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INTEREST RATE UNCERTAINTY AS A POLICY TOOL

Abstract

We study a novel policy tool—interest rate uncertainty—that can be used to discourage inefficient capital inflows and to adjust the composition of external accounts between short-term securities and foreign direct investment (FDI). We identify the trade-offs faced in navigating between external balance and price stability. The interest rate uncertainty policy discourages short-term inflows mainly through portfolio risk and precautionary saving channels. A markup channel generates net FDI inflows under imperfect exchange rate pass-through. We further investigate new channels under different assumptions about the irreversibility of FDI, the currency of export invoicing, risk aversion of outside agents, and effective lower bound in the rest of the world. Under every scenario, uncertainty policy is inflationary.

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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] Figure 1 shows a recent example of these fluctuations, with the change in portfolio flows to emerging market economies (EMEs) between 2006 and 2014. 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. A widening of this corridor implies an increase in uncertainty on the future path of the policy rate.[4] 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 carry trade 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 (see Başçı, 2012). Figure 2 illustrates the implementation of this policy between November 2010 and August 2011. Figure 3 shows an increase in FDI inflows during the application of this interest rate corridor policy.[5] There is no model that studies the unorthodox strategy used by the CBRT to pursue its goals in 2010-11. The

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

[2]See Ahmed and Zlate (2013) for a study 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]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.

goal of this paper is to fill this void and investigate the lessons that can be learned for economies facing similar challenges.

We provide a laboratory for assessing the effectiveness of interest rate uncertainty as a policy tool (IRUPT) to affect the composition of the capital account and navigate the trade-offs between internal objectives and external balance. 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 in discretionary fashion,[6] which the EME's central bank uses to discourage inefficient 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.[7] Second, we solve the model nonlinearly and trace transmission and propagation of heteroskedastic volatility. 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 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 IRUPT is effective in accomplishing the goal of affecting the composition of capital inflows. When there is an increase in demand uncertainty for RoW bonds (the shock that we use 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)). An increase in the EME's policy interest rate uncertainty discourages these capital inflows, shifting their composition towards FDI, and it induces a

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[6]The change in the width of the interest rate corridor that the CBRT implemented implied a change in the variance of domestic interest rate.

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

counteracting effect on the risk-sharing wedge across the border.

Three key channels of uncertainty transmission affect external accounts in our model. First, a *precautionary savings 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 risk 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 EME bonds do not increase enough to 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.[8] In this scenario, appreciation of the real exchange rate (from the perspective of the EME) does not affect the prices of EME exports, and this makes them relatively cheaper for RoW agents. EME exporters take advantage of higher demand by lowering markups. Finally, EME firms respond to rising uncertainty 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.[9]

To further understand the mechanisms through which IRUPT operates, we study several extensions of our benchmark framework. When FDI is irreversible through a time-to-build requirement, the fluctuations in the FDI component of the capital account are dampened by a *wait-and-see* effect. When we break the link between intertemporal elasticity of substitution and risk aversion, and we introduce high degrees of risk aversion through Epstein-Zin-Weil preferences, EME house-

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

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

holds borrow extensively using RoW securities. When the RoW policy interest rate is subject to an effective lower bound constraint, EME interest rate uncertainty generates amplified responses. Under this scenario, prices in the RoW decrease and RoW intermediate goods face higher demand. In return, production expands and producers acquire more inputs, including FDI from the EME.

Finally, we provide an evaluation of the welfare consequences of the interest rate uncertainty policy in the benchmark environment by comparing it to another uncertainty-based policy that does not interfere directly with the conduct of monetary policy: capital control uncertainty. We calculate the welfare compensating variation in consumption for the EME household to be indifferent between the two policy regimes and find that the household prefers interest rate uncertainty to capital control uncertainty. When evaluated during capital inflow periods and when both policies generate the same magnitude of uncertainty on the respective tool, IRUPT is more successful at discouraging inefficient capital flows and changing their composition towards FDI. The capital control regime affects the EME through more uncertainty on capital-control-adjusted foreign interest rates, with smaller effects than the interest rate uncertainty policy.[10]

Our contribution to the literature is three-fold. First, we contribute to the literature that studies the relationship between the global financial cycle and monetary policy in EMEs.[11] 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.[12] Instead of considering the consequences of exogenous borrowing constraints, 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 an increase in policy interest rate uncertainty can improve risk sharing by narrowing the wedge in the uncovered interest parity condition under incomplete markets.

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[10] We purposefully refrain from performing an analysis of optimal interest rate uncertainty policy, within a rule for its setting or otherwise defined. The CBRT's use of this unorthodox policy was a one-time experiment. This motivates us to treat it as a discretionary tool that policymakers may consider deploying only occasionally.

[11] 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).

[12] 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 (forthcoming), 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. See Erten et al. (forthcoming) and Rebucci and Ma (2019) for surveys of this extensive literature.

Finally, we contribute to the literature that studies the effects of uncertainty shocks on economic activity.[13] We differ from this literature by studying the implications of using uncertainty as a policy tool and by focusing on an open-economy environment.[14] 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.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 discusses calibration, solution method, and results. Section 4 summarizes the results of model extensions. Section 5 compares the welfare implications of IRUPT to those of capital control uncertainty. Section 6 concludes. An appendix contains additional details and results.

2   THE MODEL

The world is composed of two regions, EME and RoW.[15] 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. 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,

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[13]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.

[14]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).

[15]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.

which combine labor with real capital from domestic and foreign agents.

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.[16,17] 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 4 shows the model architecture.

In what follows, we focus on EME, and unless otherwise indicated, RoW is symmetric.

2.1 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 intertemporal utility from consumption, $C_t(h)$, net of the disutility from supplying labor to intermediate goods producers, $L_t(h)$:

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

where $U(C_t(h), L_t(h)) = \frac{C_t(h)^{1-\gamma}-1}{1-\gamma} - \chi \frac{L_t(h)^{1+\varphi}}{1+\varphi}$, $\gamma, \chi, \varphi \geq 0$, and $\beta \in (0,1)$ is the discount factor.

Households also accumulate physical capital in EME and RoW consumption units, K and K_*, which is used in the respective region's production of intermediate goods.[18] 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

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[16]This assumption on the currency of export pricing will be important for the transmission of interest rate uncertainty in our model. We also study how the results differ under producer currency pricing (PCP) in Section 4.

[17]Gopinath et al. (2020) introduce a three-region model to analyze dominant and non-dominant currencies. A two-region model is sufficient for our purposes.

[18]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.

final consumption bundles. The laws of motion for both types of capital are standard:

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

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

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

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

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

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

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

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

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

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

$$P_t C_t(h) + B_{t+1}(h) + S_t B_{*,t+1}(h) + \tfrac{\eta}{2} P_t (\tfrac{B_{t+1}(h)}{P_t})^2 + \tfrac{\eta}{2} S_t P_t^* (\tfrac{B_{*,t+1}(h)}{P_t^*})^2 + P_t I_t(h) + S_t P_t^* I_{*,t}(h)$$

$$= R_t B_t(h) + S_t R_t^* B_{*,t}(h) + P_t r_{K,t} K_t(h) + S_t P_t^* r_{K_*,t} K_{*,t}(h) + W_t(h) L_t(h)$$

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

$$(5)$$

where $\tfrac{\eta}{2} \xi_t (B_{*,t+1})^2$ is the cost of adjusting holdings of internationally traded bonds (with $\eta > 0$), and $T_t(h)$ is its rebate, taken as given by the household. R_{t+1} and R_{t+1}^* 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:

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

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

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:

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

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 in the calibration, we will set η to a very small value that will minimally affect the model dynamics, and its sole implication will be to ensure that zero international bond holding is the

unique non-stochastic steady state of the model. However, 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 cost is equal to the real exchange rate and, hence, for an additional unit of capital, $K_{*,t+1}$, the investment will be adjusted by the movements in the real exchange rate **so** that any future profits earned from renting the capital abroad will not be affected.

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 marginal rate of substitution between labor and consumption:

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

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.

2.2 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 paramter a is attached to the aggregate of RoW intermediate goods sold domestically. The assumption $a > \frac{1}{2}$ thus ensures home bias in the composition of final output.

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

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

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

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

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

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

supplied by the EME households, $L_t(i)$:

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

where $\frac{1-n}{n} Y^*_{E,t}(i)$ is the amount of EME intermediate good i exported to RoW, and α_1, α_2 and $\alpha_1 + \alpha_2 \in (0,1)$.[19]

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, $Y^*_{E,t}(i) = \left(\frac{P^{*e}_{E,t}(i)}{S_t P^*_{E,t}}\right)^{-\epsilon} Y^*_{E,t}$, where $P_{E,t}(i)$ is the nominal price of domestically sold EME good i, and $P^{*e}_{E,t}(i)$ is the domestic currency price of the exported good i, with the price in the foreign market being $P^*_{E,t}(i) = \frac{P^{*e}_{E,t}(i)}{S_t}$. Finally, $P_{E,t} = \left(\int_0^1 P_{E,t}(i)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}$ is the nominal price of the bundle of domestically sold EME intermediate goods, and $P^*_{E,t} = \left(\int_0^1 P^*_{E,t}(i)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}}$ is the nominal foreign currency price of the exported bundle.

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

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

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 sym-

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[19]A three-input Cobb-Douglas production function implies RoW capital and domestically produced capital are neither substitutes nor complements.

metric 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.

2.3 Equilibrium

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:

$$Y_t = C_t + I_t + I_t^* + \frac{\kappa^W}{2} \left(\Pi_t^W - 1\right)^2 w_t L_t + \frac{\kappa}{2} \left(\Pi_{E,t} - 1\right)^2 rp_{E,t} Y_{E,t} + \left(\frac{1-n}{n}\right) \frac{\kappa^*}{2} \left(\Pi_{E,t}^* - 1\right)^2 rp_{E,t}^* Y_{E,t}^*.$$

(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 A that EME net foreign assets are determined by:

$$b_{t+1} + rer_t b_{*,t+1} + \left(\tfrac{1-n}{n}\right) rer_t K_{*,t+1} - K_{t+1}^*$$

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

(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:

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

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

2.4 Monetary Policy

The central bank sets the nominal interest rate according to a Taylor rule that reacts to inflation and output and displays stochastic volatility:

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

where ρ is a smoothing parameter that captures gradual movements in interest rates, and the parameters ρ_{Π} and ρ_Y denote the responsiveness of the nominal interest rate to deviations of inflation and output from their steady-state values.

The monetary policy shock, u_t, represents discretionary deviations from the rule-based policy, including the EME central bank's reactions to international factors. We allow this term to incorporate time-varying volatility in the form of stochastic volatility.[20]

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

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

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:

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

where ε_t^{σ} is a normally distributed shock with zero mean and unit variance. The parameter σ controls the mean volatility of the exogenous component in the Taylor rule. An increase in the volatility of the exogenous process increases uncertainty about the future path of monetary policy.

2.5 Summary

Table 1 summarizes the key equilibrium conditions of the model. Equations ((2), (3), (6), (7), (8), (9), (12), (13), (14), (15), (16), (17), (46), (18), (19), (20), (21), (23)) and their RoW counterparts, together with the net foreign asset condition in equation (22), determine 37 endogenous

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[20]Introducing stochastic volatility in this fashion can be interpreted as uncertainty about deviations from the rule-based policy that responds to domestic variables.

variables of interest: $(Y_t,\ C_t,\ I_t,\ I_{*t},\ K_t,\ K_{*,t},\ L_t,\ Y_{E,t},\ Y_{E.t}^*,\ mc_t,\ rp_{E,t},\ rp_{E,t}^*,\ w_t,\ r_{K,t},\ r_{K,*,t},\ b_t,$ $R_t,\ \Pi_t)$ and their foreign counterparts, and rer_t. The auxiliary variables and exogenous processes are described above.

3 Model Calibration and Simulations

In this section, we calibrate the model and illustrate its dynamics, highlighting the role of interest rate uncertainty in the adjustment of external accounts.

3.1 Calibration

We calibrate the model with standard parameter values often used in the literature. This allows us to assess the implications of interest rate uncertainty without the risk of our findings being the product of an unusual calibration.

We set the discount factor, β to 0.9804 to match a steady-state 2% real interest rate, as in the literature that focuses on emerging markets. Relative risk aversion, γ, relative weight of labor in the utility function, χ, and Frisch elasticity, φ, are also set to conventional values in the literature: 2, 1, and 0.25, respectively. We set the scale parameter for the costs of adjusting bond holdings, η, to 0.0025 as in Ghironi and Melitz (2005). This value implies that this adjustment cost has a negligible impact on model dynamics, other than pinning down the non-stochastic steady state and ensuring mean reversion when shocks are transitory. Following Barattieri et al. (2018), we set κ^W to 116 for nominal wage stickiness. Moreover, we set the elasticity of substitution between differentiated labor inputs, ϵ^W, to 11, which implies a wage markup of 10% under flexible wages.

For the parameters that are related to producer optimization, we set the home bias in final production to 0.65, as in Unsal (2013), and 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, , is set to 1.2 as in Ghironi (2006), among others. The scale parameters for the costs of adjusting the prices of domestically sold and exported goods, κ and κ^*, are set to 116, as in Barattieri et al. (2018). We again set the elasticity of substitution between differentiated intermediate inputs, ϵ, to 11, to replicate a 10% price markup in both sectors when prices are flexible.

Finally, our choice of parameters in the Taylor rule is also in line with the previous literature: We set the smoothing coefficient, ρ, the responsiveness to inflation, ρ_Π, and the responsiveness to output, ρ_Y, to 0.7, 1.5, and 0.5/4, respectively. We also set σ, the average standard deviation of an innovation to the interest rate shock, using Turkish data, to hit the 14 percentage point average of the period 2002 to 2018 (100 exp (-1.90)).[21]

Table 2 summarizes the parametrization of the model.

3.2 Solution Method

We solve the model by using third-order perturbation techniques. 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)).

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 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. 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*.

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[21]We start from 2002 to focus on the period after the 2001 economic crisis.

3.3 Experiments

First, we study how our model reacts to a 1% interest rate *level* shock, before studying the implications of interest rate uncertainty on capital flows. Then, we focus on our main experiment, and we show how interest rate uncertainty performs as a policy tool in response to inefficient capital inflows that induce an international wealth wedge. We also analyze the channels of the transmission and propagation of interest rate uncertainty and identify the repercussions of such an unconventional policy.

3.3.1 Interest Rate Level Shocks

Our first experiment is with an unexpected interest rate shock in the EME in order to compare our model outcome with the monetary open-economy models in the literature that are solved using first-order approximation techniques. We solve the log-linearized version of our model and calculate the impulse responses as deviations from the non-stochastic steady state for the model's comparability purposes. Figure 5 shows the impulse responses after a 1% increase in u_t.

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 markups fall accordingly. 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. Moreover, from the international no-arbitrage condition, the 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.[22]

Finally, the fall in income negatively affects the demand for EME bonds and contributes to the outflow in the bond component of the capital account. Most of the movement in the capital account is due to changes in the FDI component as investment dynamics are more volatile.

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[22]Convex adjustment costs for bond holdings imply deviations from UIP; however, given our calibration, the deviation is miniscule. UIP violations are much larger in magnitude when a third-order perturbation solution technique is used.

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We conclude that our model passes the sanity check and move on to our main experiments.

3.3.2 Inefficient Capital Inflows and Interest Rate Uncertainty as a Policy Tool

We turn to our main experiments and examine whether an increase in interest rate uncertainty can be an effective tool to improve risk sharing and discourage inefficient capital flows.

We consider the case in which inefficient capital inflows are generated due to risk-premium shocks to the Euler equations for holdings of RoW bonds, in a similar fashion to Smets and Wouters (2007) and as in the subsequent literature. One of our distinct features is in introducing the risk-premium shock as a second-order shock, instead of a first-order-shock. A positive realization of these shocks can be interpreted as an increase in demand uncertainty for the respective financial asset. We do not attempt to endogeneize the risk-premium shocks. Our focus is on assessing the effects of EME interest rate uncertainty when there are inefficient capital flows into EME. The global financial crisis period exhibits significant movements in risk premia and we motivate our analysis from this episode (see, e.g., di Giovanni et al. (2017) and Rey (2013)).

