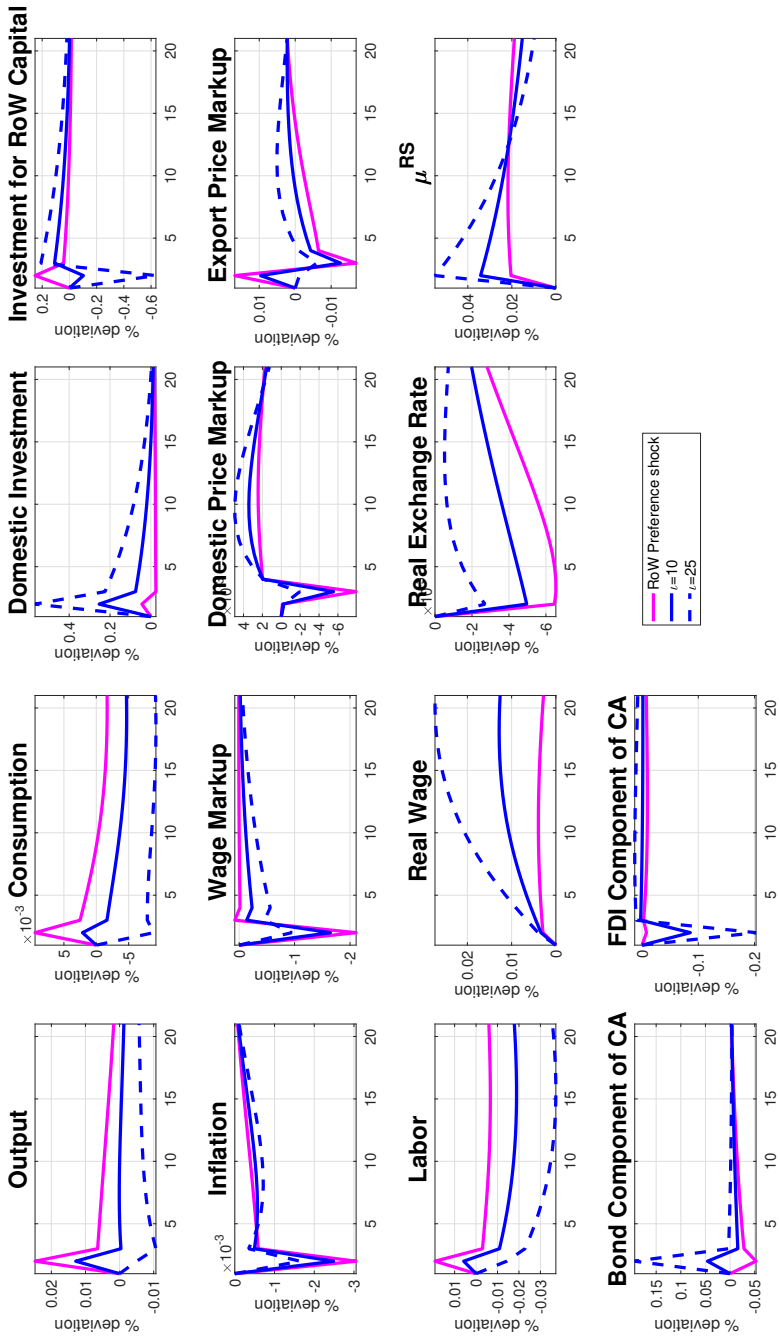


Figure 16: Impulse Responses to RoW Preference SV Shock (Taylor rule comparison)