The Euler equations for the EME and RoW households are modified accordingly:

$$1 + \eta b_{t+1} = \frac{R_{t+1}}{e^{u_t^{SW}}} \mathbb{E}_t \left[\frac{\beta_{t,t+1}}{\Pi_{t+1}} \right],$$

$$1 + \eta b_{*t+1} = \frac{R_{t+1}^*}{e^{u_t^{SW*}}} \mathbb{E}_t \left[\frac{\beta_{t,t+1}}{\Pi_{t+1}^*} \frac{rer_{t+1}}{rer_t} \right],$$

$$1 + \eta b_{*,t+1}^* = \frac{R_{t+1}^*}{e^{u_t^{SW*}}} \mathbb{E}_t \left[\frac{\beta_{t,t+1}^*}{\Pi_{t+1}^*} \right],$$

$$1 + \eta b_{t+1}^* = \frac{R_{t+1}}{e^{u_t^{SW}}} \mathbb{E}_t \left[\frac{\beta_{t,t+1}^*}{\Pi_{t+1}} \frac{rer_t}{rer_{t+1}} \right].$$

The Smets-Wouters shocks that apply to the EME and RoW Euler equations, u_t^{SW} and u_t^{SW*}, follow an $AR(1)$ process:

$$u_t^x = \rho^x u_{t-1}^x + e^{\sigma_t^x} \varepsilon_t^x,$$

for $x \in \{SW, SW*\}$. The log of the standard deviation of the Smets-Wouters shock, σ_t^x, is random

and modeled as an $AR(1)$ process:

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

We use the VIX index as a proxy for the UIP risk premium and set the average standard deviation of an innovation to the RoW risk-premium shock, σ^{SW*}, to 34%.

<center>INTEREST RATE UNCERTAINTY AS A RISK-SHARING TOOL</center>

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:

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

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

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}^{UIP}. Under incomplete markets, stochastic volatility shocks to the Smets-Wouters disturbances (henceforth, risk-premium shocks) induce movements in μ_{t+1}^{UIP}, causing real exchange rate misalignment, and the allocation of wealth across countries is inefficient due to movements in relative prices that are not internalized by the agents across the border.[23]

To assess the impact of IRUPT on risk sharing, we generate dynamics with two-standard-deviation shocks to the stochastic volatility processes of the RoW risk-premium and the EME interest rate, and we focus on the movements of the risk-sharing wedge.[24] The RoW risk premium shock triggers an inflow of capital into EME whereas an increase in the uncertainty of EME interest rate generates an outflow.

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[23]The real exchange rate misalignment creates discrepancies in calculating the current and future values of income, which leads to distortions in valuation of wealth.

[24]The literature that provides justification for the introduction of welfare improving taxes in the presence of pecuniary externalities focused on the same friction: market incompleteness (e.g. Hart (1975)), Stiglitz (1982))). We show that IRUPT can correct this friction through a different mechanism.

Figure 6 shows that μ_{t+1}^{UIP} moves in opposite directions in response to the two shocks. The RoW risk-premium shock induces a negative wedge between the marginal value of wealth across the border. This is due to a dominant fall in RoW consumption in response to the shock. On the other hand, using IRUPT generates an opposite movement in μ_{t+1}^{UIP}. As we will study in more detail below, the increase in the risk-sharing wedge in response to IRUPT is mainly due to a rise in prices and a fall in consumption in the EME. The inflationary effect of IRUPT has valuation effects on EME debt similar to a capital-inflow tax. IRUPT is effective in correcting the movements in the cross-country risk sharing wedge that are generated in response to the RoW risk-premium shocks.

In addition to the distributive externality due to incomplete international markets, our setting also incorporates aggregate demand externalities due to the presence of nominal rigidities (see Auray and Eyquem (2014) and Farhi and Werning (2016)). In the literature that studies prudential taxes in response to capital inflows, these two inefficiencies are expected to affect each other in opposite directions (see Erten et al. (forthcoming)). Although the terms of trade are distorted under the distributional externality, price rigidities can limit the movements of international relative prices. Unlike in the macro-prudential taxation literature, we show that the fluctuations in μ_{t+1}^{UIP} are amplified in response to an increase in uncertainty when the incomplete markets assumption is combined with price rigidities.

To see the contribution of price rigidities to the movement of μ_{t+1}^{UIP}, we repeat the exercise above when prices are flexible (*i.e.* $\kappa = \kappa^* = 0$). The dashed lines in Figure 6 show the dynamics for this case. We observe that nominal rigidities reinforce the movement of the risk sharing wedge in response to higher uncertainty. Precautionary effects are at the heart of our result. In response to an increase in uncertainty, households reduce their consumption (precautionary saving) and the aggregate price index increases (precautionary pricing). However, due to stronger precautionary saving, the fall in consumption is more pronounced than the increase in the aggregate price index. Therefore, the risk-sharing wedge moves upward. When prices are sticky, the increase in the marginal utility of consumption is not offset by the increase in aggregate price index as before, and this leads to a more pronounced increase in the wedge.

Having established that interest rate uncertainty can be used as a macroprudential intervention that enhances risk sharing, we now study the implications of the central bank using this discretionary tool to respond to inefficient capital inflows. We conduct the following exercise: We generate dynamics with a two-standard-deviation increase in the RoW risk premium (*i.e.*, $\varepsilon_t^{\sigma^{SW*}}$) in $t = 1$ and a two-standard-deviation increase in the time-varying volatility of the EME interest rate (*i.e.*, ε_t^{σ}) in $t = 2$. Figure 7 shows the dynamics of this exercise. The blue lines indicate the dynamics generated by the RoW risk-premium shock in the absence of IRUPT, and the purple lines indicate the dynamics when IRUPT is put in place starting in $t = 2$ as response to the consequences of the RoW shock. The persistence of IRUPT is equal to 0.86, which implies that changes in heteroskedastic volatility fade away in about four years.

We observe that IRUPT is successful in discouraging inefficient capital inflows. There is a correction in the bond component of the capital account, but EME interest rate uncertainty also encourages incoming FDI. Consumption falls significantly due to precautionary motives, and EME households shift their savings into domestic investment. The jump in domestic investment is reflected as an increase in output. 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. 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, with consumption falling, prices do not fully accommodate the lower demand that occurs 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.

The decline in the real exchange rate (appreciation from the EME perspective) decreases EME exporter profits. Exporters lower their markups to increase competitiveness in the RoW market. Exporter markups fall also due to the precautionary pricing behavior of exporters, which we will discuss more in detail below.[25] Higher demand for EME goods from the RoW (due to the fall in markups) boosts production, and EME firms demand more capital from both domestic and foreign

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[25] We discuss the strength of this effect when we provide additional results under producer currency pricing in Section 4.

investors, where the latter implies net FDI inflows.

From here onwards, for clarity of our analysis, we focus on the sole effect of IRUPT by analyzing the impulse responses to the interest rate uncertainty as deviations from the stochastic steady state of the economy (instead of IRUPT being put in place in $t = 2$ in response to inefficient capital inflows). Figure 8 shows how the model behaves in this exercise.[26]

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

How does IRUPT affect the RoW investors' portfolio problem? To further understand the effects of EME's interest rate uncertainty, we investigate the movements it induces in the risk premia in the RoW portfolio. Objects of our 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:

$$x_{t+1}^{B^*, B_*^*} \equiv \hat{r}_{t+1} - \hat{r}_{t+1}^* - \hat{s}_{t+1} + \hat{s}_t, \tag{27}$$

$$x_{t+1}^{K^*, K_*^*} \equiv \hat{r}_{K^*, t+1} - \hat{r}_{K_*^*, t+1} - \hat{rer}_{t+1} + \hat{rer}_t, \tag{28}$$

$$x_{t+1}^{B^*, K^*} \equiv \hat{r}_{t+1} - \hat{\pi}_{t+1} - \hat{r}_{K^*, t+1}. \tag{29}$$

The lowercase hatted variables are the percentage deviations of the respective variables from their non-stochastic steady state.[27] Certainty equivalence would imply that $\mathbb{E}_t \left[x_{t+1}^{B^*, B_*^*} \right] = \mathbb{E}_t \left[x_{t+1}^{K^*, K_*^*} \right] = \mathbb{E}_t \left[x_{t+1}^{B^*, K^*} \right] = 0$. However, given the non-linear solution of our model, endogenous fluctuations in higher-order terms lead to nonzero expected relative excess returns.[28] These terms are also nonzero when evaluated at the stochastic steady state, because the agents are taking future uncertainty into account.

We study how the relative excess returns across RoW investors' assets move in response to an

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[26]Although the way IRUPT operates is the same, it is important to note that the stochastic steady state of the economy is different in the structural absence of risk-premium shocks.

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

[28]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.

increase in the uncertainty of the EME policy rate. 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 increases in response to an increase in the uncertainty of the EME interest rate, but after two periods, it starts to decline. With an increase in the uncertainty (or risk) of the EME interest rate, EME bonds offer a higher expected return to induce investors to hold them. However, the premium is not increasing as much as the RoW investor risk appetite, and we still observe an outflow in the bond component of the capital account. The main reason why the relative excess return on EME bonds is decreasing after two periods is the increase in EME inflation, which diminishes the real return from holding EME bonds.

EME assets are riskier with the increase in the uncertainty of the EME interest rate but the real exchange rate acts as a hedging mechanism, and it appreciates (from the EME perspective) to push the price of EME physical capital up (*i.e.* $q_t^* = \frac{1}{rer_t}$). This appreciation contributes to the decrease in the relative excess return from investment in EME physical capital vis-à-vis the investment in RoW physical capital. Finally, when we compare the relative return of EME bonds to the return from EME physical capital, we observe a decrease, although it is EME bond investment that initially becomes riskier. With EME inflation becoming more volatile, a more volatile interest rate can provide a better hedge against inflation risk. But we also observe FDI inflows and bond outflows in the EME capital account, which suggests that the domestic repercussions of interest rate uncertainty are more important than the transmission of risk in the investor portfolio in affecting the composition of the EME capital account, as we explain below.

To provide more intuition for our results, we use the assumption of log-normality to express the relative excess returns as follows:[29]

$$\mathbb{E}_t \left[x_{t+1}^{B^*, B_*} \right] \approx -\frac{1}{2} Var_t(\Delta s_{t+1}) + Cov_t(m_{t+1}^*, \Delta s_{t+1}), \tag{30}$$

$$\begin{aligned} \mathbb{E}_t \left[x_{t+1}^{K^*, K_*} \right] &\approx -\tfrac{1}{2} \left(Var_t \Delta r\tilde{e}r_{t+1} + Var_t \tilde{r}_{K^*, t+1} - Var_t \tilde{r}_{K_*, t+1} \right) \\ &+ Cov_t \left(\Delta r\tilde{e}r_{t+1}, \tilde{r}_{K^*, t+1} \right) - Cov_t \left(log\beta_{t,t+1}^*, \tilde{r}_{K^*, t+1} - \Delta r\tilde{e}r_{t+1} - \tilde{r}_{K_*, t+1} \right), \end{aligned} \tag{31}$$

---

[29]Appendix B provides detailed derivations of these relations.

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$$\mathbb{E}_t \left[x_{t+1}^{B^*,K^*} \right] \approx -\frac{1}{2} Var_t \pi_{t+1} + \frac{1}{2} Var_t \tilde{r}_{K^*,t+1} + Cov_t \left(\tilde{r}_{K^*,t+1} + \pi_{t+1}, log\beta_{t,t+1}^* - \Delta r\tilde{e}r_{t+1} \right). \quad (32)$$

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.[30] Equation (30) shows that the EME currency is not a good hedge when there is an increase in EME interest rate uncertainty. The EME interest rate uncertainty causes consumption to decrease in both EME and RoW. The RoW investor is seeking assets whose currency negatively covaries with her stochastic discount factor (she wants assets that are valuable in bad times). A nominal depreciation of the EME currency and a decrease in the RoW consumption imply an increase in the covariance term. EME currency being a bad hedge against RoW consumption volatility pushes the excess return rate up.

Regarding the relative returns on physical capital in EME and RoW, movements in the real exchange rate play a crucial role. As discussed above, the real exchange rate appreciates and increases the price of EME physical capital. In Equation (31), we see that the appreciation affects relative returns through an increase in real exchange rate volatility and an increase of the covariance between the RoW stochastic discount factor and the change in the real exchange rate. The sign of the covariance term implies that the movements of the real exchange rate make investment in EME physical capital a good hedge against RoW consumption volatility.

In Figure 9, we also see that the relative risk of EME bonds is decreasing vis-à-vis that of EME physical capital but the RoW investor is decreasing her exposure to EME bonds. Equation (32) tells us that the movement in the relative excess return is due to increase in EME inflation volatility. With the relative return on bonds decreasing, one would expect EME physical capital to be riskier, and therefore a stronger outflow in the FDI component of the EME capital account, if this were a partial equilibrium analysis. Our general equilibrium framework shows that the transmission of interest rate uncertainty within the EME is central to the adjustment in the composition of the external flows between bonds and FDI, as we explain next.

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[30]We omit the terms related to the costs of adjusting bond holdings when deriving these relations. Due to our calibration, the effects of convex adjustment costs are minuscule in our simulations. 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.

3.3.4 Transmission within the Emerging Market Economy

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

Precautionary Savings Channel and Oi-Hartman-Abel Effects

Figure 10 shows the dynamics after an increase in interest rate uncertainty with flexible prices, *i.e.* $\kappa = \kappa^* = 0$ (black lines). For comparison purposes, we also provide the dynamics from the baseline model (purple). In the absence of price adjustment costs, there are no time-varying inefficient wedges between prices and marginal costs. Flexible prices abstract from the effects of markup variation, and the inflationary effect of interest rate uncertainty is much smaller.

After an increase in uncertainty in the EME, we still observe a fall in consumption due to precautionary motives, but this is less pronounced than in the baseline scenario. Savings are channeled to domestic investment because firms demand more inputs from both EME and RoW to expand production in the absence of price rigidities. This is because, 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)). In the absence of frictions that impact production, volatility can positively affect EME production and increase the demand for incoming FDI.[31]

Precautionary Pricing Channel

Ferńandez-Villaverde et al. (2015) studied the behavior of markups in response to uncertainty shocks in a closed economy and showed that firms move their prices upwards. A similar mechanism is at work in our model, but we show that having the same result as in a closed economy is crucially dependent on the level of the exchange rate pass-through. To single out the effects of price-setting frictions, in Figure 11, we show the model dynamics after removing the wage adjustment frictions from the baseline economy. The black lines indicate the dynamics when wages are flexible.

Costly price adjustment causes firms to smooth price changes by letting markups vary. When wages are not sticky, firms cut labor demand and wages fall in response to uncertainty. Through

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[31]In a closed economy without frictions that affect production, volatility can be welfare enhancing if this channel is dominant (e.g., Lester et al. (2014)).

factors of production, rental rates of capital decline as well. The downward pressure on the rental rates reduces the supply of investment from abroad. Exporters increase competitiveness by lowering markups more than when wages are sticky. The latter effect prevents FDI from changing direction (*i.e.*, EME is still receiving FDI).

Markups also move because EME firms' profits are asymmetric in terms prices and the real exchange rate. To show the mechanism, 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. However, the increase in profits is more pronounced in the case of real exchange rate depreciation and decreasing prices than with appreciation and increasing prices. Hence, in response to uncertainty, exporters engage in precautionary pricing by lowering prices, and exporter markups fall.[32]

4   Additional Results

In this section, we discuss the effects of modifying our baseline model in several directions. First, to capture the long-run nature of FDI, we introduce a time-to-build requirement for the physical

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[32]In the next section, we show that the closed economy results hold under producer currency pricing.

capital that will be used in overseas production. Second, 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. Third, 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 ineffective conventional monetary policy in advanced economies.

4.1 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:

$$
\begin{aligned}
K_{*,t+1}(h) &= (1-\delta)K_{*,t}(h) + I_{*,1,t}(h), \\
I_{*,j-1,t+1}(h) &= I_{*,j,t}(h); \qquad j = 2, ..., J. \\
I_{*,t}(h) &= \sum_{j=1}^{J} \tfrac{1}{J} I_{*,j,t}(h),
\end{aligned}
\tag{33}
$$

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.[33]

The conditions in (33) 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:

$$
q_{*,t+J-1} = \mathbb{E}_{t+J-1}\left[\beta_{t+J-1,t+J}\left(rer_{t+J}r_{K,*,t+J} + q_{*,t+J}\left(1-\delta\right)\right)\right],
\tag{34}
$$

$$
\mathbb{E}_t\left[\beta_{t,t+J-1}q_{*,t+J-1}\right] = \frac{1}{J}\left(rer_t + \mathbb{E}_t\left[\beta_{t,t+1}rer_{t+1}\right] + ... + \mathbb{E}_t\left[\beta_{t,t+J-1}rer_{t+J-1}\right]\right).
\tag{35}
$$

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

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Equations ([34](#)) and ([35](#)) 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 ([35](#)) 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.

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

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

Appendix C shows the modifications in the law of motion for net foreign asset when FDI is subject to time-to-build.

Figure [13](#) shows the impulse responses to an increase in EME interest rate uncertainty when FDI is subject to a four-period time-to-build condition. The irreversibility of FDI dampens fluctuations in the FDI component of the capital account. EME households cannot expand intermediate goods production on impact. Instead, they borrow from RoW to increase imports of intermediate goods. This manifests itself as an inflow in the bond component of the external account, in contrast with the policymaker's goal of discouraging short-term capital inflows.

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.[34] To sum up, the irreversibility and long-run nature of FDI increase short-run bond inflows into EME right after its use of IRUPT. The policy remains inflationary.

4.2 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

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

(PCP). Appendix D provides the details of the firms' problem under PCP.

Figure 15 shows impulse responses after an increase in EME interest rate uncertainty in this scenario. EME bonds are riskier and there is an outflow in the bond component of the capital account as in the baseline model. However, PCP reverses the behavior of net FDI flows in response to EME interest rate uncertainty. The response of the export price markup is key in generating this outcome.

To see the impact of the currency of export invoicing on markups more clearly, we also simulate the model under dominant currency pricing (our baseline pricing assumption) and PCP when wages are flexible. Figure 16 shows the responses of markups and the components of the current account to an increase in EME interest rate uncertainty. Under PCP, export price markups and the FDI component of the current account move in opposite directions relative to the baseline setting. Higher markups and appreciation of the real exchange rate make EME exports more expensive, and RoW agents decrease their demand of these goods. EME producers respond by decreasing their demand of inputs for intermediate goods production, including the demand of FDI. As a consequence, we observe an outflow in the FDI component of the capital account.

The reason why export price markups rise is 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 17 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 17 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, markups rise.

Figure 18 shows impulse responses from the model version in which FDI is subject to four

periods time-to-build and firms engage in PCP. The real options channel dampens the fluctuations in the FDI component of the capital account, as before. EME households shift their investment toward physical capital that will be used in RoW production, where risk is lower. However, because FDI takes four periods to be completed, EME agents cannot generate immediate rental gains from shifting their investments and, instead, borrow from RoW to prevent a further fall in consumption. The latter is reflected as an inflow in the bond component of the capital account.

A comparison of current account dynamics under different duration of the time-to-build requirement is provided in Figure 19. The figure shows that as the periods of time to build increase from one period to four periods, the net outflow of FDI becomes milder. However, as the desired rental gain from shifting investments is not immediately received, the magnitude of the increase in short-term borrowing is more pronounced when more periods are required to build FDI.

4.3   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 policy rate risk, 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 for RoW agents and we study their interaction with EME policy.[35]

We follow the literature and generalize equation (1) to an Epstein-Zin-Weil (Epstein and Zin (1989) and Weil (1989)) specification:

$$V_t \equiv (1 - \beta)U(C_t(h), L_t(h)) - \beta \left[\mathbb{E}_t \left(-V_{t+1} \right)^{1-\alpha} \right]^{1/(1-\alpha)}, \tag{36}$$

where $\alpha \in \mathbb{R}$.[36] When $\alpha = 0$, (36) reduces to the standard expected utility in (1). With $U \leq 0$ everywhere, lower values of α correspond to greater risk aversion.

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[35]We start our analysis by introducing high risk aversion only to RoW agents. Then, we compare model dynamics when both EME and RoW agents have high risk aversion.

[36]Our utility kernel employs an elastic intertemporal substitution (*i.e.* $\gamma = 2$) and, therefore, $U \leq 0$ everywhere and recursion is formulated as in (36). As highlighted by Rudebusch and Swanson (2012), when $U \geq 0$ everywhere, the recursion needs to be reformulated as $V_t \equiv (1 - \beta)U(C_t(h), L_t(h)) + \beta \left[\mathbb{E}_t \left(V_{t+1} \right)^{1-\alpha} \right]^{1/(1-\alpha)}$.

The discount factor of RoW agents, $\beta^*_{t,t+1}$, becomes

$$\beta^*_{t,t+1} \equiv \frac{\beta U^*_{C,t+1}}{U^*_{C,t}} \left(\frac{-V^*_{t+1}}{\left(\mathbb{E}_t \left[-V^{*1-\alpha^*}_{t+1} \right] \right)^{1/(1-\alpha^*)}} \right)^{-\alpha^*}. \tag{37}$$

With Epstein-Zin-Weil preferences, the discount factor now has an additional term that reflects the early resolution of uncertainty. With $\alpha^* < 0$, any unfavorable changes in utility imply a higher discount factor for RoW agents.

Using (37) and its EME counterpart, we can express the no-arbitrage condition as:[37]

$$\frac{R_{t+1}}{R^*_{t+1}} = \frac{(1+\eta b^*_{t+1})\mathbb{E}_t \big[\frac{\beta U^*_{C,t+1}}{U^*_{C,t}} \left(\frac{-V^*_{t+1}}{\left(\mathbb{E}_t \left[-V^{*1-\alpha^*}_{t+1} \right] \right)^{1/(1-\alpha^*)}} \right)^{-\alpha^*} \frac{1}{\Pi^*_{t+1}} \big]}{(1+\eta b^*_{*,t+1})\mathbb{E}_t \big[\frac{\beta U^*_{C,t+1}}{U^*_{C,t}} \left(\frac{-V^*_{t+1}}{\left(\mathbb{E}_t \left[-V^{*1-\alpha^*}_{t+1} \right] \right)^{1/(1-\alpha^*)}} \right)^{-\alpha^*} \frac{rer_t}{\Pi_{t+1} rer_{t+1}} \big]}.$$

Figure 20 compares the impulse responses to rising uncertainty in the EME interest rate when RoW agents are becoming more risk averse. To highlight the role of RoW risk aversion, without loss of generality, we consider the cases in which α^* is equal to 0, -8, and -48 while α is equal to 0.

We observe that the responses of the bond and FDI components of the capital account reverse when RoW agents are more risk averse. In response to higher EME interest rate risk, RoW agents smooth consumption using RoW bonds and increase investment in RoW physical capital. The bond market clearing condition implies that EME agents borrow extensively using RoW bonds and this is reflected in an inflow in the bond component of the capital account. More risk averse RoW agents also decrease their exposure to the EME by shifting physical investment. The change in the investment for EME physical capital is reflected in an outflow in the FDI component of the capital account. Figure 21 shows the responses of the RoW discount factor under different degrees of risk aversion. As RoW agents significantly prefer early resolution of uncertainty under higher degrees of risk aversion, their stochastic discount factor moves by more in response to EME interest rate risk.

We also conduct simulations when EME agents have the same degree of risk aversion as RoW agents. Figure 22 shows the impulse responses in this case. Simulations generate similar responses

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[37]It is important to note that recursive preferences induce deviations from UIP even under internationally complete markets and perfect foresight.

to those when only RoW agents are more risk averse. The main difference is that fluctuations in the bond component of the capital account are dampened due to reduced borrowing by EME households. RoW households still want to save by holding RoW bonds but their saving is constrained by the willingness of EME households to borrow internationally. RoW households shift investments away from EME physical capital in less severe fashion because they are not able to save in RoW bonds as much as they would like. Figure 23 further shows the movements in the EME stochastic discount factor under different degrees of EME household risk aversion. The preference for early resolution of uncertainty is seen in the more pronounced responses of the EME stochastic discount factor under higher degrees of risk aversion.

4.4 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.[38]

We assume that the RoW nominal interest rate is pegged at its steady-state value for four periods, and we induce dynamics with an increase in the uncertainty of the EME's interest rate in period one.[39] The impulse responses from our experiment are in Figure 24. We observe that the responses are heavily magnified. There are strong outflows both in the bond and FDI components of the capital account. Interestingly, exporter markups increase when the RoW interest rate cannot

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

[39]Fernández-Villaverde et al. (2015) also conduct a zero-lower-bound exercise under tax-uncertainty shocks. In their setting, they introduce a combination of exogenous innovations to keep the interest rate at zero for a fixed amount of time.

decrease to expand the economy.

When the RoW interest rate is bounded from below, prices in the RoW fall down. Lower prices in the RoW and an appreciation of the real exchange rate result in an increase in EME imports. RoW agents also shift their demand toward domestic goods due to relatively lower prices. These shifts in demand hurt EME exporters, who increase prices to compensate for the fall in their revenues, and export markups increase. With an effective lower bound in the rest of the world, competitiveness effects offset the precautionary pricing channel in determining capital flows. The increase in demand for RoW goods manifests itself as an increase in demand for the inputs of RoW production. RoW producers attract more FDI and, hence; there is an outflow in the FDI component of the EME capital account.

The effect of competitiveness in the EME export sector is transparent when we change the home-bias parameter, a, to 0.95. Figure 25 shows the impulse responses under the new calibration. We note the change in the direction of export price markups. Moreover, fluctuations are now much smaller. The share of exports being very small implies a more dominant precautionary pricing channel, resulting in markups being lowered in response to an increase in the uncertainty of the EME interest rate. However, we still observe FDI outlfows from EME. The reason is that with lower prices in RoW, RoW producers still expand production due to increase in domestic demand. They expand production by acquiring more inputs, including the FDI they need for production. Thus, when the RoW interest rate is unresponsive to economic fluctuations, there are outflows both in the bond and FDI components of the EME capital account. The effect of exporter competitiveness on markups is clearer when we run simulations under different degrees of home bias in Figure 26.

5   WELFARE ANALYSIS

Having explored the transmission and propagation mechanisms of IRUPT, we now evaluate its performance in the baseline model in terms of a consumption compensating variation metric. We compare IRUPT to another "second-order" policy option that can be effective in tackling inefficient capital flows: capital control uncertainty (CCU). We first study how CCU affects the current account, and then we compare CCU with IRUPT in terms of the compensating variation—the percentage of consumption that must be altered under IRUPT to generate the same welfare as

under CCU.

<div align="center">

CAPITAL CONTROL UNCERTAINTY

</div>

Capital controls have been studied in the literature in terms of their role as a prudential policy tool for smoothing aggregate demand. However, these policies might have undesirable consequences.[40] Hence, policymakers can consider creating uncertainty on capital controls to adjust the current account without actually introducing the policy. We study CCU as follows.

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

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

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

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

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

The new equilibrium conditions tell us that the after-tax returns of EME and RoW bonds to EME households are R_{t+1} and $\widetilde{R}_{t+1}^* \equiv (1 + \tau_t) R_{t+1}^*$, respectively. We further model capital-control uncertainty as a stochastic volatility process for the gross rate of capital-inflow taxation: $1 + \tau_t = e^{u_t}$, where $u_t = \rho^u u_{t-1} + e^{\sigma_t} \varepsilon_t$, with the standard deviation, σ_t, following an $AR(1)$ process, $\sigma_t = (1 - \rho^\sigma) \sigma + \rho^\sigma \sigma_{t-1} + \varepsilon_t^\sigma$. We keep the notation the same as for the interest-rate-uncertainty process because we assume exactly the same policy behavior, with the same calibration, to treat both policies fairly in comparison.[41]

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[40] For instance, Benigno et al. (2013) show that the interaction between agents' behavior in crisis and normal times is crucial for the outcome of introducing ex ante macroprudential taxes. Moreover, Kaplan and Rodrik (2001) highlight that introducing capital controls explicitly can diminish market confidence even further during outflow periods.

[41] For comparison purposes, there needs to be a normalization of the alternative policy option. Another way to introduce normalization is to generate dynamics under both policies so that the bond component of the capital

CCU can be willingly introduced by policymakers through communication (or lack thereof) with markets. From the perspective of our model, it will make the earnings from holding RoW bonds more uncertain (for EME households).

Figure 27 shows the impulse responses to a two-standard-deviation increase in CCU. Although the magnitude of the shock is the same, CCU generates much smaller fluctuations than IRUPT. The reason is that CCU increases uncertainty on the RoW interest rate for the EME investor rather than increasing EME interest rate uncertainty that affects both EME and RoW investors. Consumption falls due to precautionary savings behavior, and EME households tilt their portfolio toward EME bonds. Hence, there is an outflow in the bond component of the capital account. Another significant difference with IRUPT is that the real exchange rate depreciates in response to CCU. Because the RoW interest rate is riskier for EME investors, the real exchange rate moves to compensate for the drop in RoW asset prices. A depreciating real exchange rate translates into a lower real price of physical capital in EME, thereby generating inflows of FDI. Since the direction in the movement of the real exchange rate flips, so does the qualitative response of exporter markups, showing that competitiveness motives prevail on precautionary pricing.

In the end, CCU is successful at controlling the external account and attracting FDI while discouraging bond inflows, but its effect is through national absorption and its impact is quantitatively small.[42]

Welfare Comparison

We compare IRUPT with CCU in terms of their effect on the lifetime utility of the EME household and calculate a compensating variation in the welfare metric for the two different unconventional policy options. We take a third-order approximation of both the model and the utility function.

We evaluate the welfare when both the risk premium shocks and the uncertainty policy are present simultaneously. This is important because it is related to how uncertainty policy operates

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account moves exactly by the same amount. As it will be clearer in our analysis, the magnitude of the capital control uncertainty would be much higher in that case.

[42] As discussed above, it is also possible to generate larger fluctuations by creating more uncertainty. In addition, under both policy options, the curvature of the profit functions (i.e. the degree of demand elasticity), the risk aversion of the agents, or an effective lower bound in the RoW would all be additional ingredients that can contribute to much larger fluctuations.

in discouraging capital flows. Instead of merely dampening the fluctuations in inefficient wedges, the uncertainty policy operates through creating fluctuations in the wedges in the opposite direction relative to the risk premium shocks. Hence, this type of policy is obviously welfare reducing if not evaluated *intra* capital inflow periods.[43]

When calculating welfare, it is also important to determine whether a conditional or unconditional metric is used, and whether calculations are made when the steady state is efficient or inefficient. The unconditional metric measures welfare as the unconditional expectation of the value of the utility function and abstracts from the transition costs when policies are in effect. Hence, it is useful to evaluate the economy from a longer-term perspective. In addition, having distinct ergodic means under each policy option makes the comparison difficult. Hence, we focus more on the conditional metric—conditioned on the value of the non-stochastic steady state—in accounting for the transitional costs when uncertainty policies are in place.

Since our exercise was motivated by a clearly non-cooperative interaction of EMEs with advanced economies, neither of the policies we consider is introduced from the perspective of a global policymaker (or social planner) to introduce perfect risk sharing in international financial markets. Hence, when evaluating welfare, we focus only on the EME lifetime utility and simulations are from the inefficient steady state.

We calculate the conditional compensating variation as follows. Let us denote the expected present discounted value of utility under each policy option as follows:

$$V_t^i = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left(\frac{C_{t+j}^i {}^{1-\rho} - 1}{1 - \rho} - \chi \frac{L_{t+j}^i {}^{1+\varphi}}{1 + \varphi} \right) \qquad i \in \{IRUPT, CCU\}.$$

Define λ as the percentage of consumption the representative EME household needs for each period during which IRUPT is in place in order to have the same lifetime utility as when CCU is in place:

$$V_t^{CCU} = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{\left((1+\lambda) C_{t+j}^{IRUPT} \right)^{1-\rho} - 1}{1 - \rho} - \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \chi \frac{L_{t+j}^{IRUPT\, 1+\varphi}}{1 + \varphi}.$$

In this equation, the value functions are conditional on the same point. The derivations of the

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[43]If uncertainty policy is introduced in pre capital-inflow periods, it creates inefficiency by creating volatility. If it is evaluated in post capital inflow periods, it will further contribute to the adverse effects of reversal of capital flows. Hence, this policy option can only be beneficial within capital-inflow boom periods.

conditional and unconditional compensating variations are in Appendix E. We calculate the unconditional metric by simulating the model with risk premium and policy uncertainty shocks together for 4,000 periods, starting from the non-stochastic steady state and taking the average of the simulations.

Table 3 shows the compensating variation in consumption for both the conditional and unconditional metrics. We showed in the impulse response analysis that the fluctuations under CCU are much smaller because the domestic repercussions of CCU are much more limited than those of IRUPT. This is further reflected in the welfare analysis. The unconditional compensating variation shows that, in order to live under IRUPT, EME households desire a level of consumption that is almost six times the level of consumption under CCU. However, when transition effects are calculated, IRUPT performs much better than CCU. EME households need a level of consumption under CCU that is almost eleven times the level of consumption under IRUPT. The main reason is that IRUPT is stronger in closing the risk sharing wedge in response to increases in the RoW risk premium.

The analysis in this section shows that capital flow cycles can be very costly from the perspective of the EME, and a policy that discourages inefficient flows and alters the composition of the capital account can be desirable from the EME policymaker's perspective. In an environment of sudden stops and regime switches, the cost of boom-bust cycles would be much higher. We leave it for further research to study whether using IRUPT can be a successful at decreasing the probability of switching into a crisis regime.