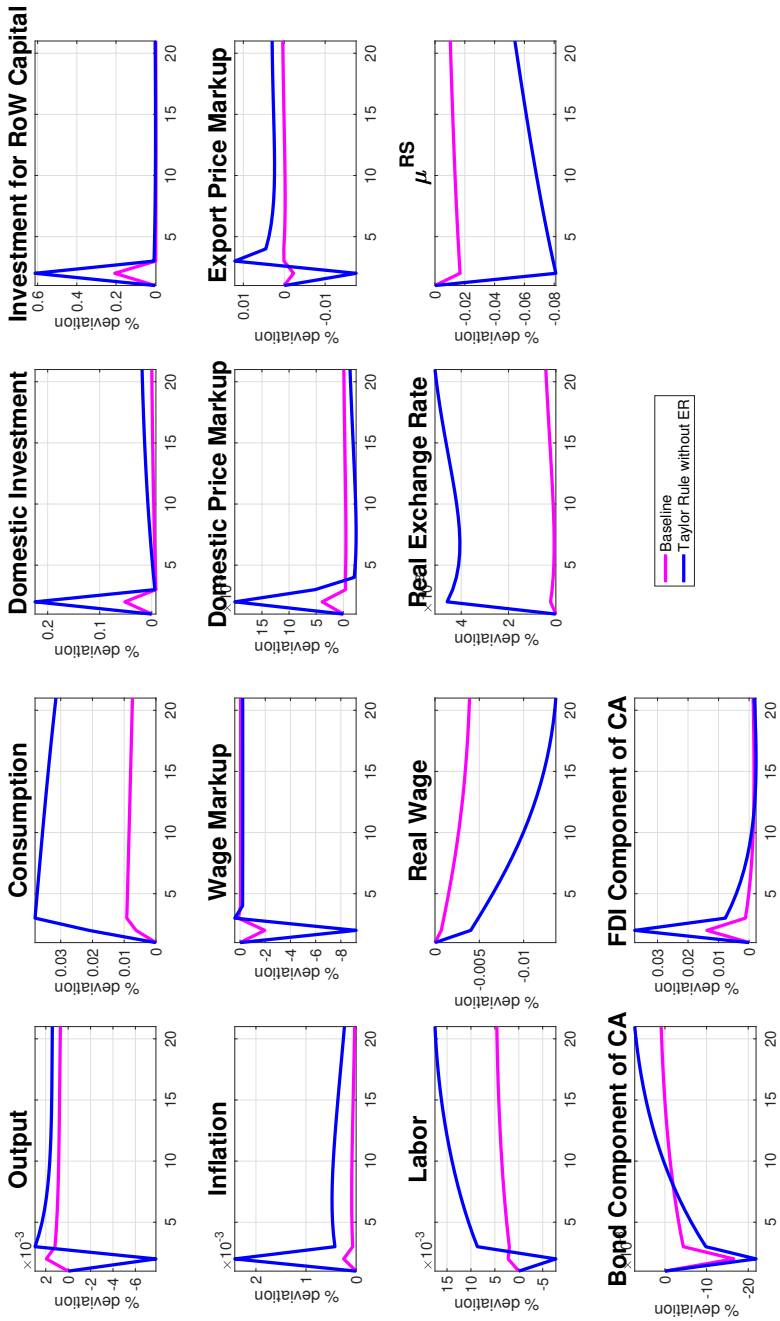


Figure 17: Impulse Responses to EME SV Shock (DCP vs. PCP)

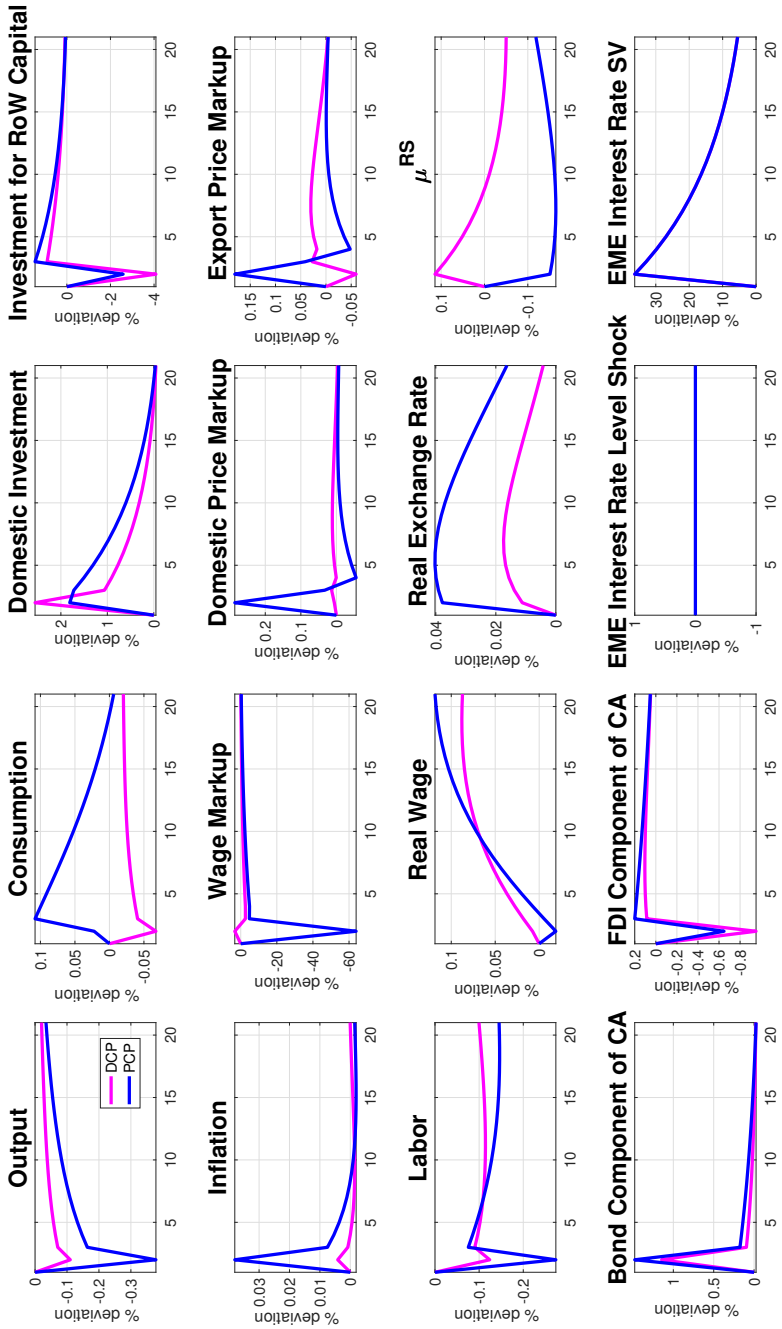


Figure 18: Period Profit (PCP)