6 Conclusions

We examined interest rate uncertainty 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. Appreciation of the real exchange rate acts as a hedging mechanism and increases asset prices in the emerging economy. Precautionary price setting ensures that this effect is strong enough to incentivize FDI flows into the emerging economy.

Irreversibility of FDI through a time-to-build mechanism generates a wait-and-see effect, damp-ening the inflow of FDI. Advanced economy interest rates tied to an effective lower bound as in the aftermath of the Great Recession implies outflows in the FDI component of the emerging economy's capital account. The direction of the bond component of the capital account also depends on the degree of risk aversion of the agents. With high risk aversion under Epstein-Zin-Weil preferences, Rest of the World (RoW) investors increase their holdings of RoW bonds. A comparison of wel-fare costs shows that emerging economy households prefer interest rate uncertainty—IRUPT—to a policy of capital control uncertainty. Importantly, under all scenarios we studied, IRUPT is inflationary.

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 fully discretionary 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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Table 1: Model Summary (Baseline)

Euler equation, domestic bonds	$1 + \eta b_{t+1} = R_{t+1}\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}}\right]$
Euler equation, RoW bonds	$1 + \eta b_{*t+1} = R_{t+1}^*\mathbb{E}_t\left[\frac{\beta_{t,t+1}}{\Pi_{t+1}^*}\frac{rer_{t+1}}{rer_t}\right]$
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	$b_{t+1} + rer_t b_{*,t+1} + \left(\frac{1-n}{n}\right)rer_t K_{*,t+1} - K_{t+1}^*$
	$= \frac{R_t}{\Pi_t}b_t + \frac{R_t^*}{\Pi_t^*}rer_t b_{*,t} + \left(\frac{1-n}{n}\right)rer_t\left(r_{K,*,t} + 1 - \delta\right)K_{*,t}$
	$- \left(r_{K,t}^* + 1 - \delta\right)K_t^* + TB_t$
Monetary policy	$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^\rho\left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho)\rho_\Pi}\left(\frac{Y_t}{Y}\right)^{(1-\rho)\rho_Y}e^{u_t}$

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Table 2: Calibration

Parameter		Value	Comments
Discount factor	β	0.9804	2% Real Rate
Relative risk aversion	ρ	2	Literature
Relative weight of labor in utility	χ	1	Literature
Frisch elasticity	φ	0.25	Literature
Bond adjustment	ψ	0.0025	Literature
Rotemberg wage adjustment	κ^W	116	Barattieri et al. (2018)
Elasticity of substitution of differentiated labor	ϵ^W	11	Wage markup of 10%
Home bias	a	0.65	Unsal (2013)
Share of domestic capital	α_1	0.30	Aoki et al. (2016)
Share of foreign capital	α_2	0.15	Aoki et al. (2016)
Rotemberg domestic price adjustment	κ	116	Barattieri et al. (2018)
Inverse elasticity of substitution between Home and Foreign goods	ω	1.2	Literature
Rotemberg export price adjustment	κ^*	116	Barattieri et al. (2018)
Elasticity of substitution of differentiated goods	ϵ	11	Price markup of 10%
Interest rate smoothing coefficient	ρ_R	0.7	Literature
Steady state response to inflation	ρ_Π	1.5	Literature
Steady state response to output	ρ_Y	0.5/4	Literature

Table 3: Welfare

	Welfare under IRUPT	Welfare under CCU	Welfare Cost, λ
Conditional	-4278.011	-265.275	-11.109
Unconditional	-2590.448	-128.664	6.782

FIGURES

Figure 1: Portfolio Flows to EMEs (13-week moving average, bn USD)
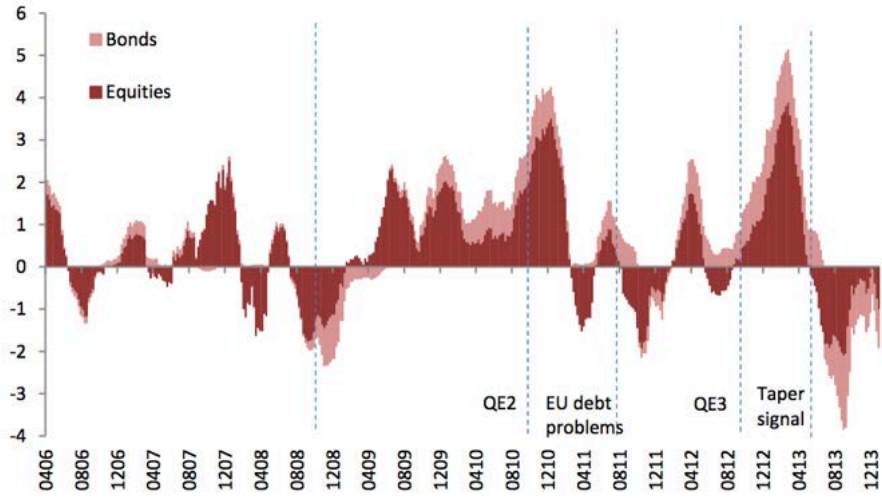
Source: Central Bank of the Republic of Turkey

Figure 2: Interest Rate Corridor and Average Funding Cost, Turkey

Source: Central Bank of the Republic of Turkey

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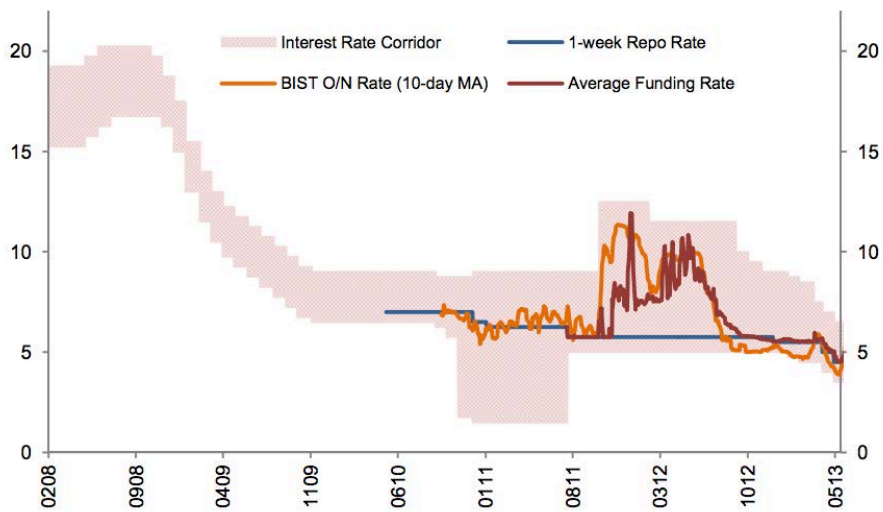
Figure 3: Financing the Current Account, Turkey (12-month cumulative, bn USD)
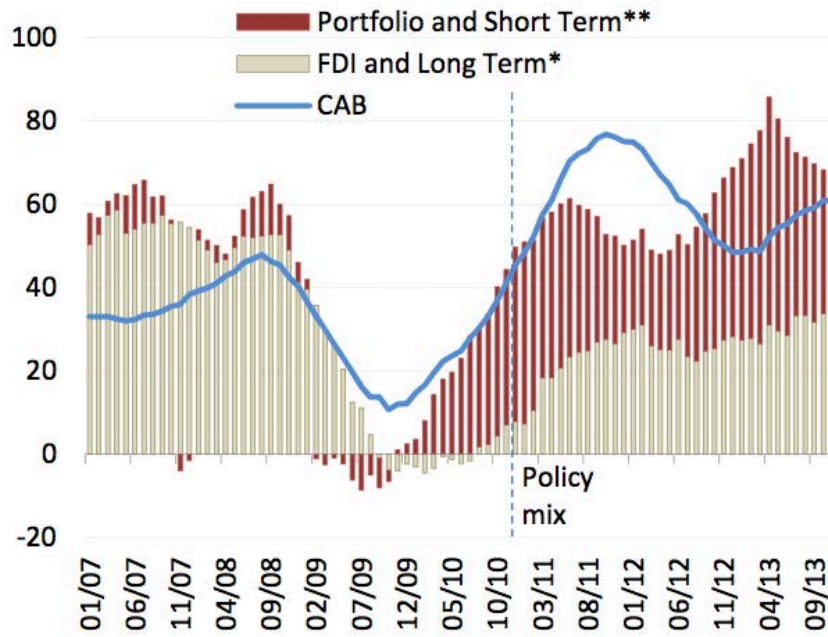
Source: Central Bank of the Republic of Turkey

Figure 4: Model Architecture
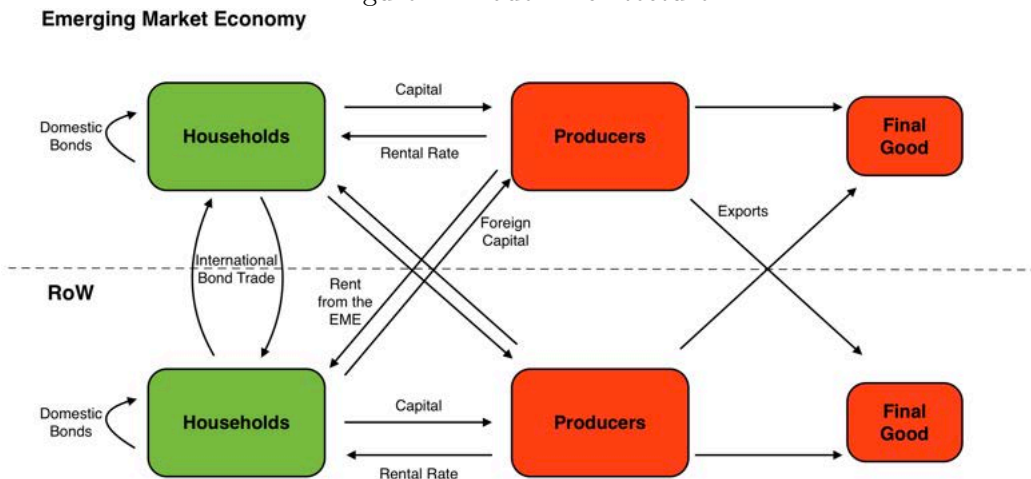
Figure 5: Impulse Responses to an Increase in Interest Rate Level
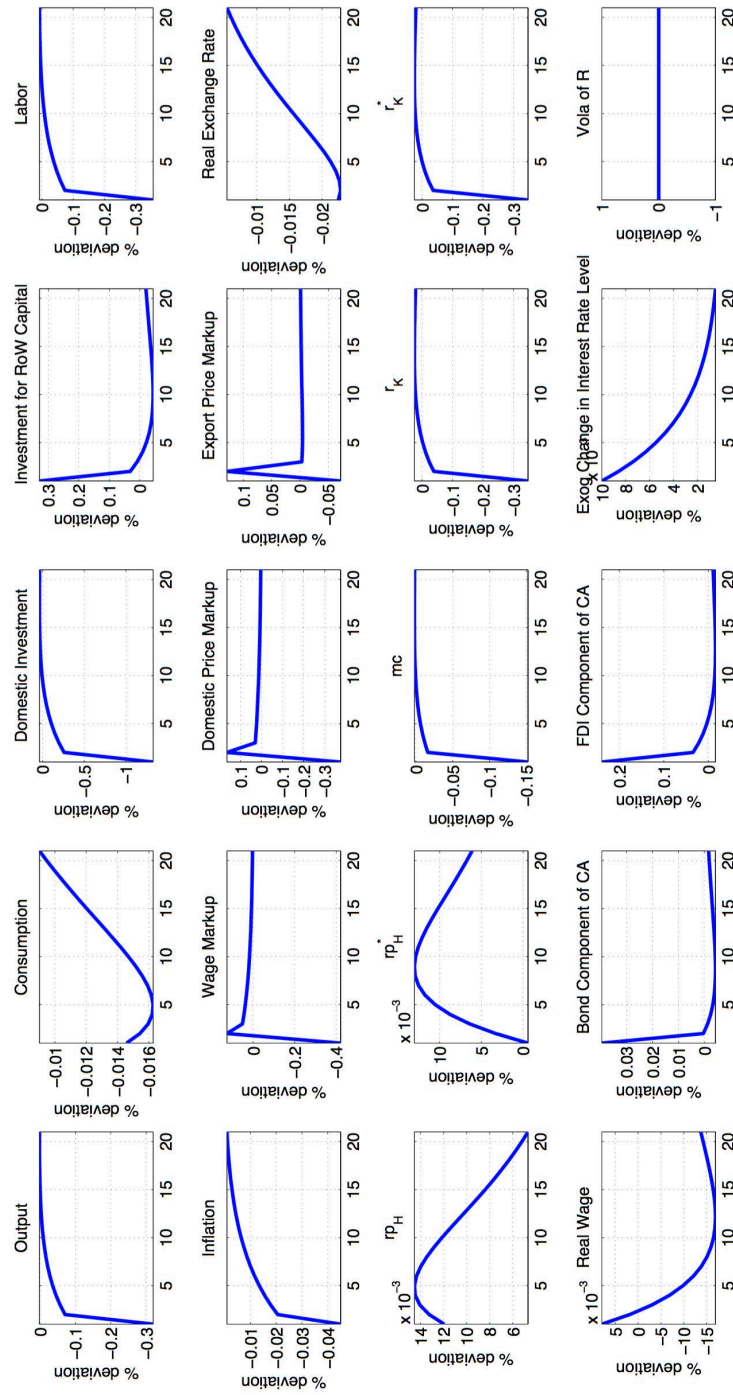
Figure 6: Movements in the UIP "Wedge"

μ^{UIP}
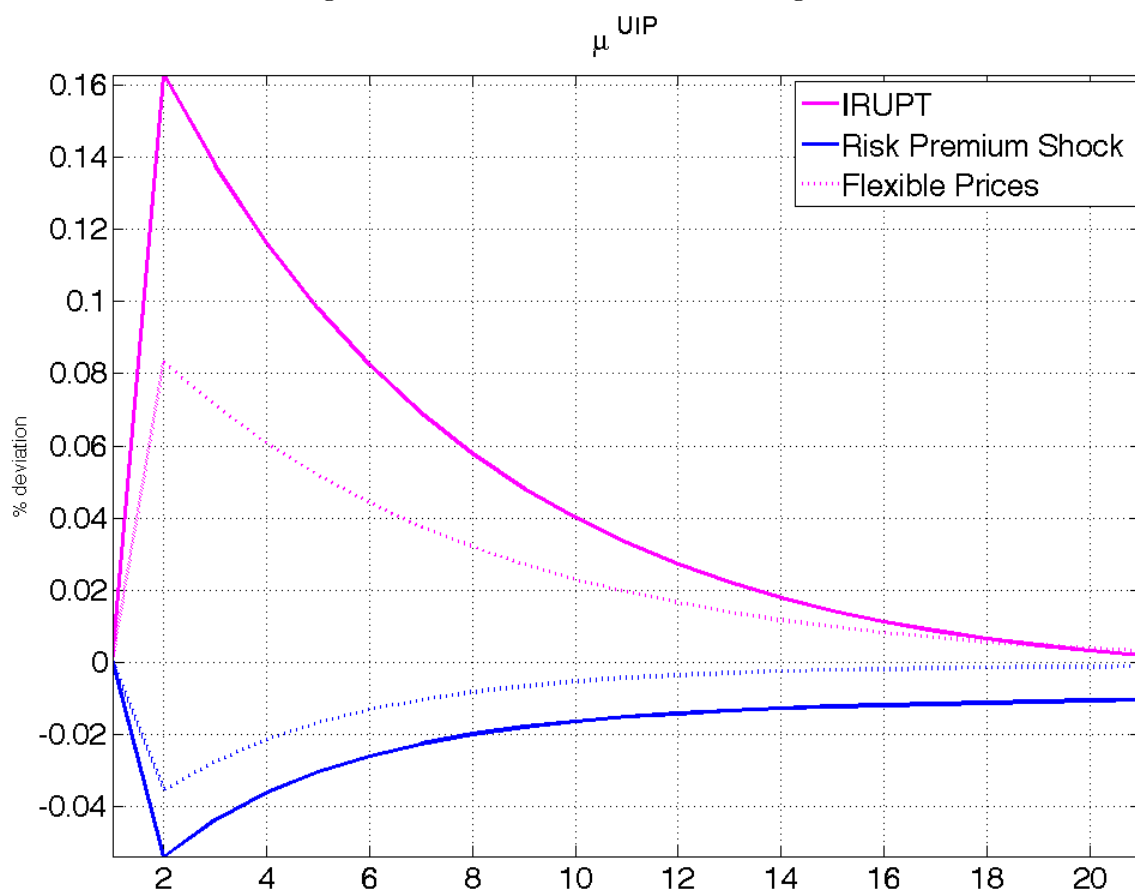
Figure 7: Inefficient Capital Inflows and IRUPT
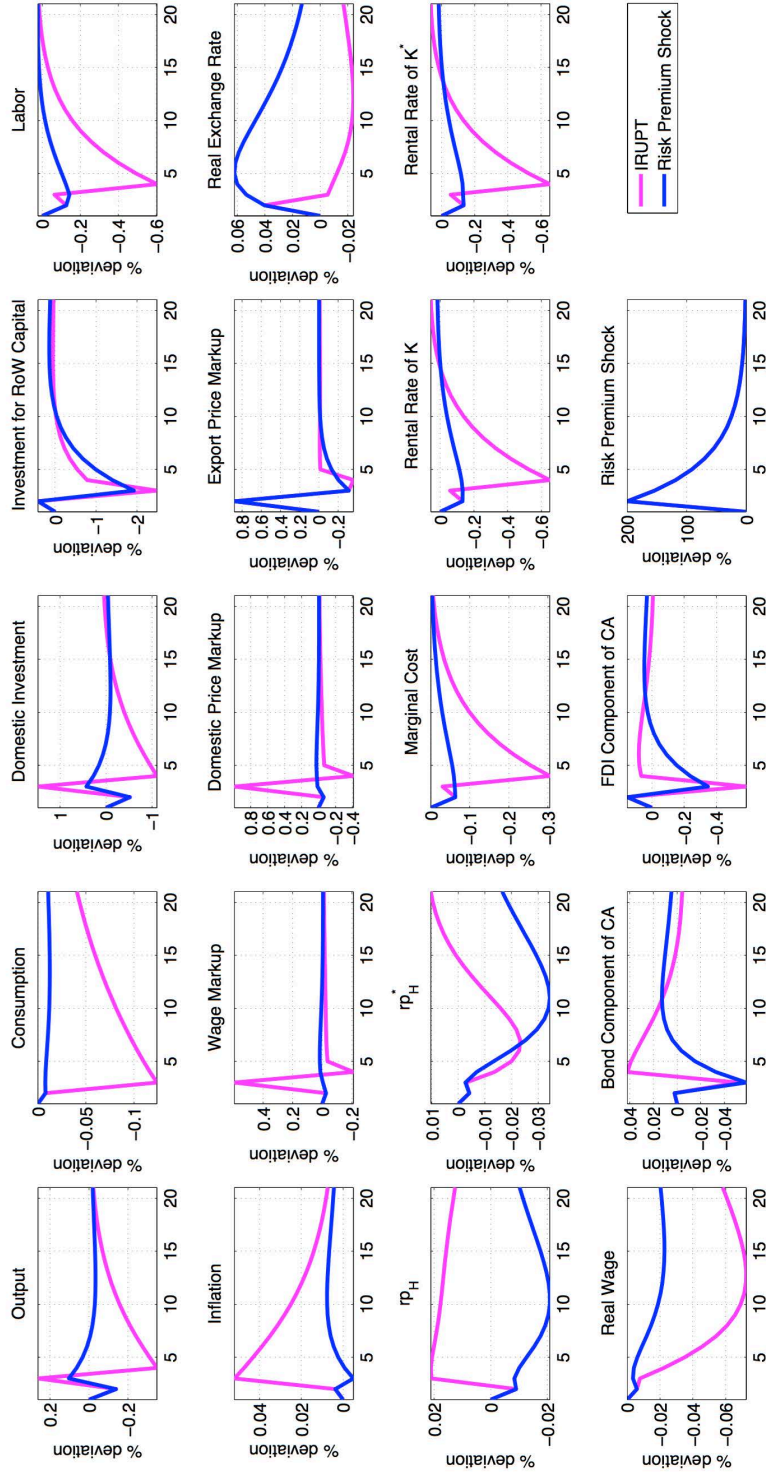
Figure 8: Impulse Responses to an Increase in Interest Rate Uncertainty (baseline)
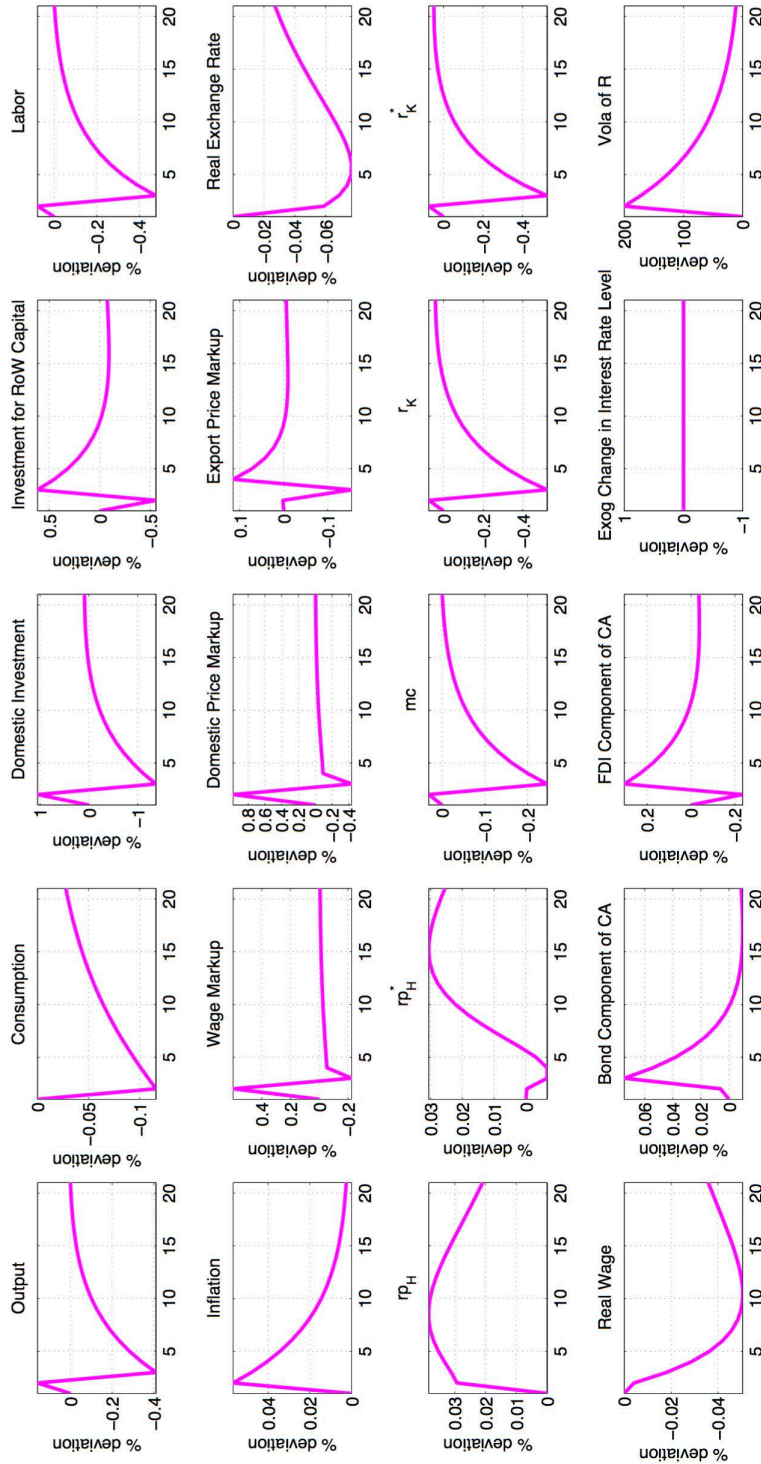
Figure 9: Relative Excess Returns and the Composition of the External Account
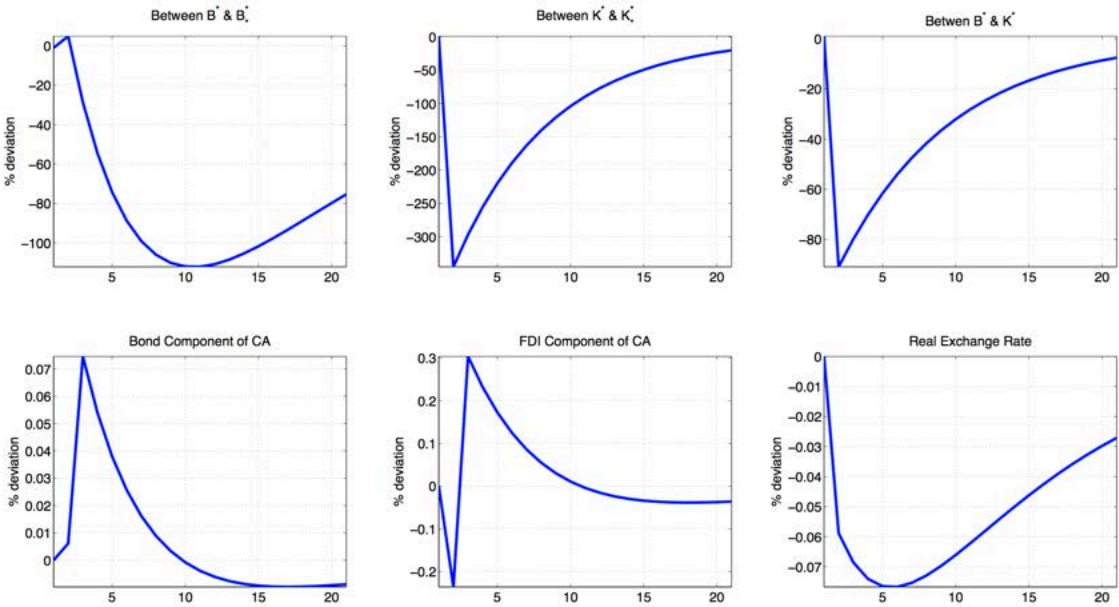
Figure 10: Impulse Responses to an Increase in Interest Rate Uncertainty ($\kappa = \kappa^* = 0$)
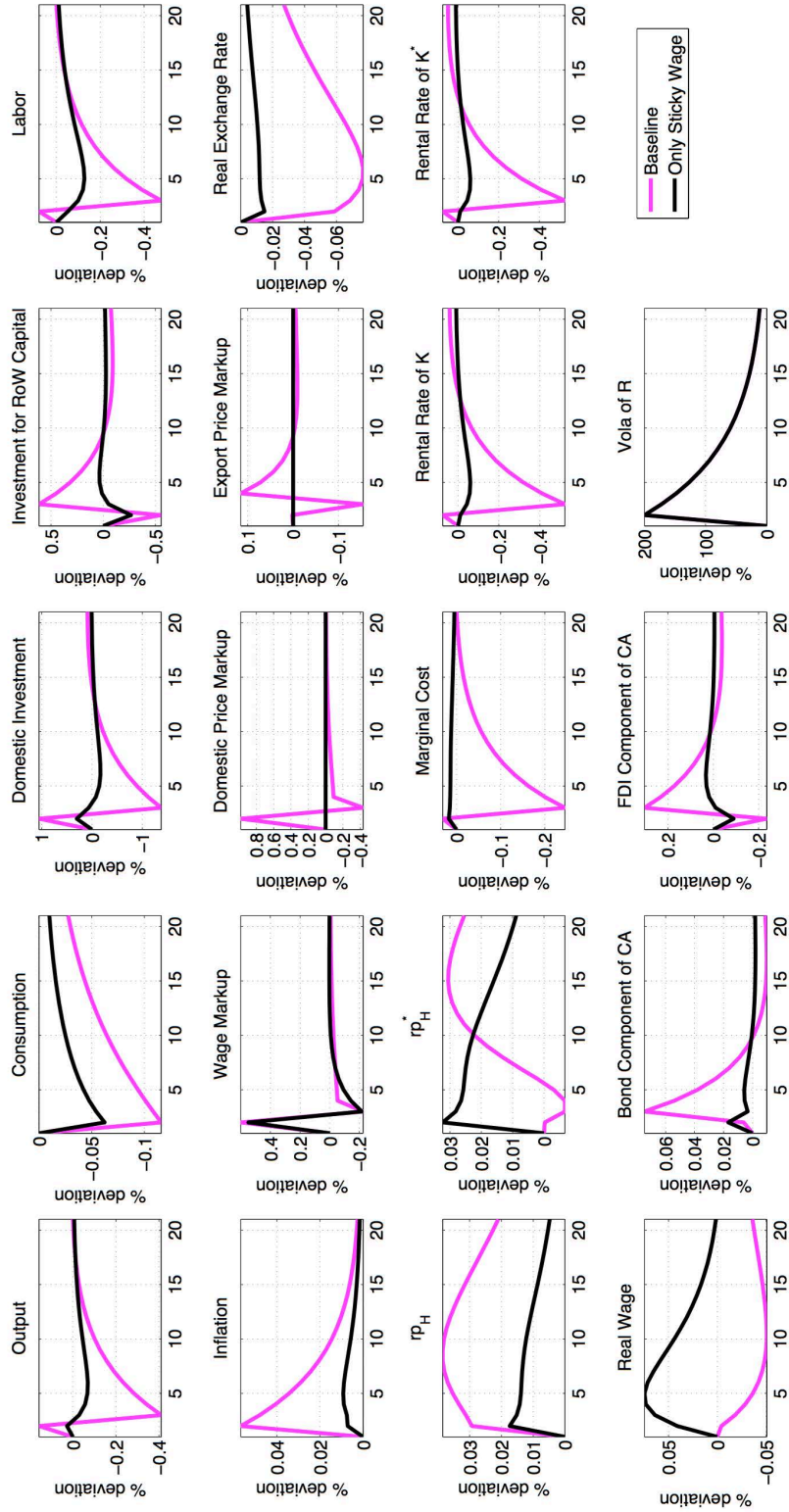
Figure 11: Impulse Responses to an Increase in Interest Rate Uncertainty ($\kappa^W = 0$)