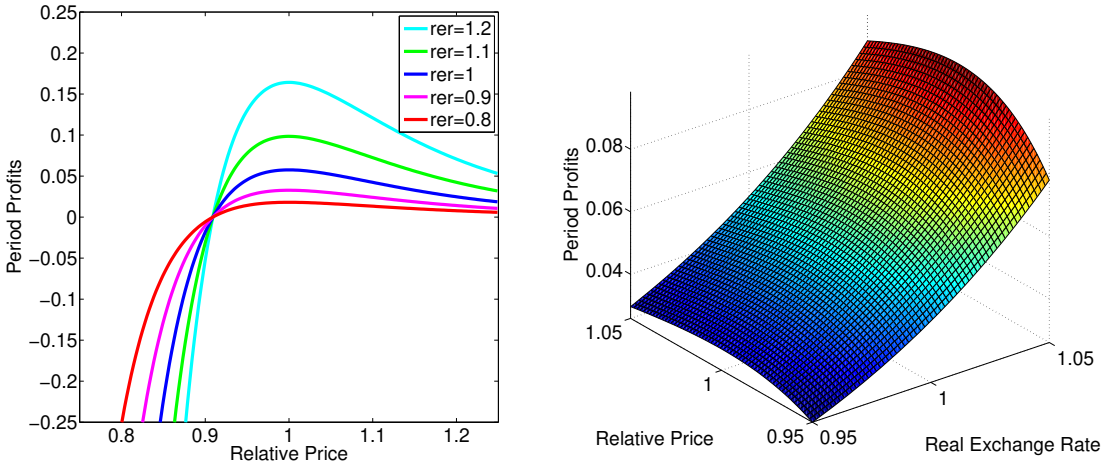
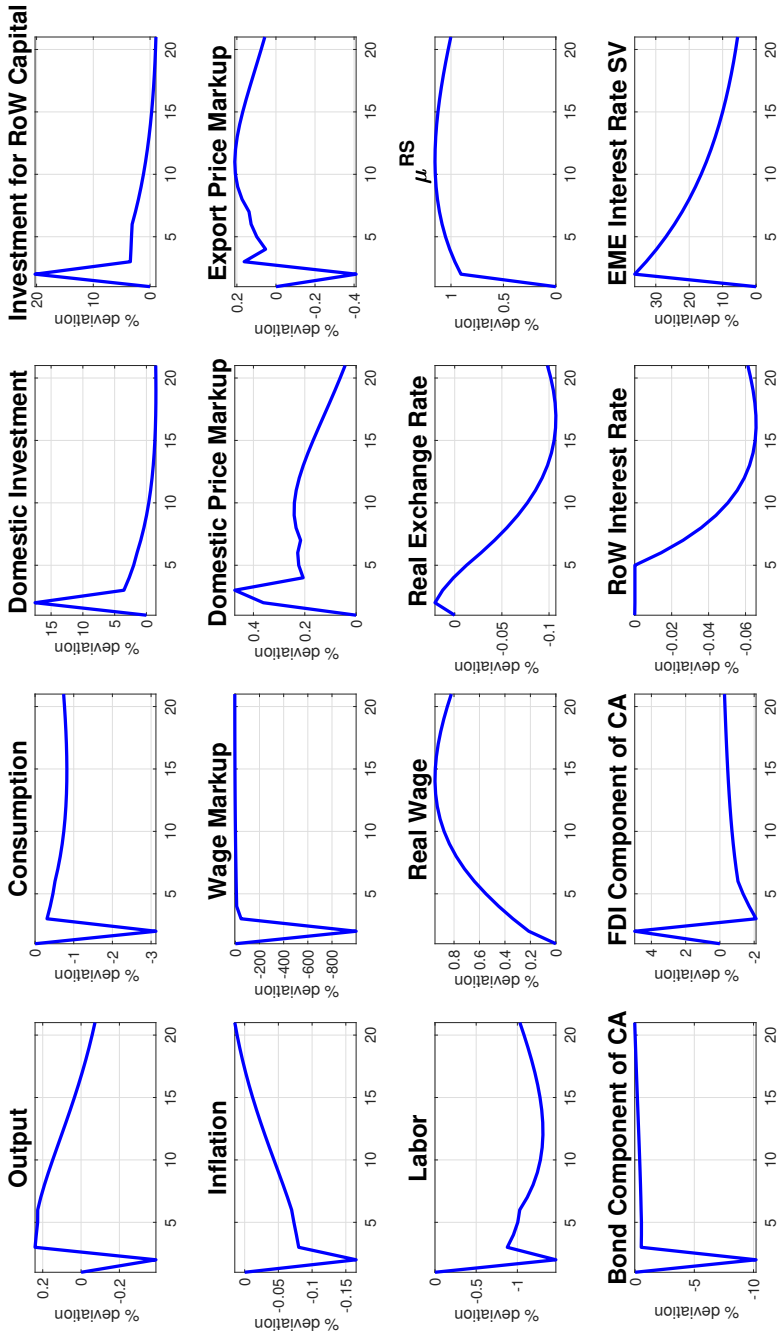


Figure 19: Impulse Responses to EME SV Shock (ELB in RoW)



Interest Rate Uncertainty as a Policy Tool?

Online Appendix

A: Additional Details on the Empirical Analysis

We provide additional details about data construction and estimation procedure in this section. We estimate our baseline VAR using data on overnight interbank interest rates, real gross domestic product (GDP), consumption price index (CPI), current-account-to-GDP, and net-FDI-inflows-to-GDP. 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. Real GDP and CPI enter the VAR in log levels.

We collect overnight interbank interest rates and real GDP from Haver Analytics. In this appendix, we also conduct 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.

We include four lags in the estimation of the VAR and we plot our confidence intervals by using the methodology in Basu and Bundick (2017). For comparison purposes and robustness, we run several other estimations. First, we estimate our baseline specification for several advanced economies. Second, we re-estimate our baseline specification for the same set of emerging economies but use policy rate volatility instead of interbank rate volatility. Third, we provide another extension by including two lags in the estimation of the VAR for emerging economies. Finally, we also estimate the VAR by replacing net-FDI-to-GDP with net-equity-flows-to-GDP. We obtain the equity flows data from Sander (2019)'s dataset.

Figure 20 shows estimated impulse responses to an identified interbank rate volatility shock and the 95% confidence intervals 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.

Figure 21 plots estimated impulse responses to an identified policy rate volatility shock. On average, the results are in line with our baseline specification. In response to higher policy rate volatility, all countries exhibit capital outflows (i.e., improvement in the current account). The response of FDI is positive for Indonesia and Chile. Net FDI inflows turn positive in Brazil after four periods. Net FDI inflows are positive on impact in Turkey, but outflows take place after two periods. On average, we argue that policy rate volatility has similar implications to interbank rate volatility.

Figure 22 plots estimated impulse responses including two lags instead of four. Qualitative features of the majority of the results that we presented in the paper stays the same. Only notable difference is in the response of Indonesia's current-account-to-GDP and net-FDI-infows-to-GDP. Capital outflows are more significantly seen when two lags is used (i.e., current-account-to-GDP improves). Net-FDI-inflows show a decline under two lags for Indonesia.

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.

Figure 20: Impulse Responses to an Increase in Interest Rate Volatility (Advanced Economies)

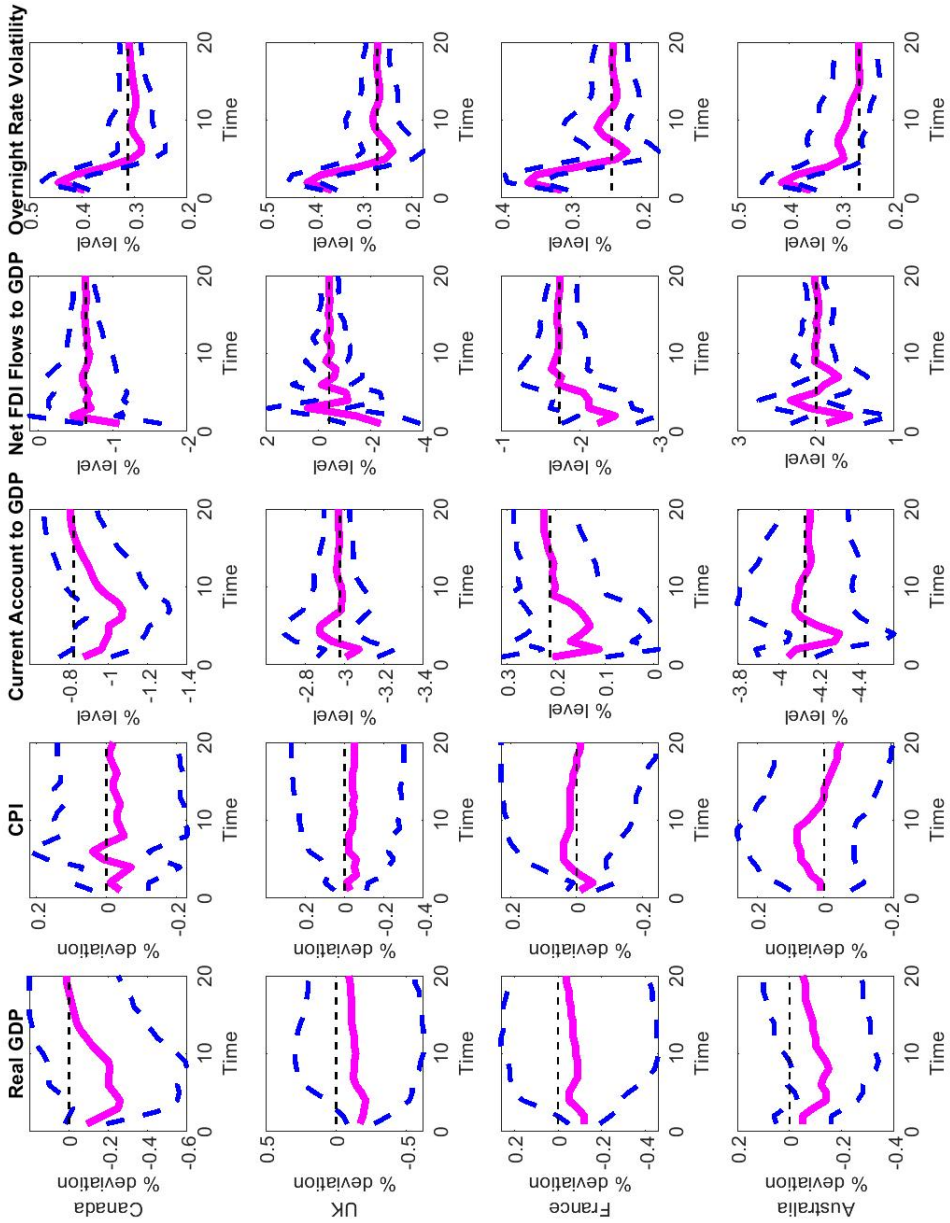


Figure 21: Impulse Responses to an Increase in Interest Rate Volatility (Policy Rate Volatility)