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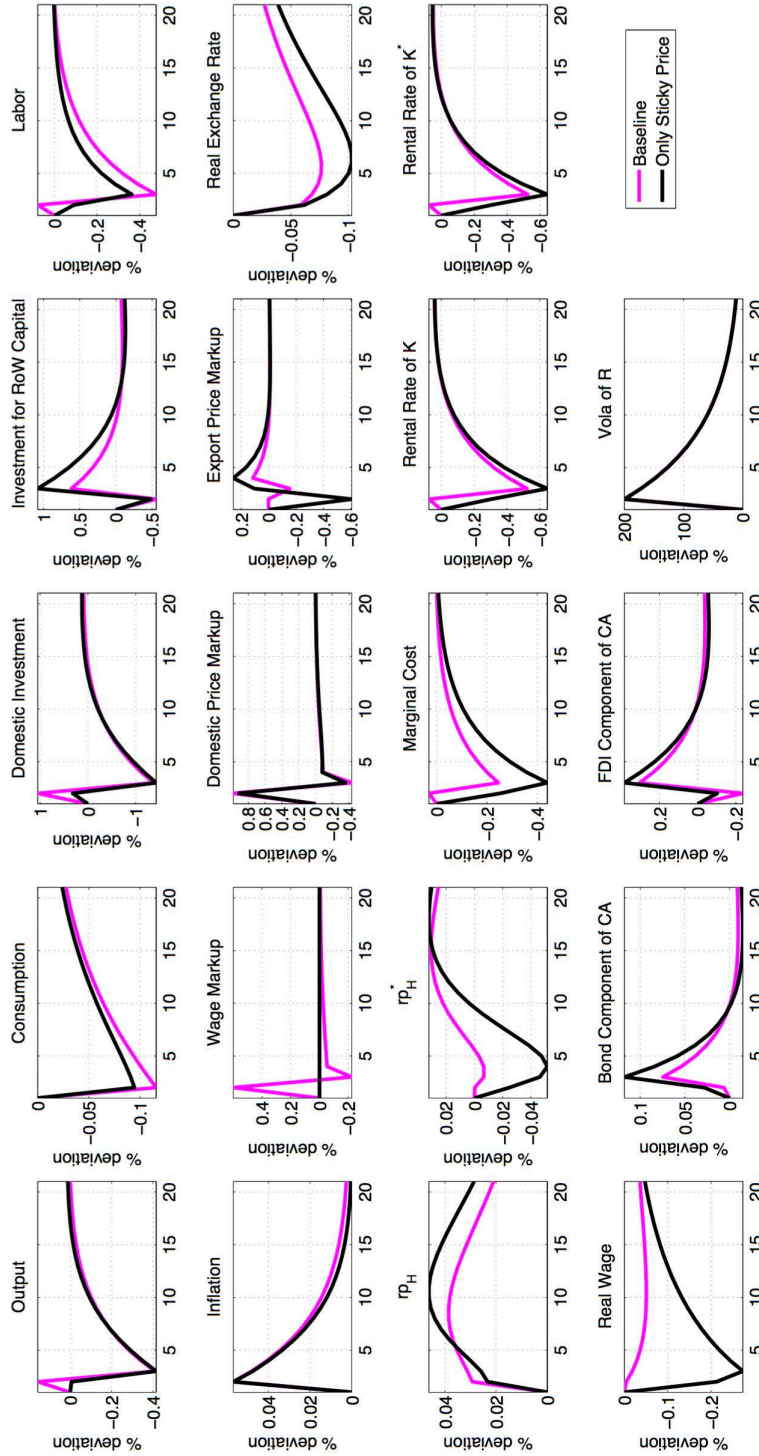
Figure 12: Period Profit (LCP)
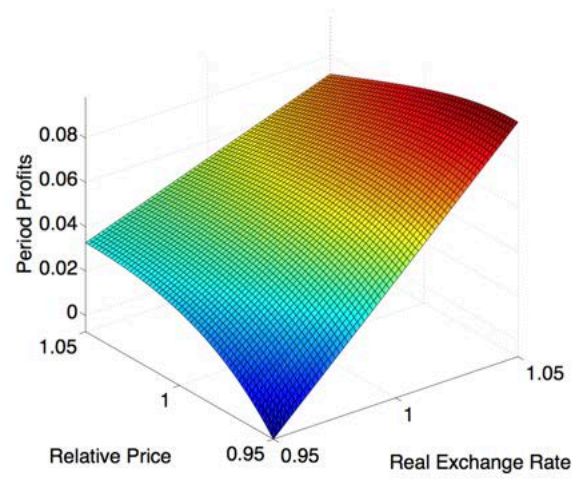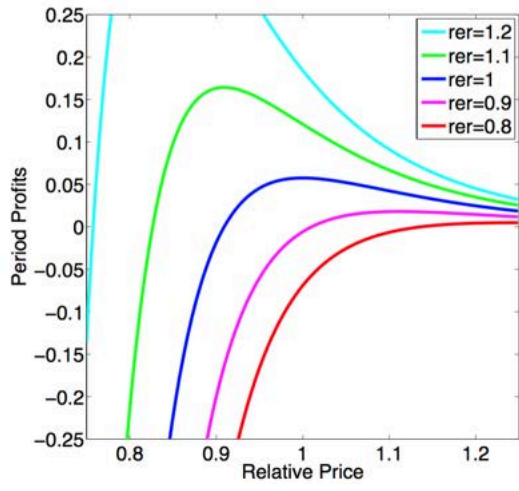
Figure 13: Impulse Responses to an Increase in Interest Rate Uncertainty (4-period time-to-build FDI)
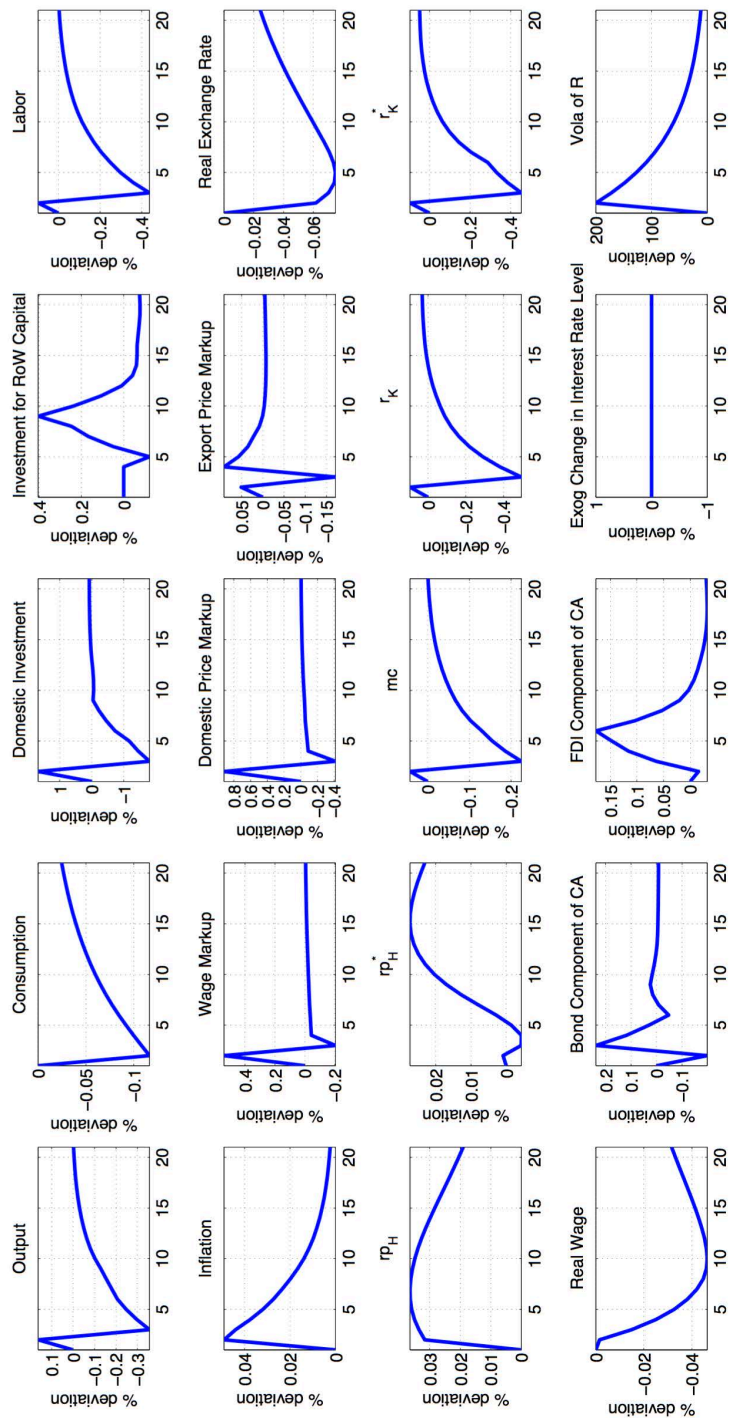
Figure 14: Comparison of Current Account Dynamics under Time-To-Build FDI

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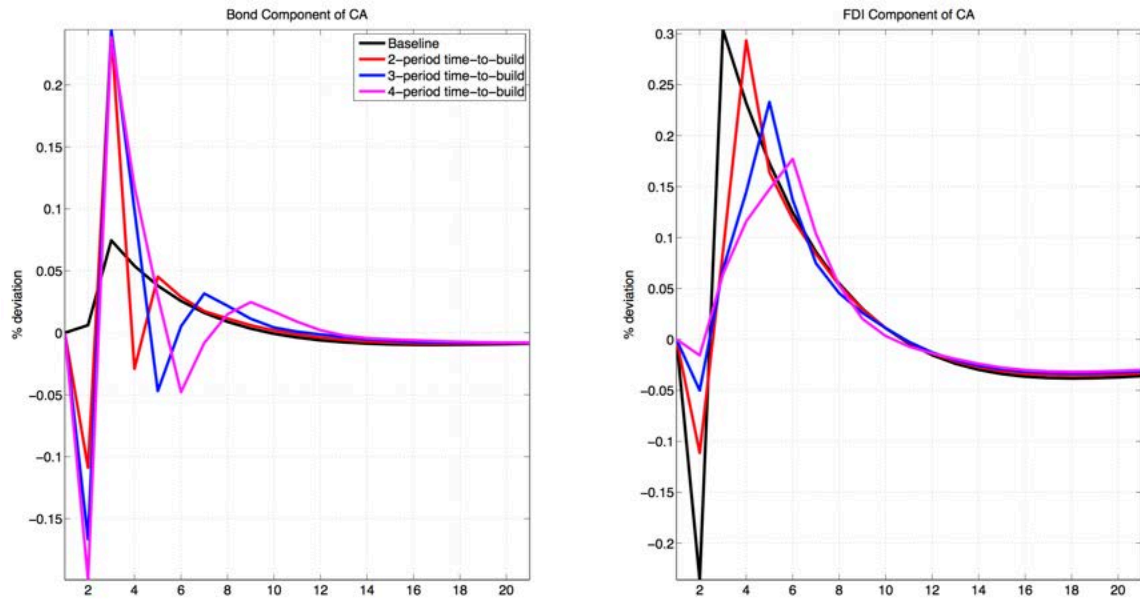
Figure 15: Impulse Responses to an Increase in Interest Rate Uncertainty (PCP)
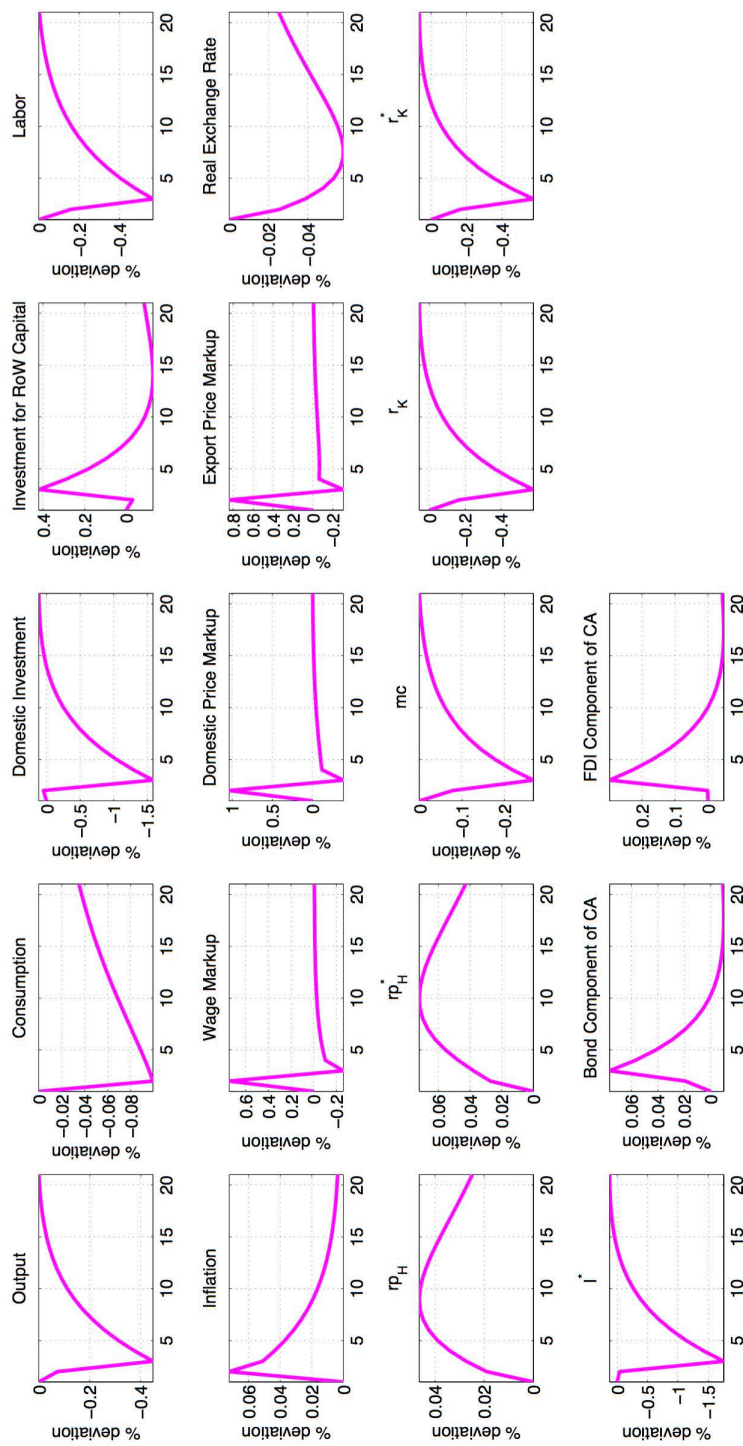
Figure 16: Markups and the Composition of the Current Account (Under Flexible Wages)
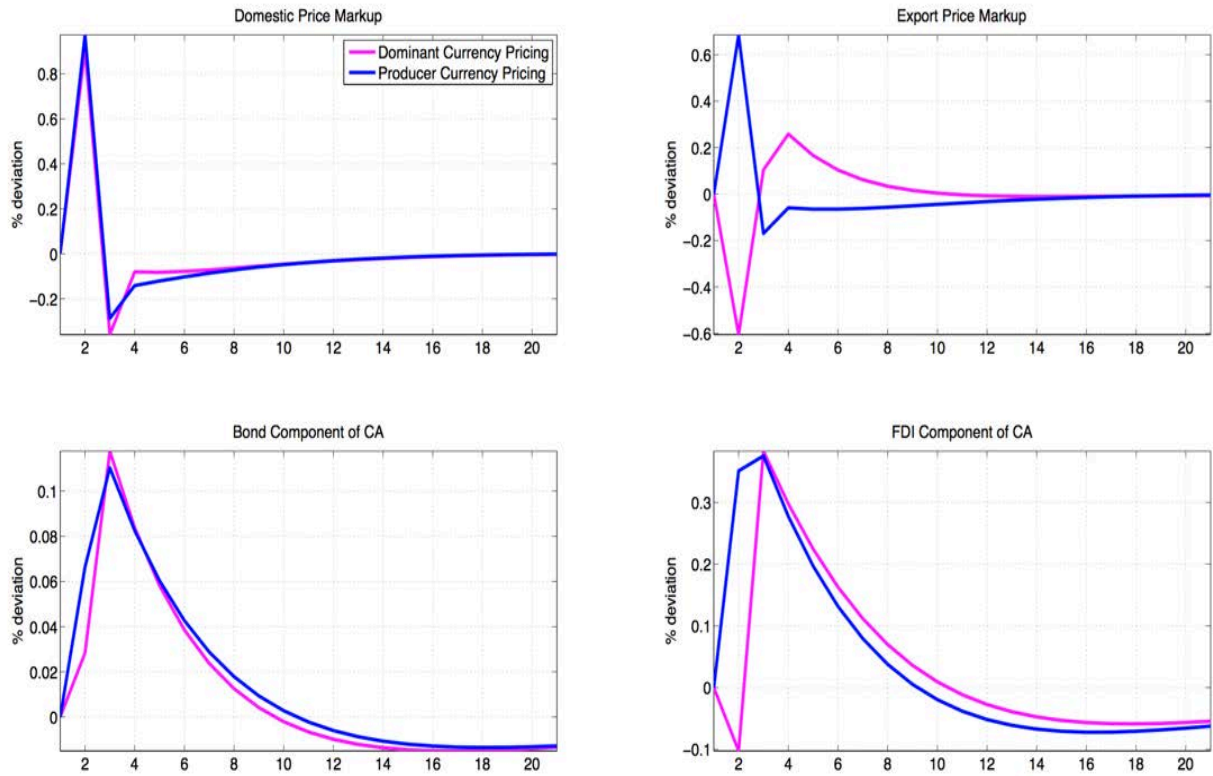
Figure 17: Period Profit (PCP)
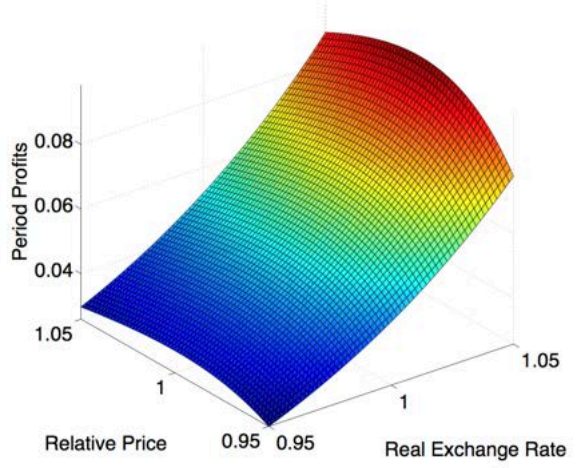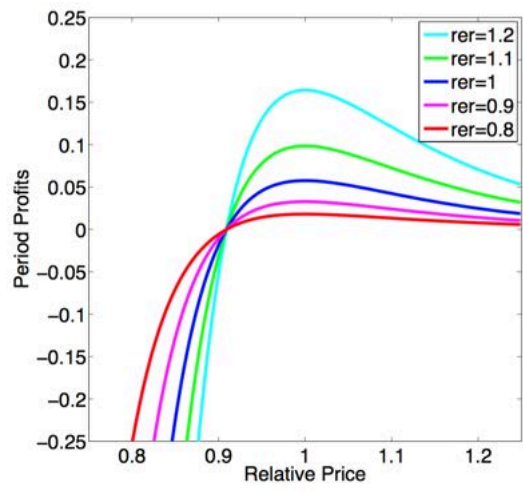
Figure 18: Impulse Responses to an Increase in Interest Rate Uncertainty (PCP, 4-period time-to-build FDI)
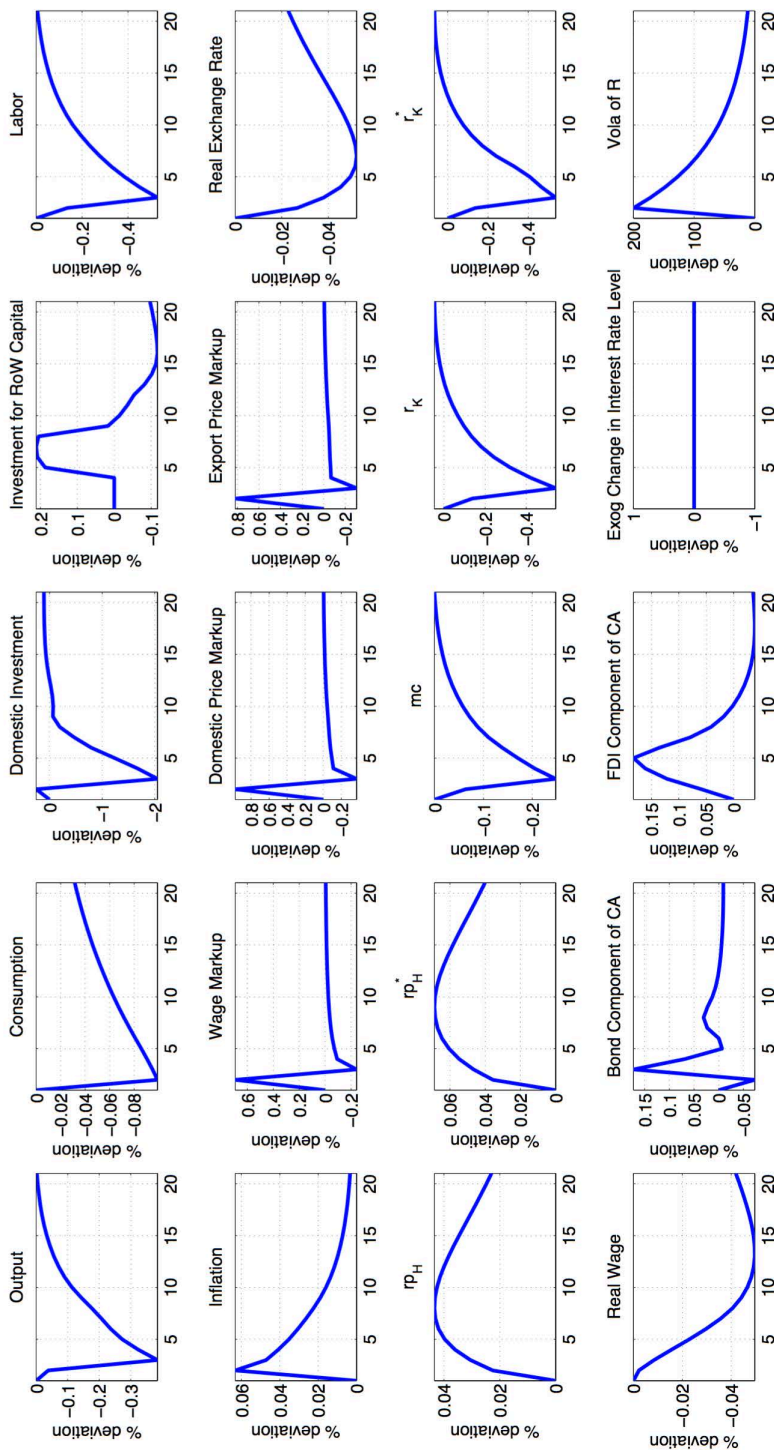
Figure 19: Comparison of Current Account Dynamics under PCP