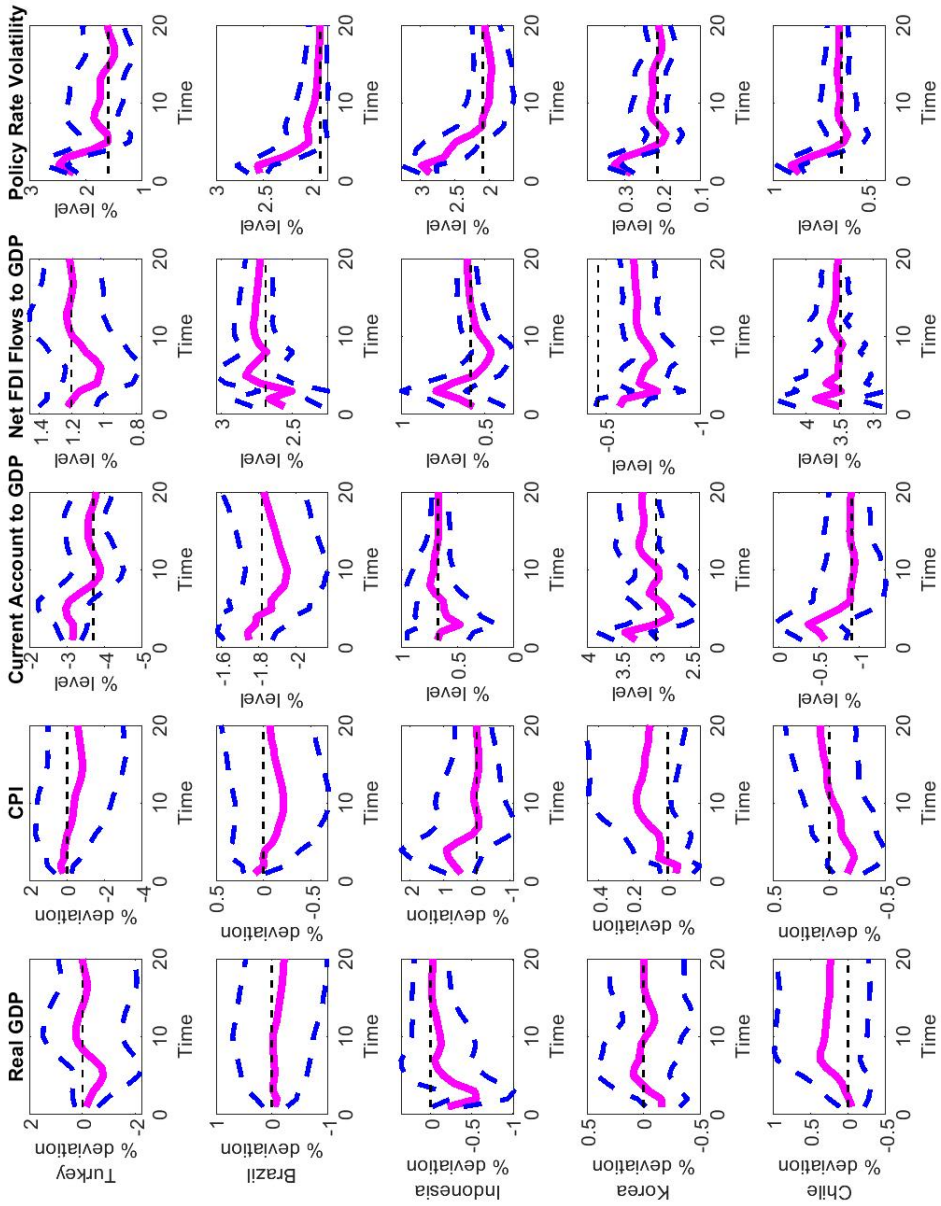


Figure 22: Impulse Responses to an Increase in Interest Rate Volatility (2 lags)

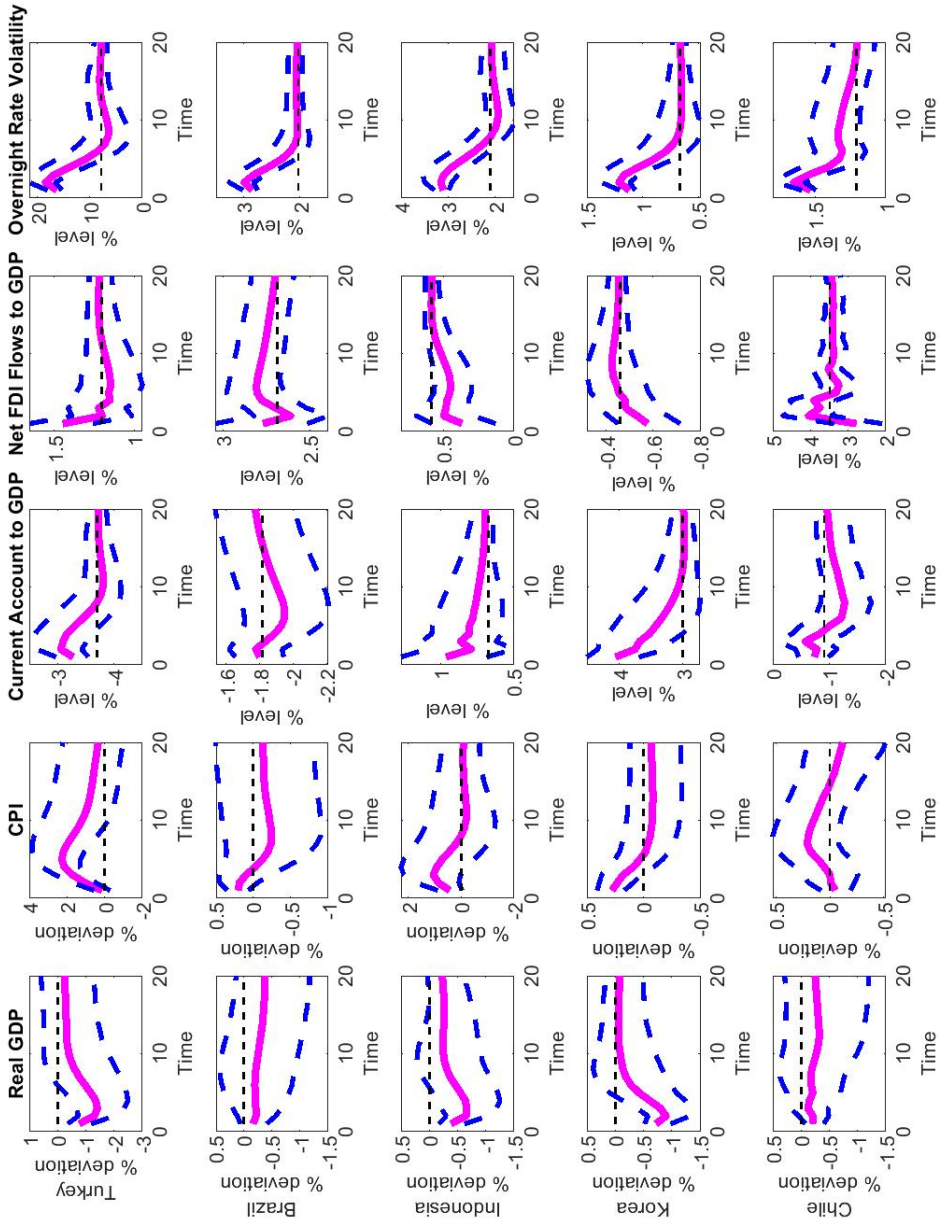
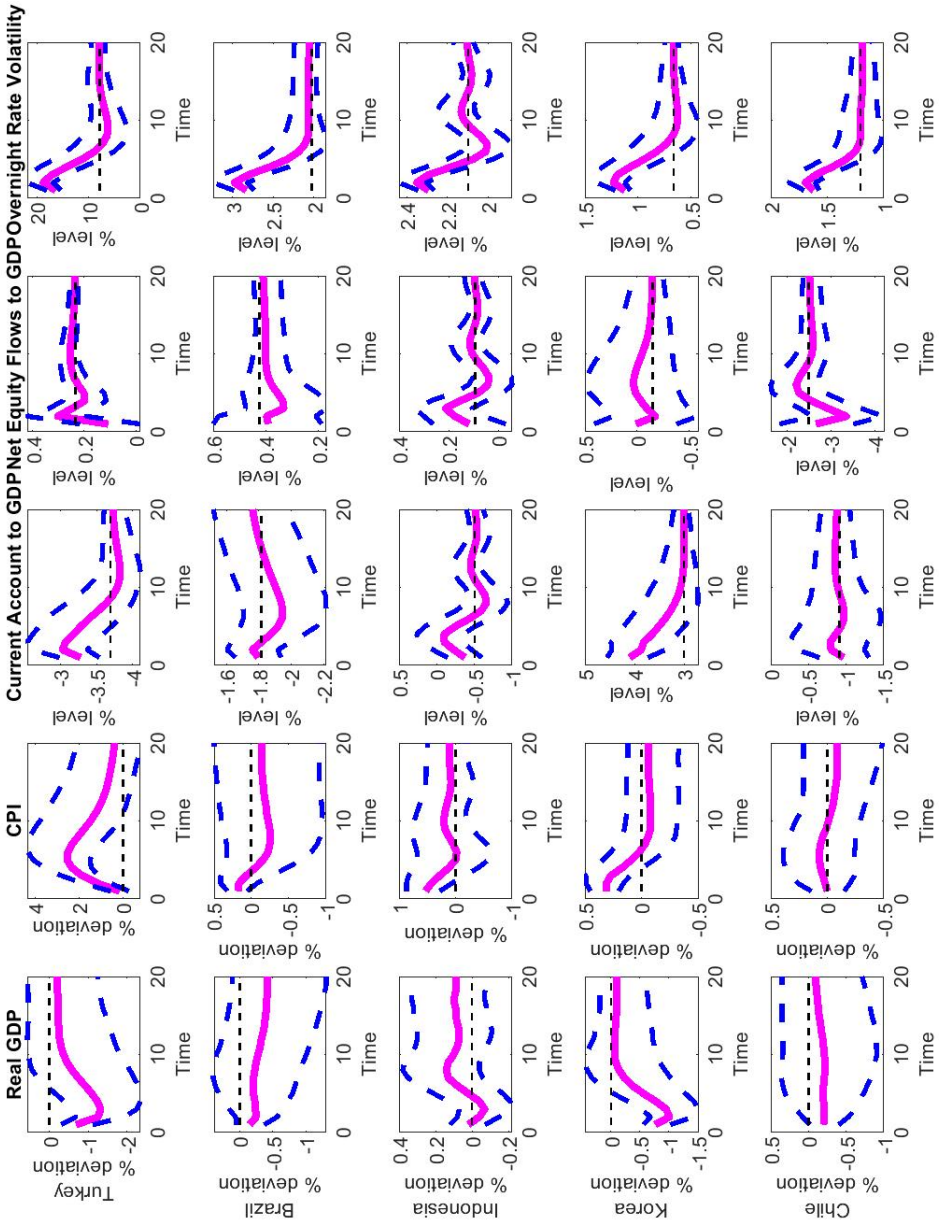


Figure 23: Impulse Responses to an Increase in Interest Rate Volatility (Portfolio Equity instead of FDI)



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:

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

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:

$$\frac{b_{t+1}}{R_t} + \frac{rer_t b_{*,t+1}}{R_t^*} + \left(\frac{1-n}{n}\right) rer_t I_{*,t} - I_t^* = \frac{b_t}{\Pi_t} + \frac{b_{*,t}}{\Pi_t^*} rer_r + \left(\frac{1-n}{n}\right) rer_t r_{K,*,t} K_{*,t} - r_{K,t}^* K_t^* + \left(\frac{1-n}{n}\right) \mu_{E,t}^* mc_t Y_{E,t}^* - rer_t \mu_{R,t} mc_t^* Y_{R,t}. \tag{38}$$