Figure 20: Impulse Responses to an Increase in Interest Rate Uncertainty (Recursive Preferences)
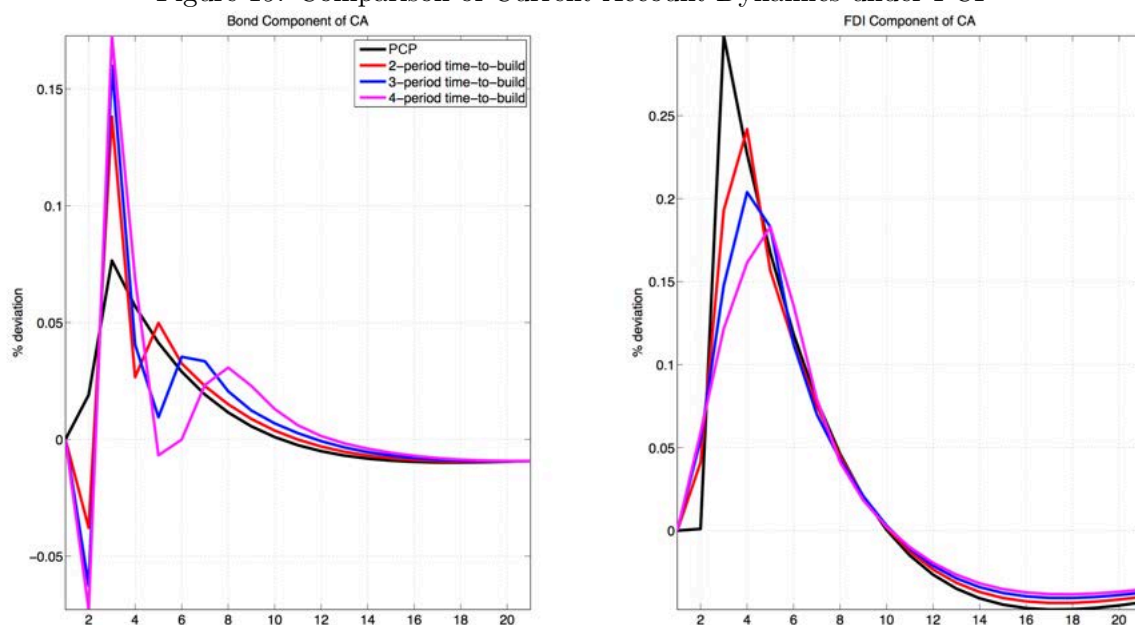
Figure 21: Comparison of Current Account Dynamics under Different Degrees of RoW Risk Aversion
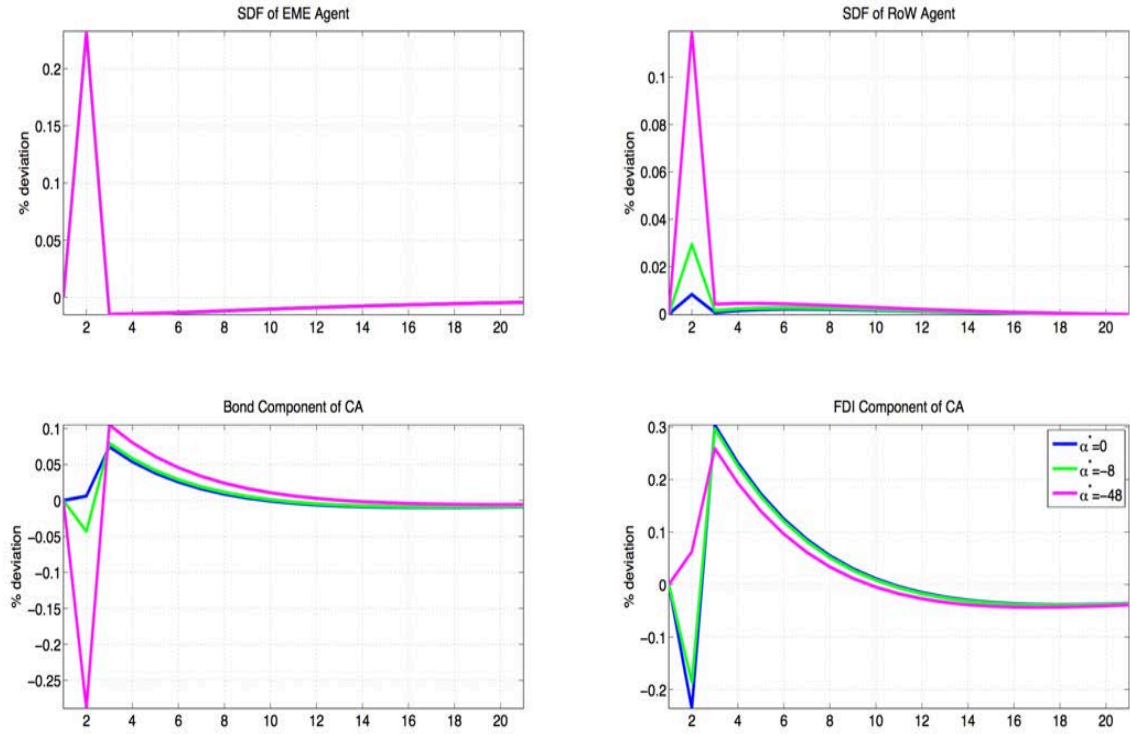
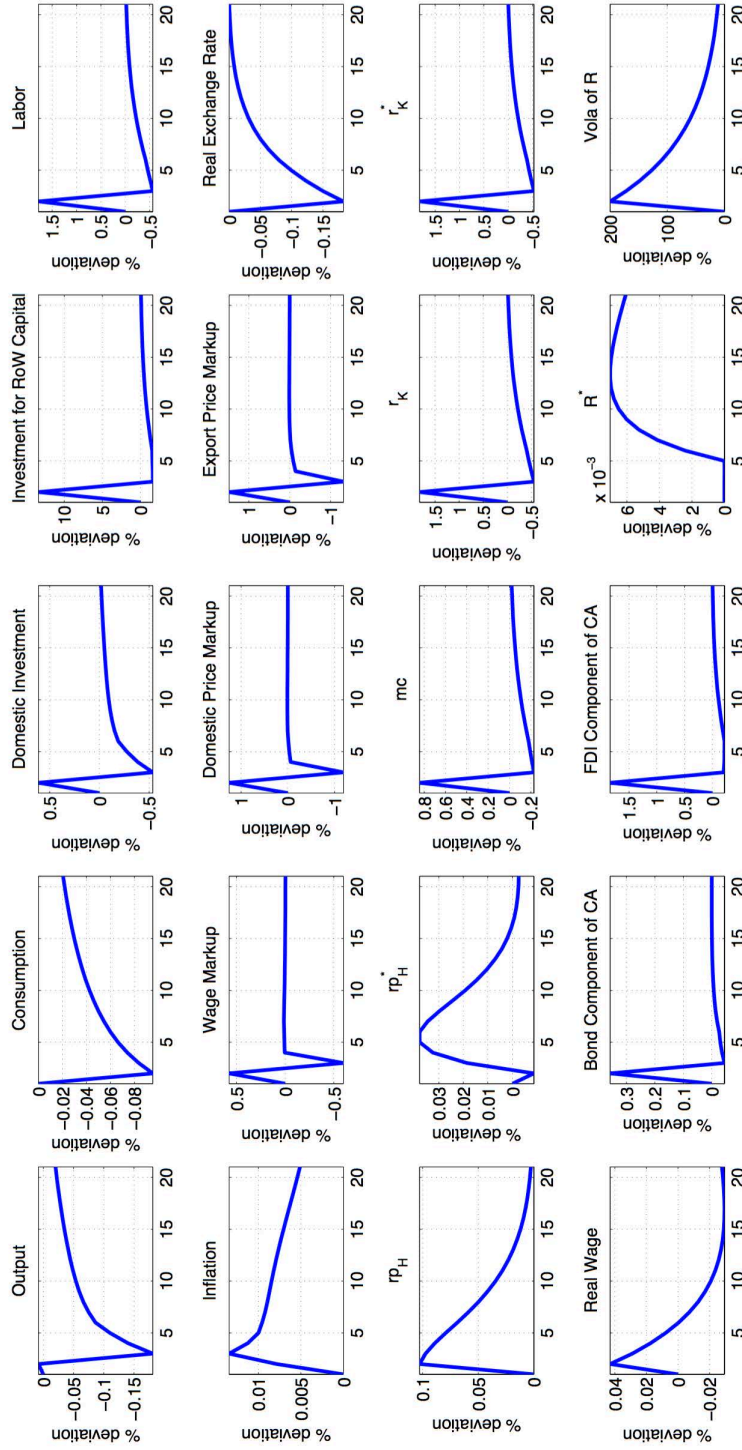Figure 22: Impulse Responses to an Increase in Interest Rate Uncertainty (Recursive Preferences, same degree of risk aversion in the EME and the RoW)
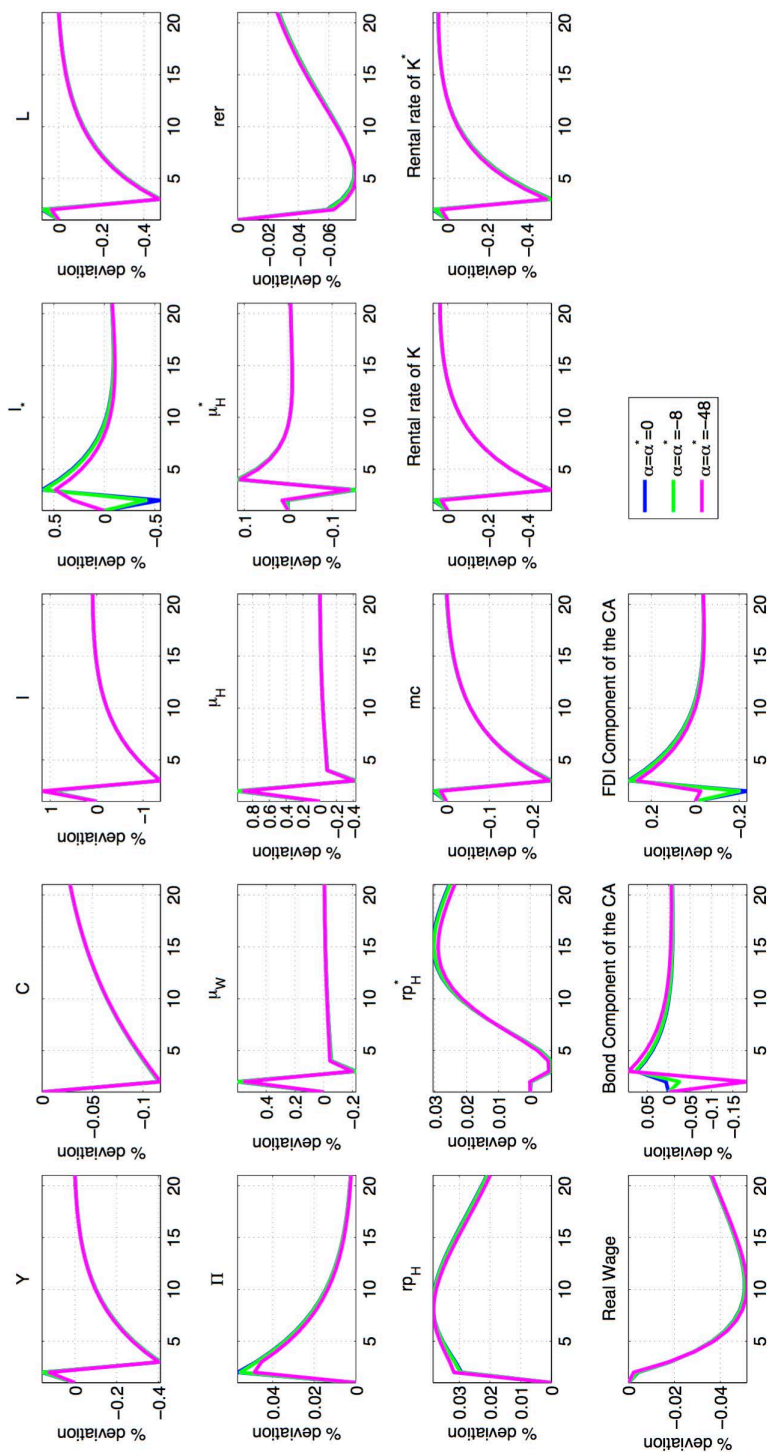
Figure 23: Comparison of Current Account Dynamics under Different Degrees of EME and RoW Risk Aversion
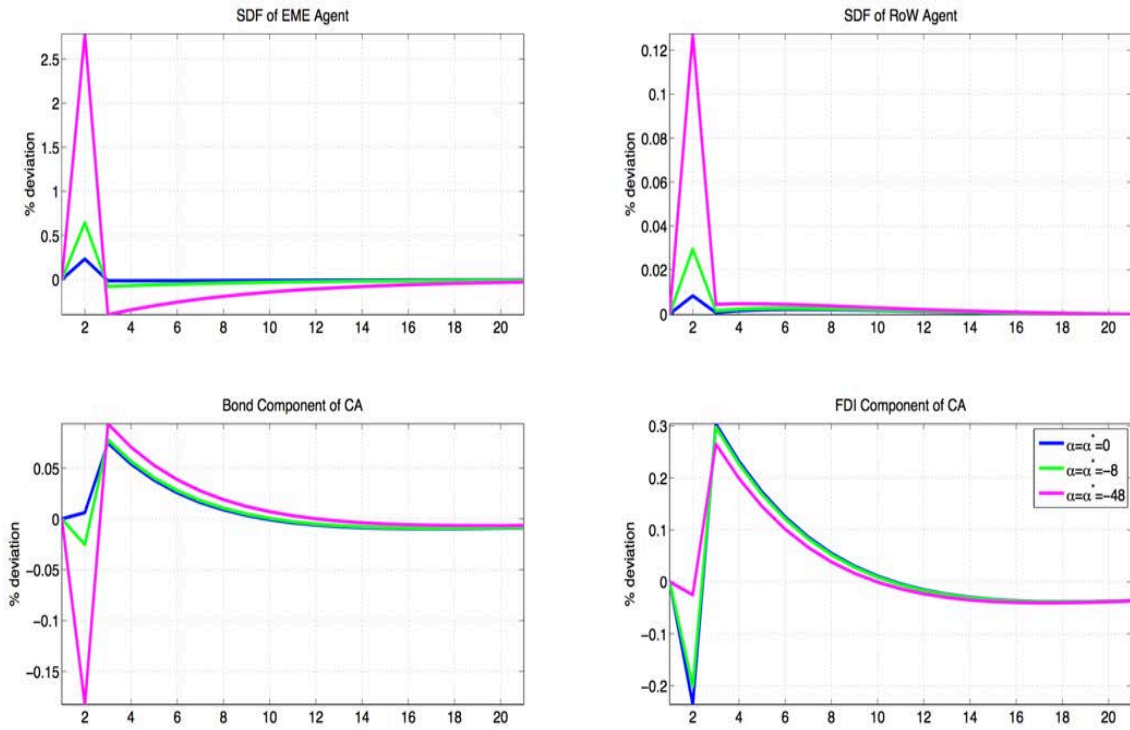
Figure 24: Impulse Responses to an Increase in Interest Rate Uncertainty (ELB in the RoW)