Use isomorphic equations for RoW to obtain:

$$\frac{b_{*,t+1}^*}{R_t^*} + \frac{b_{t+1}^*}{rer_t R_t} + \left(\frac{n}{n-1}\right) \frac{I_t^*}{rer_t} - I_{*,t} = \frac{b_{*,t}^*}{\Pi_t^*} + \frac{b_t^*}{rer_t \Pi_t} - r_{K,*,t} K_{*,t} + \left(\frac{n}{1-n}\right)\left(\frac{r_{K,t}^* K_t^*}{rer_t}\right) + \left(\frac{n}{1-n}\right) mc_t^* \mu_{R,t} Y_{R,t} - \frac{mc_t}{rer_t} \mu_{E,t}^* Y_{E,t}^*. \tag{39}$$

Now, multiply equation (39) with $rer_t(1-n)$, subtract it from equation (38) and impose the bond market clearing conditions, $nb_{t+1} + (1-n)b_{t+1}^* = 0$ and $nb_{*,t+1} + (1-n)b_{*,t+1}^* = 0$:

$$2n\left(\frac{b_{t+1}}{R_t} + rer_t \frac{b_{*,t+1}}{R_t^*}\right) + 2((1-n) rer_t I_{*,t} - nI_t^*) = 2n\left(\frac{b_t}{\Pi_t} + \frac{rer_t b_{*,t}}{\Pi_t^*}\right) + 2(1-n) rer_t r_{K,*,t} K_{*,t} - 2nr_{K,t}^* K_t^* + 2(1-n)\mu_{E,t}^* mc_t Y_{E,t}^* - 2n rer_t \mu_{R,t} mc_t^* Y_{R,t}. \tag{40}$$

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

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

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

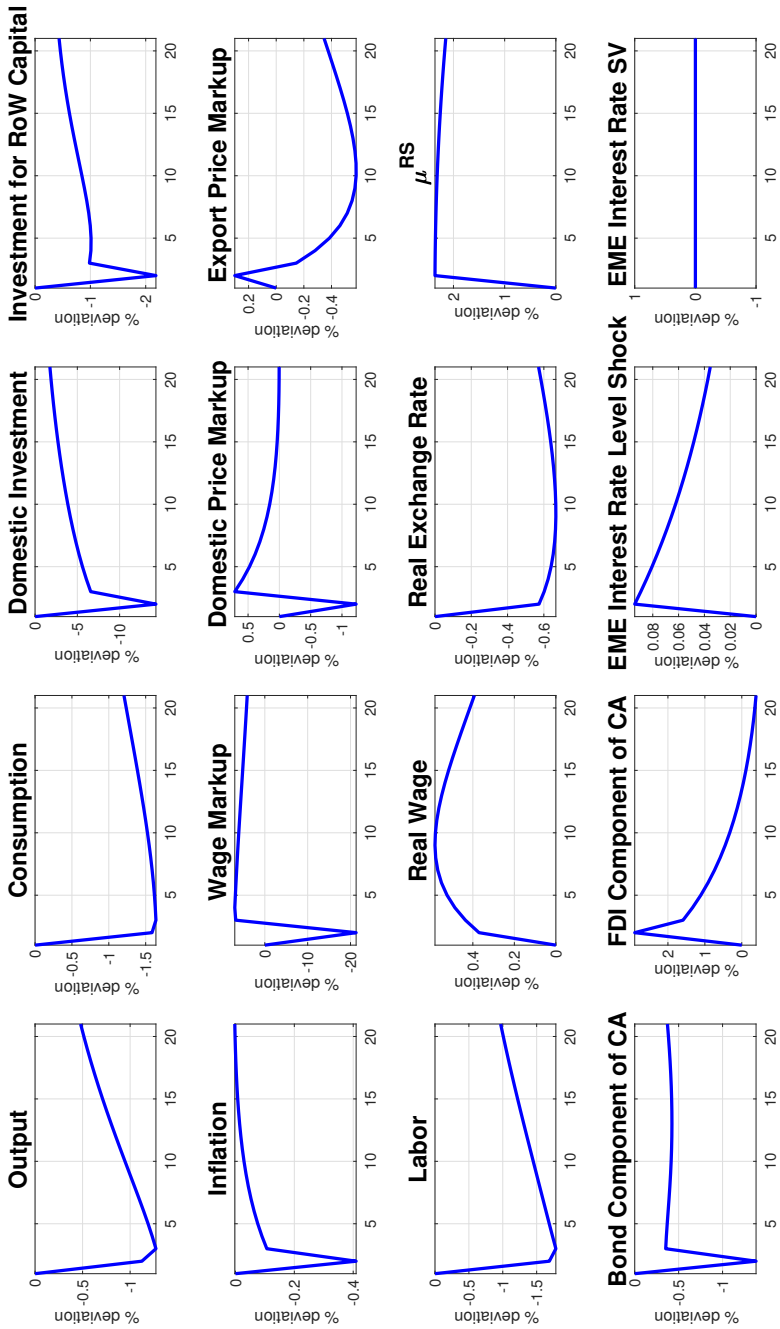
C: Interest Rate Level Shock

The model delivers responses to a one-time exogenous increase in the interest rate that are familiar in the literature, except for the dynamics of FDI that are usually not considered. The upward movement in the level of the interest rate causes domestic absorption to contract. 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 documents 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:

$$\frac{1}{R^*_{t+1}} = \mathbb{E}_t \left[\frac{\beta^*_{t,t+1}}{\Pi^*_{t+1}} \right] - \eta b^*_{*,t+1}, \tag{41}$$

$$\frac{1}{R_{t+1}} = \mathbb{E}_t \left[\frac{\beta^*_{t,t+1}}{\Pi_{t+1}} \frac{rer_t}{rer_{t+1}} \right] - \eta b^*_{t+1}, \tag{42}$$

$$1 = \mathbb{E}_t \left[\beta^*_{t,t+1} \left(\underbrace{r_{K^*_*,t+1} + 1 - \delta}_{\equiv R_{K^*_*,t+1}} \right) \right], \tag{43}$$

$$1 = \mathbb{E}_t \left[\beta^*_{t,t+1} \frac{rer_t}{rer_{t+1}} \left(\underbrace{r_{K*,t+1} + 1 - \delta}_{\equiv R_{K^*,t+1}} \right) \right]. \tag{44}$$