Figure 25: Impulse Responses to an Increase in Interest Rate Uncertainty (ELB in the RoW, strong home bias ($a = 0.95$)
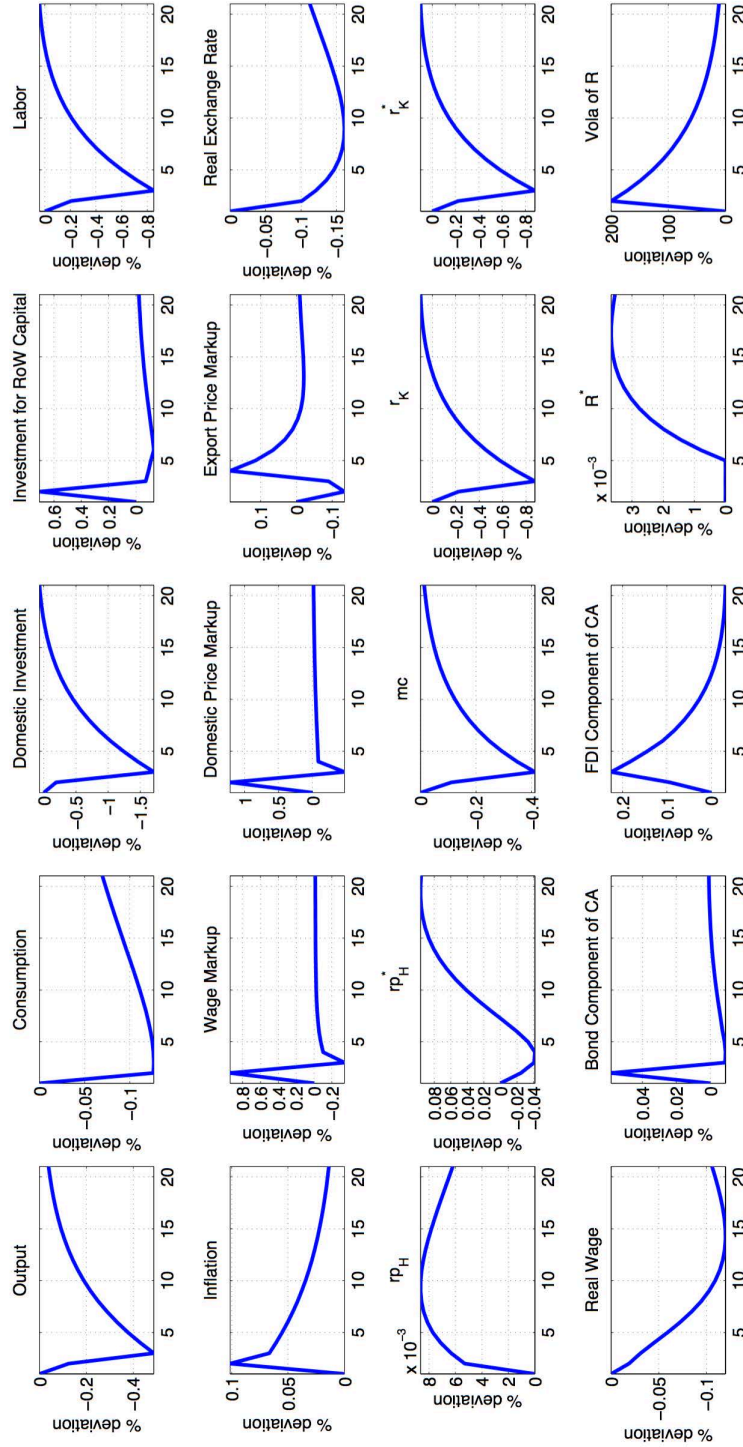
Figure 26: Comparison of Impulse Responses under Different Degrees of Home Bias
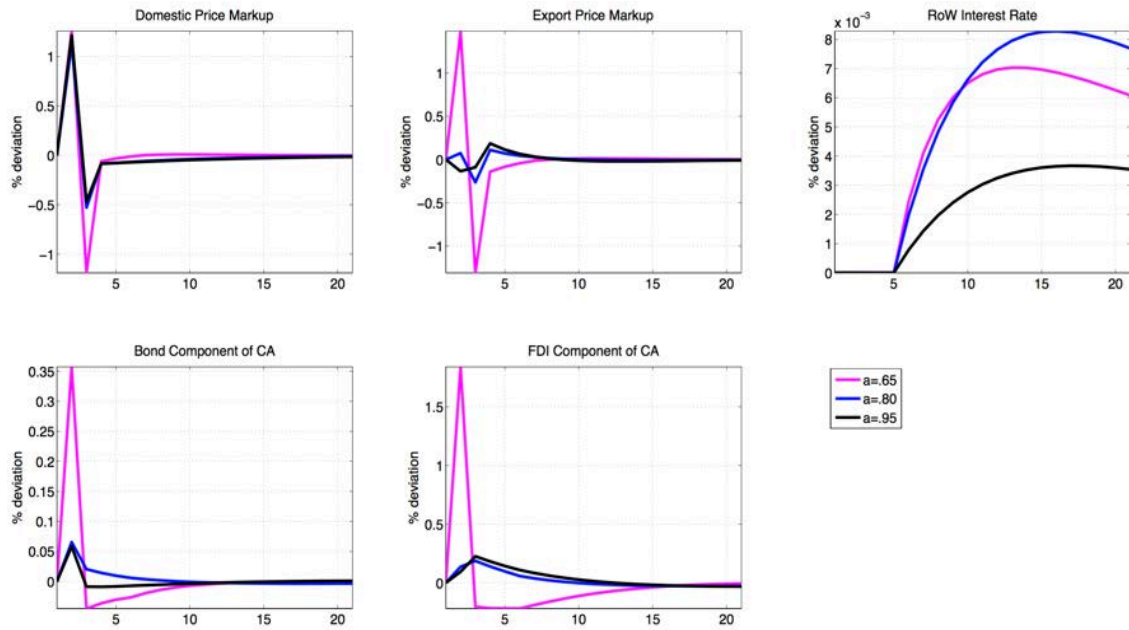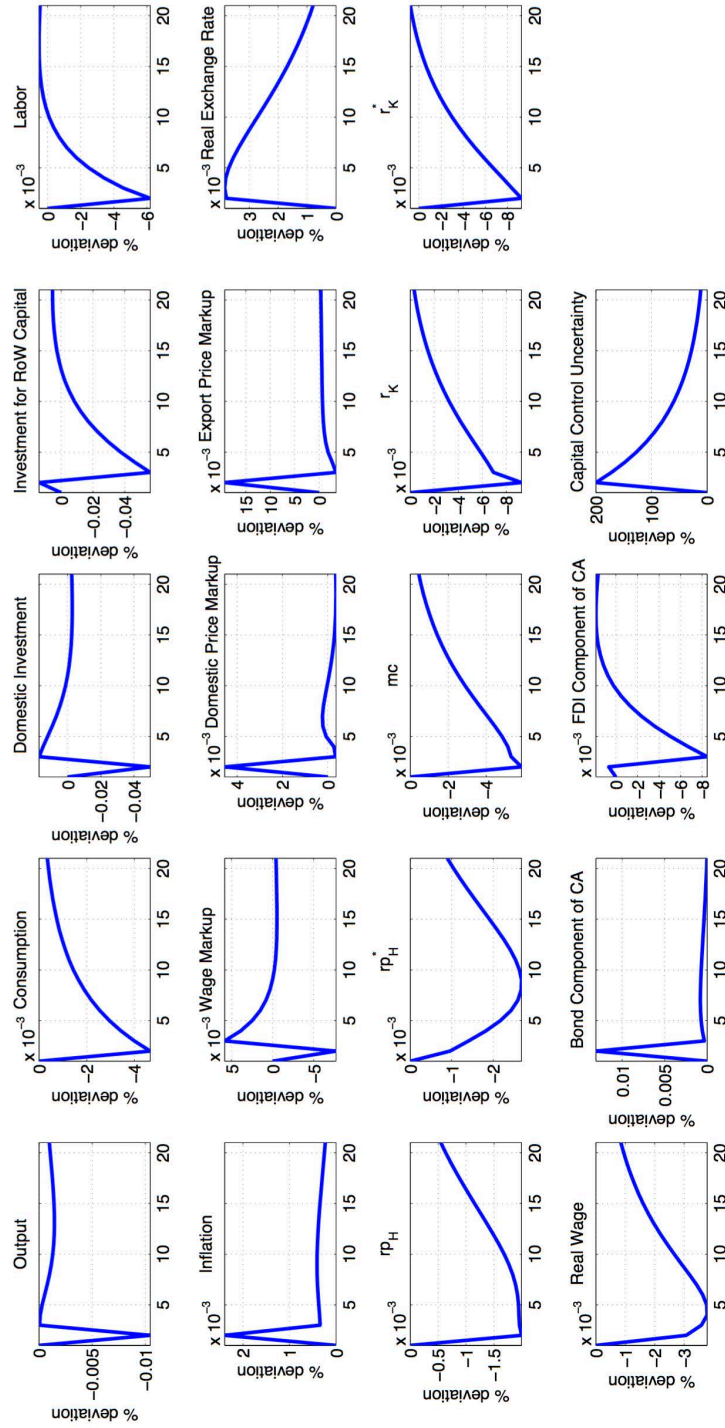
Figure 27: Impulse Responses to an Increase in Capital Control Uncertainty (CCU)

Interest Rate Uncertainty as a Policy Tool

Online Appendix

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A: 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:

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

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:

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

Use isomorphic equations for RoW to obtain:

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

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

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

Finally, divide the above equation with $2n$, and impose law of motion of capital for K^* and K_*

to obtain equation (22):

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

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

B: 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:

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

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

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

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

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:

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

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

The latter can be further written as:

$$-\underbrace{log(R_{t+1})}_{r_{t+1}} \approx \underbrace{\mathbb{E}_t log M_{t+1}^*}_{\equiv \mathbb{E}_t m_{t+1}^*} + \underbrace{log\,(S_t)}_{\equiv s_t} - \mathbb{E}_t log\,(S_{t+1})$$

$$+\tfrac{1}{2}\left[Var_t m_{t+1}^* + Var_t\,(s_t - s_{t+1})\right] + Cov_t\left(m_{t+1}^*, s_t - s_{t+1}\right).$$

So, we can express the relative excess return as:

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

To derive the relative excess return between K^* and K_*^*, we write down the equations (43) and (44) as follows:

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

and

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

Hence, the relative excess return is:

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

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,

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

Similarly, using (44):

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

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

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

C: Modifications with Time-to-Build

Starting from Equation (40), let us impose bond market clearing conditions and combine the conditions in (33) and their RoW counterpart to obtain:

$$I_{*,t} = \frac{1}{J}\left[(K_{*,t+1} - (1-\delta)K_{*,t}) + ... + (K_{*,t+J} - (1-\delta)K_{*,t+J-1})\right]$$

$$I_t^* = \frac{1}{J}\left[\left(K_{t+1}^* - (1-\delta)K_t^*\right) + ... + \left(K_{t+J}^* - (1-\delta)K_{t+J-1}^*\right)\right]$$

Now, starting from Equation (40), let us impose the bond market clearing conditions and the conditions above to obtain the modified net foreign asset equation:

$$b_{t+1} + rer_t b_{*,t+1} + \left(\frac{1-n}{n}\right) rer_t \frac{1}{J}\left(K_{*,t+J} + \delta K_{*,t+J-1} + ... + \delta K_{*,t+1}\right) - \frac{1}{J}\left(K_{t+J}^* + \delta K_{t+J-1}^* + ... + \delta K_{t+1}^*\right)$$

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

$$(45)$$

D: Producer Currency Pricing

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

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

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

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

From the first-order-conditions with respect to $P_{E,t+s}(i)$ and $P_{E,t+s}^{*e}(i)$ 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

$$rp_{E,t}^*=\frac{\mu_{E,t}^*mc_t}{rer_t},\tag{46}$$

where

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

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

with $\Pi_{E,t}^{*e}\equiv\frac{rp_{E,t}^*}{rp_{E,t-1}^*}\frac{rer_t}{rer_{t-1}}\Pi_t$.

E: Consumption Equivalent Welfare

Define two auxiliary value functions:

$$V_t^{i,C} = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{(C_{t+j}^i)^{1-\rho} - 1}{1-\rho}, \qquad V_t^{i,L} = -\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{(L_{t+j}^i)^{1+\varphi}}{1+\varphi}.$$

Set the compensating variation in consumption under IRUPT to generate the same welfare as under CCU:

$$V_t^{CCU} = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \frac{\left((1+\lambda^{cond})C_{t+j}^{IRUPT}\right)^{1-\rho} - 1}{1-\rho} - \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \chi \frac{\left(L_{t+j}^{IRUPT}\right)^{1+\varphi}}{1+\varphi}.$$

Express the above equation using auxiliary value functions defined above:

$$V_t^{CCU} = (1+\lambda^{cond})^{1-\rho} \left[V_t^{IRUPT,C} + \frac{1}{(1-\beta)(1-\rho)} \right] - \frac{1}{(1-\beta)(1-\rho)} + V_t^{IRUPT,N}.$$

Hence,

$$\lambda^{cond} = \left(\frac{V_t^{CCU} - V_t^{IRUPT,N} + \frac{1}{(1-\beta)(1-\rho)}}{V_t^{IRUPT,C} + \frac{1}{(1-\beta)(1-\rho)}} \right)^{\frac{1}{1-\rho}} - 1.$$

For the unconditional compensating variation, we follow the same steps using the unconditional expectation:

$$\lambda^{uncond} = \left(\frac{\mathbb{E}\left[V_t^{CCU}\right] - \mathbb{E}\left[V_t^{IRUPT,N}\right] + \frac{1}{(1-\beta)(1-\rho)}}{\mathbb{E}\left[V_t^{IRUPT,C}\right] + \frac{1}{(1-\beta)(1-\rho)}} \right)^{\frac{1}{1-\rho}} - 1.$$