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 (41) and (42) 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:

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

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 (43) and (44) as follows:

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

and

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

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 (44):

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

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

$$rp^*_{E,t} = \frac{\mu^*_{E,t} mc_t}{rer_t}, \tag{45}$$

where

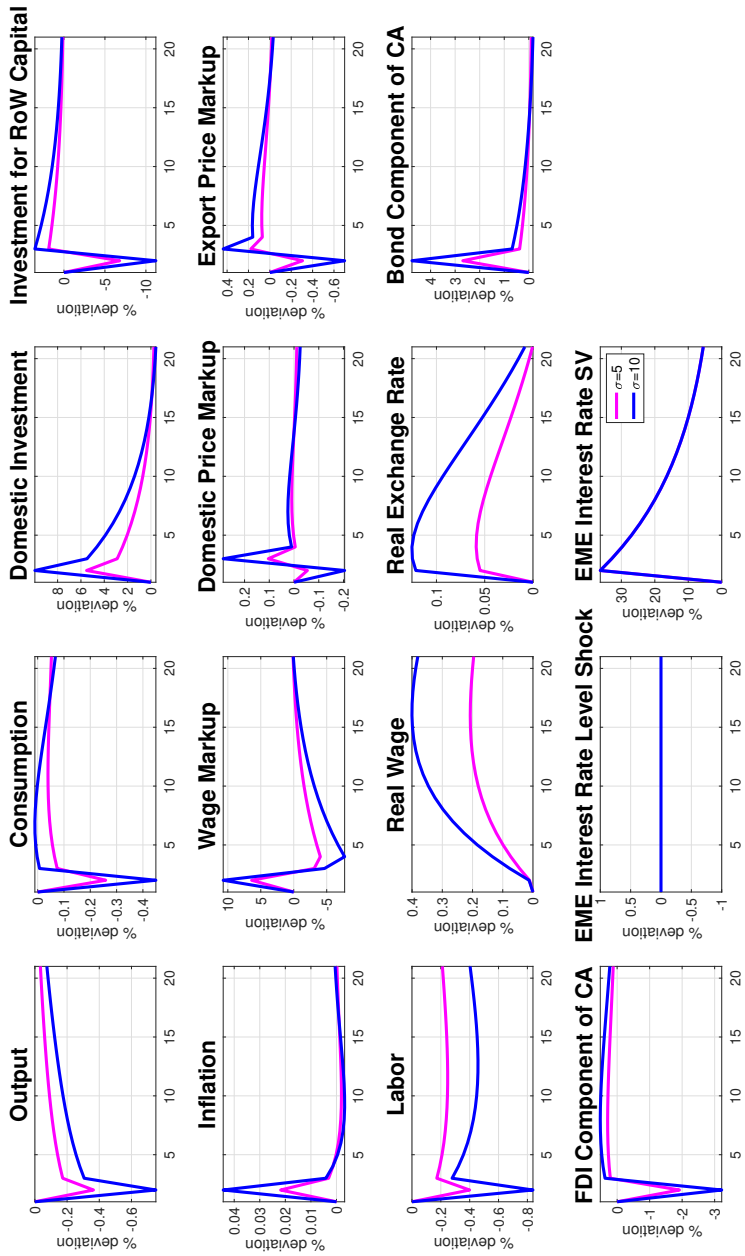
$$\mu_{E,t} \equiv \frac{\epsilon}{(\epsilon-1)\left(1-\frac{\kappa}{2}(\Pi_{E,t}-1)^2\right)+\kappa\left(\Pi_{E,t}(\Pi_{E,t}-1)-\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}(\Pi_{E,t+1}-1)(\Pi_{E,t+1})^2\frac{Y_{E,t+1}}{Y_{E,t}}\right]\right)},$$

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

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:

$$\begin{aligned} K_{*,t+1}(h) &= (1-\delta)K_{*,t}(h) + I_{*,1,t}(h), \\ I_{*,j-1,t+1}(h) &= I_{*,j,t}(h); \qquad j = 2, ..., J. \\ I_{*,t}(h) &= \textstyle\sum_{j=1}^{J} \frac{1}{J} I_{*,j,t}(h), \end{aligned} \tag{46}$$

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.[52]

The conditions in (46) 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:

$$q_{*,t+J-1} = \mathbb{E}_{t+J-1}\left[\beta_{t+J-1,t+J}\left(rer_{t+J} r_{K,*,t+J} + q_{*,t+J}\left(1-\delta\right)\right)\right], \tag{47}$$

$$\mathbb{E}_t\left[\beta_{t,t+J-1} q_{*,t+J-1}\right] = \frac{1}{J}\left(rer_t + \mathbb{E}_t\left[\beta_{t,t+1} rer_{t+1}\right] + ... + \mathbb{E}_t\left[\beta_{t,t+J-1} rer_{t+J-1}\right]\right). \tag{48}$$

Equations (47) and (48) 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 (48) 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.

[52] 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.[53] The policy remains inflationary.

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